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Potentiality of The Groundwater Resources in North River Side Wadis Basin, Jordan and its God Vulnerability

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Abstract

This paper aims at assessing the potentiality of groundwater resources in North River side wadis Basin (NRSW), North Jordan, in addition to the effect of vulnerability of groundwater within the catchment. This basin is determined as one of the important basins in Jordan; it is one of the high rainfall areas. The groundwater potentiality is determined using managed aquifer recharge (MAR) tool, along with GOD vulnerability index which is an important tool to evaluate the sensitivity of groundwater to pollution; this is to ensure the quality of water that will be artificially recharged in areas of high potentiality. Under the Geographic Information System (GIS) environment, both groundwater vulnerability and MAR layers were prepared for the basin. MAR mapping showed high to medium potential areas, over 10% and 35% of the total basin area respectively, while low potential areas represented 55% of the total area. The vulnerability of groundwater to contamination in the study area has been evaluated using GOD methodology. This methodology is highly recommended in area under environmental and natural conditions which is the case in North – Side Valley Basin. The elaborated GOD vulnerability map shows that 7%, 44%, and 49% of the study area are belong to high, moderate vulnerability and very low vulnerability classes respectively. The area overlying Rijam aquifer is of highest vulnerability because the water table in this area is shallower than it for Amman- Wadi Es Sir Aquifer (B2/A7). The area overlying B2/A7 is of moderate vulnerability; where the groundwater is of low vulnerability class where the confined or unsaturated conditions are available. The areas of A1/A6 exposing show very low vulnerability classes. Areas that show high potentiality for MAR concept without considering the vulnerability of groundwater were a total of 10% of the study area, while this figure was reduced to 8% of the total basin area, after eliminating areas classified as high vulnerability.

Keywords: North River side wadis basin; GOD Vulnerability index; groundwater potentiality; groundwater vulnerability; managed aquifer recharge (MAR)

INTRODUCTION

Groundwater represents the main source of water supply in the basin. Most of the groundwater exists in and is being extracted from the Amman-Wadi Sir (B2/A7) and Wadi Shallaleh Um Rijam (B4/5) aquifers (see Figure 1). Within North River Side Wadis Basin, the most important aquifer is Amman-Wadi Sir (B2/A7) system (BGR and WAJ, 1994). In late 70s and early 80s, decline in water levels in the basalt and in the B2/A7 aquifer in different areas were noticed in both government and private wells in the basin. Both the extent and the annual rate of decline vary considerably. The decline in water levels of the B2/A7 aquifer range between 0.67m and 2.0m per year (MWI, 2015). Hydro-geologically, there are three main aquifers in the study area: the B2/A7 limestone aquifer, Wadi Shallaleh Um Rijam (B4/5) aquifer, and alluvial aquifers. Figure 3 shows the distribution of these aquifers in the study area. Between these aquifers many aquitards are found, which minimize the possibility of applying any MAR models in the area. In addition, the presence of the alluvial aquifers enhances MAR projects.

Vulnerability of groundwater to contamination still has different meanings for different investigators (Albuquerque et al. 2013; Stigter et al. 2006). The easiness of contaminant moving from the land surface to groundwater seem to be an acceptable definition for the vulnerability term. This definition could be retrieved by analyzing the variables used in different vulnerability methods, where the majority of them are related to process or condition that make the contaminant movement from the surface to groundwater easier or harder (Aller et al. 198; Forster 1987; Ribeiro 2000).Evaluation the groundwater vulnerability to contamination is an important measure in order to manage groundwater resources. Groundwater vulnerability maps visualize the susceptibility of groundwater to contamination, which help in managing this water and orienting the land uses to take into consideration the groundwater presence and quality.

There are numerous methodologies to determine aquifers' vulnerability to contamination. In this study we adopt GOD method. It has been developed by Foster and herata(1988). GOD methodology is one of the effective models used to evaluate groundwater vulnerability to contamination. It considers only three variables. However, it is the second most common methodology beyond the famous DRASTIC model.

In Jordan several intents have been carried out to evaluate the groundwater vulnerability in different parts of Jordan using different methods (Gougazeh and Sharadqah 2009; Sharadqah 2001, 2010, 2011, 2015; Hammouri and El-Naqa 2008; Mohammad 2010, 2013, 2015, 2017). Although, no one of these studies used GOD model to evaluate groundwater vulnerