Groundwater Vulnerability to Contamination in Jordan Evaluated in Two Levels of Analysis

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ABSTRACT

Vulnerability of groundwater to contamination in Jordan was evaluated using the DRASTIC methodology. The study had two levels of analysis: (1) a DRASTIC index scale was calculated on a national scale simulating the conditions of high limitation of data and considering only the parameters of depth to groundwater **(D)** and net recharge **(R)**. The results showed that the maximum value of the index in most areas of the country did not exceed 149, which corresponds to the category of moderate vulnerability. (2) A detailed application of the DRASTIC model to the Ramtha region, which has transitive climatic characteristics between the most humid zone of the country and the desert and with varied hydrogeological conditions. For this region, the DRASTIC index varied between 40 and 97, which corresponds to low vulnerability category.

KEYWORDS: Groundwater vulnerability, DRASTIC model, DRASTIC index, Jordan groundwater, Ramtha.

INTRODUCTION

The semi-aridity of Jordan results in limited surface and groundwater resources. During the past few decades, population growth, industrialization, irrigation projects and improving living standards have led not only to increasing water use and overexploitation, but also to a deterioration of water quality (MWI, 2009). Nitrate contents of more than 100 mg/l in groundwater in many intensively cultivated areas and more than 200 mg/l in some urban zones indicate that groundwater is already polluted to an alarming extent (Salameh, 1996). Existing legislations are strong enough to control the use of groundwater resources and protect groundwater. However, up till now the application of these legislations is still unsatisfactory, thus suggesting the need for future strengthening of law enforcement (NWMP, 2004).

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Over the past three decades, groundwater vulnerability maps have been developed in many countries for such purposes. One of the aims of such maps is to show decision-makers the areas in which there is a high possibility of contaminants reaching the groundwater. All practices that could lead to a contamination of the groundwater resources should be banned in these highly vulnerable areas. Areas where the natural protection of the groundwater against pollution is high are also illustrated on such maps. And they could be suitable locations for waste water treatment plants, waste disposal sites, intensive agriculture or industries. However, such maps do not replace more detailed studies of the geological and hydrogeological conditions in order to ensure the suitability of a particular site for the envisaged use.

The widely used DRASTIC Index (Aller et al., 1987) is an example of intrinsic vulnerability models. The index is based on the rating of seven physical factors within each environmental setting. These factors are: depth to water, net recharge, aquifer media, soil media, topography, vadose zone and hydraulic conductivity of the aquifer.

The purpose of this study was two-fold. First, to use DRASTIC model on a national scale depending on minimal available information. The second level purpose is to evaluate the groundwater to contamination in Ramtha region using the DRASTIC methodology.

The DRASTIC Model

DRASTIC is an acronym for the seven factors considered in this model (see Table 1). Each factor is assigned a rating between 1 and 10, based on the field setting, and a weighting from 1 to 5 according to the factor's importance as fixed by the index authors (see Table 1). The overall DRASTIC index is established by applying the following formula:

$$DI= D_R * D_W + R_R * R_W + A_R * A_W + S_R * S_W + T_R * T_W + I_R * I_W + C_R * C_W$$

where: **DI** = DRASTIC Index, **R**= Rating, **W**= Weight.

General Conditions on National Scale

Annual rainfall intensities range from 600 mm in the northwest mountain zones to less than 200 mm in the eastern and southern deserts, which form about 91% of the whole surface area (Fig. 1). Approximately 92% of the rainfall evaporates, while the rest flows in rivers and streams as flood flows and recharge to groundwater. Groundwater recharge amounts to approximately 5% of the total rainfall (Yacoub, 2000). Groundwater aquifers of Jordan are divided into three main complexes. Those are: deep sandstone aquifer complex, upper Cretaceous aquifer complex and shallow aquifer complex (Abed, 2000).

The first complex is fossil and crops out only in the southern part of the country and a narrow zone in the dead sea rift valley.

The upper Cretaceous aquifer complex consists of an alternating sequence of limestones, dolomite, marl and chert beds and its total thickness in central Jordan is about 700 m. The limestone and dolomite units form excellent aquifers. A thick marly layer, especially in the eastern deserts, mainly overlies this complex.

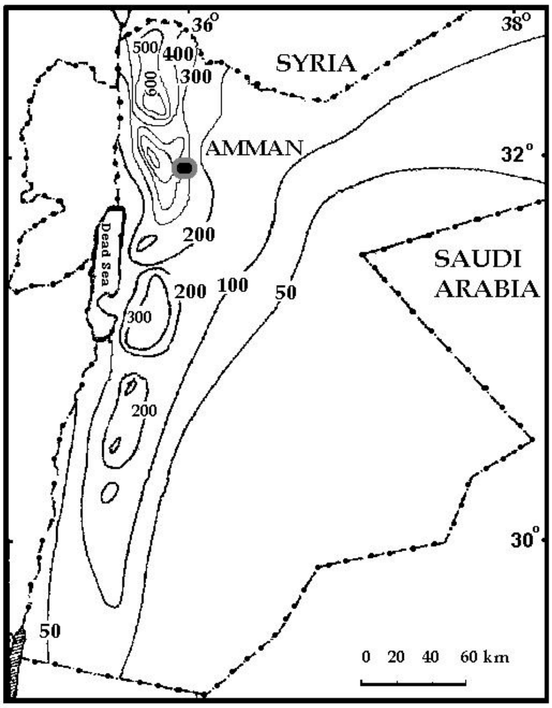

Fig. (1): Rainfall Distribution in Jordan, mm/yr. (50-years average).

The shallow aquifer complex consists of a basalt aquifer system, sedimentary rocks and alluvial deposits of tertiary and quaternary ages. The basalt aquifer is normally recharged from the high zone in the south of Syria, where the groundwater moves radially to all directions. The second system forms local aquifers overlying partly the mentioned aquifer complexes or are separated from them by aquitards (Abed, 2000).

An Estimation of DRASTIC Index on a National Scale Using Only the D and R Parameters

According to DRASTIC methodology, the depth to the water table is the most important factor, and consequently it has been assigned the highest weighting. The fast evaluation of this factor on a national scale reveals that the deep sandstone aquifer complex is non-renewable and is overlain by hundreds of meters of sedimentary rocks except in a limited zone in the southern part of the country. The upper Cretaceous complex is also confined in the main parts of its extension and mostly outcrops as narrow bands in the deep valleys (Abed, 2000).

The basalt aquifer of the shallow aquifer complex is mostly lateral recharged, so its vulnerability to contamination cannot be evaluated by the DRASTIC methodology, where the recharge is assumed to be vertical. The shallow sedimentary rock and alluvial deposit aquifers of tertiary and quaternary ages are more probable to have shallower water table depths.

The Water Authority of Jordan (WAJ) is the major source of groundwater data. From 3614 wells in the northern part of Jordan, just 247 have depths less than 40m. Moreover, many of them are conglomerated in very limited areas. In the southern part, only 1 well has a depth of less than 30 m. That means that the water table is mostly deeper than 30 meters (WAJ, 1987). At present times, the groundwater budget is negative. Thus, as a consequence of the over-exploitation of the groundwater resources, the groundwater levels decline progressively (NWMP, 2004; Steinkampf et al., 2006).

Depending on the general estimation that the recharge represents less than 8% of the total rainfall (Yacoub, 2000), it can be concluded that the recharge rate under the normal conditions will not exceed 50 mm/year.

Depending on general estimation for depth to water and recharge factors, and assuming the worst scenario for the other factors, the DRASTIC Index (**DI**) for the whole country was calculated as follows:

- The weight of D factor is 5, and it was assigned a rate of 1 when it was greater than 30m.
- The weight of R factor is 4, and it was assigned a rate of 1 when it was less than 50 mm/year. So:

D I= (5*1)+(4*1)+(3*10) + (2*10) + (1*10) + (5*10)+ (3*10) = 149

This estimated maximum value for the DRASTIC Index in the major part of the country corresponds to the moderate vulnerability category.

Groundwater Vulnerability to Contamination in the Ramtha Zone

Ramtha is a transitionary zone between the desert and the mountain region that receives the highest precipitation level in the Kingdom. Also, groundwater aquifers of the zone belong to two different systems; the shallow aquifer system in the north and the upper Cretaceous aquifer system in the south. The land uses in the region vary widely. Groundwater of Ramtha region is locally contaminated, and in some wells the nitrate concentration is greater than 200 mg/l. The relative availability of data in the study zone was another reason for selecting this area for detailed application of the DRASTIC model to evaluate the groundwater vulnerability to contamination.

The depth to water in Ramtha zone is greater than 40 m in the most area especially in the southern parts. In the central northern parts, the depth ranges from 40 to 20 meters. Just in a very limited area at the northwestern corner of the study area, the depth to water was less than 20 m (Fig. 2).

The net recharge in the study zone ranged from less than 25 mm/year in the majority of the area to (25-50) mm/year in the northwestern corner (WAJ, 1997).

The **B4** (one of shallow aquifer complex system) is the uppermost aquifer in the northern part of the study

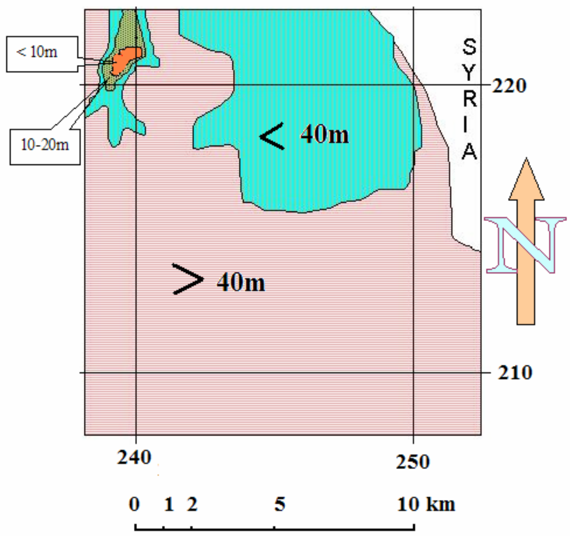

Fig. (2): Water Table Depth in Ramtha Region.

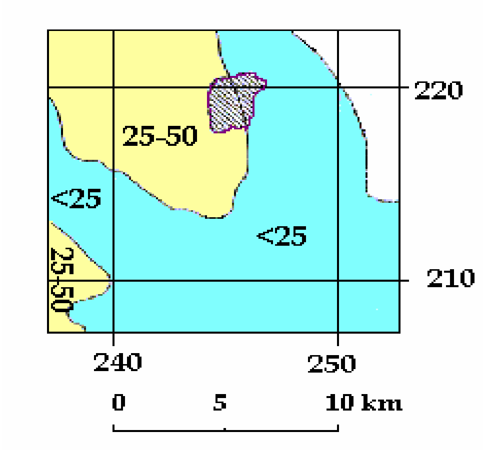

Fig. (3): Net Recharge in the Ramtha Region.

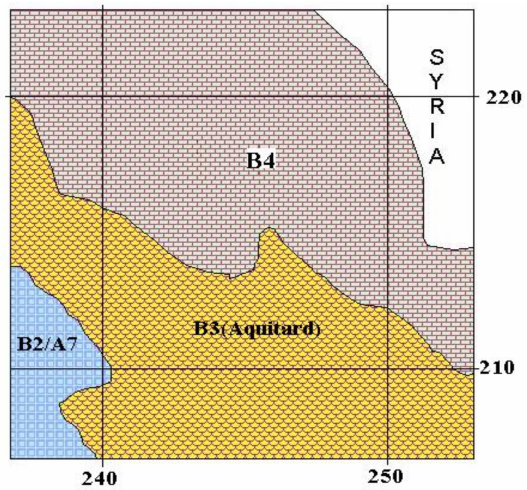

Fig. (4): Geologic Map of the Ramtha Region.

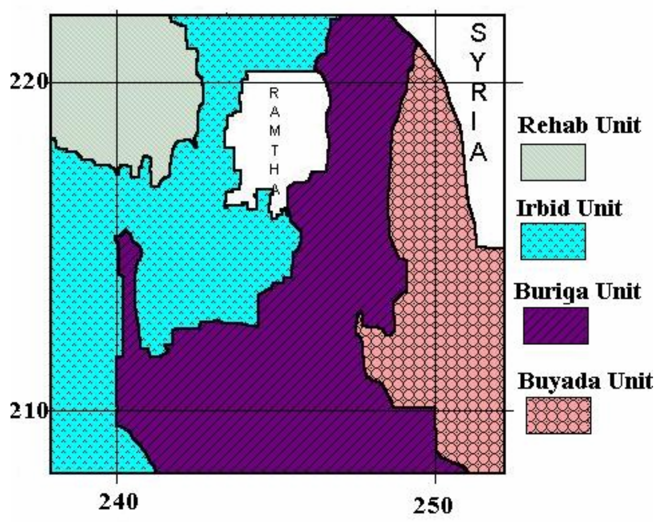

Fig. (5): Soil Distribution in Ramtha Zone.

area (see Fig. 4). The aquifer medium is limestone with sequences of marl. The uppermost aquifer in the southern part is **A7/B2** (one of upper Cretaceous aquifer complex system), which mainly consists of alternations of limestone, chert and fosfatic limestone. Jointing and fracturing are moderate to high and the degree of karstification is regarded moderate (WAJ, 1997).

Soils of the study zone belong to four units (see Fig. 5). Rehab unit (north-western corner) is of clay and is common in areas with slopes of about 10%. Irbid unit (central part) is of shrinking clay and is common in areas of gentle slopes less than 4%. Soils at the east of Ramtha city belong to the Buriqa unit which is clay loam. The slope of the zone covered by Buriqa unit is variable, but is generally higher than 6%. The soils of the southeastern part are silt loam of Buayda unit. This unit is more common in areas with slopes less than 6% (Ministry of Agriculture, 1994).

The impact of the vadose zone medium factor was evaluated assuming that the A7/B2 aquifer was confined. The vadose medium of B4 aquifer is the same as the aquifer itself.

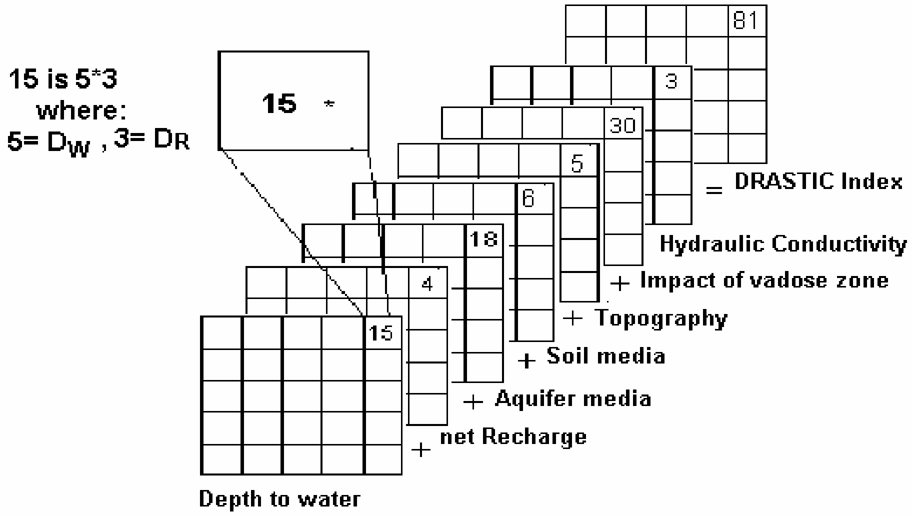

Fig. (6): Method Used for the DRASTIC Index Calculation.

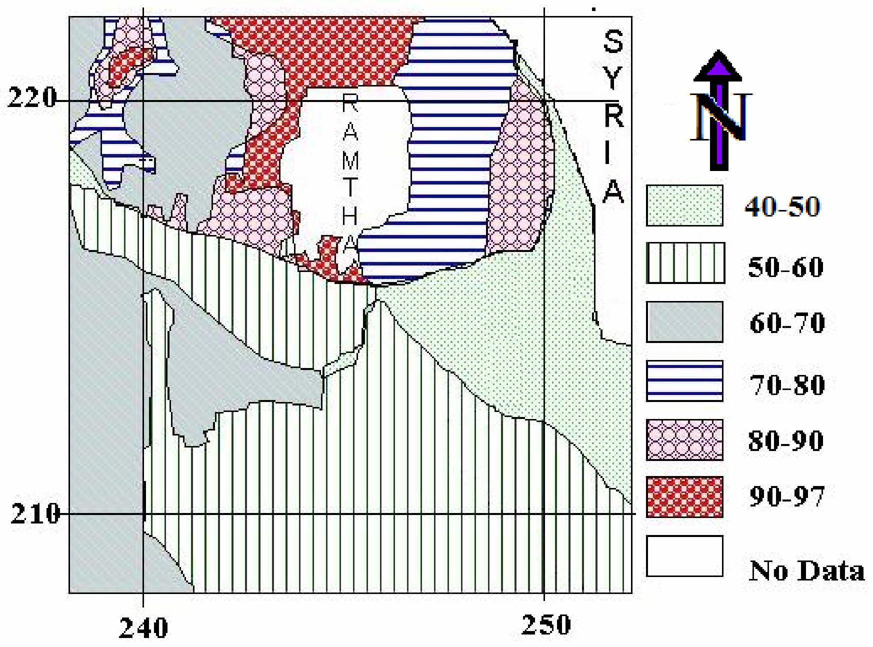

Fig. (7): DRASTIC Vulnerablility Index.

Table (1): DRASTIC Model Factors, Factor Weights and the Assigned Rating for Each Factor for the Ramtha Region.

DRASTIC Factor	Weight	Factor State	Rating
D (depth to water)(m)	5	>40	1
		<40 (20 as acceptable value)	3
		20-10 (15 as acceptable value)	5
		<10 (5 as acceptable value)	7
R (net recharge)	4	< 50 mm/Año (all study area)	1
A (aquifer media)	3	Fractured limestone (B2/A7)	9
		Limeston with sequence of marl (B4)	6
S (soil media)	2	Shrinking caly (Irbid unit)	7
		Non-shrinking clay (Rihab unit)	1
		Clay loam (Buriqa unit)	2
		Silt loam (Buayda unit)	3
T (topography)	1	> 6% (Rihab and Buriqa units)	5
		< 6% (Irbid and Buayda units)	9
I (impact of vadose zone)	5	Confined aquifer (B2/A7)	1
		Limestone with sequence of marl (B4)	6
C (hydraulic conductivity)	3	5.10^{-5} to 5.10^{-3} cm.s^{-1} (All study area)	1

Due to unavailability of digital elevation model for the study zone and the lack of information about the elevation variation in other forms, the topography factor in the study zone was evaluated depending on the typical slope range of each soil unit as indicated in the catalogues of Jordan soil map 1/50000 (Ministry of Agriculture, 1994).

The hydraulic conductivity for the B4 aquifer ranges from 1.10^{-6} to 1.10^{-4} with an average of 5.10^{-5} and for the B2/A7 ranges from 1.10^{-7} to 1.10^{-3} with an acceptable representative value of 2.10^{-5} (BGR, 1997).

The weights and ratings for all factors are listed in Table (1).

To calculate the DRASTIC Index, each factor was presented in a map layer. Each layer was divided into a net of 50 m* 50 m cells. Each cell had a value which is a result of Factor **W** * Factor **R** (Fig. 6). The DRASTIC vulnerability map was then obtained by combining the seven map layer values (Fig. 7).

It can be observed that the DRASTIC Index ranges from 40 to 97, indicating that the relative vulnerability of the zone aquifers is very small. This result is in agreement with the first level study which estimated that the DRASTIC Index in the major part of Jordan would be less than 149.

DISCUSSION AND CONCLUSIONS

The results of groundwater vulnerability to contamination on the national scale of this research coincide perfectly with many local studies which have used much more sets of data. Fore example, (El-Naqa et al., 2006) found that the DRASTIC index in Russiefa area ranged between 122 and 148. This result fits exactly in the estimated national scale range of DRASTIC index. Also, the result of groundwater vulnerability study for

Basaltic aquifer of the Azraq basin (Al-Adamat et al., 2003) ranged between low and moderate vulnerability. This result also adequately fits in the estimated DRASTIC index values on the national scale. Many other researches have a good agreement with the result of this study on the national scale (Awad, 2007; Hammouri and El-Naqa, 2008).

The agreement between the result of groundwater vulnerability to contamination assessment on the national scale and numerous local studies indicates that the obtained DRASTIC Index value may act as an indicator for groundwater vulnerability to contamination in Jordan on macro-scale. However, more studies are still necessary, especially where the DRASTIC parameter conditions differ widely with the contemplate general conditions implemented in this study.

The main conclusions of this study are:

1. The estimated DRASTIC Index on a national scale using only D and R factors was less than 149 in the majority of the Jordan area.
2. Calculated DRASTIC Index values in Ramtha region using all factors required by the method ranged between 40 and 97.
3. The study in its two levels shows that the DRASTIC Index value was within a narrow interval of the whole possible DRASTIC Index range (23-226). That means a limitation to the relative classification of the different zones based on relative vulnerability, which questions the effectiveness of the DRASTIC model to evaluate the vulnerability of groundwater to contamination in Jordan and another zones with similar conditions. However, further studies are still necessary.

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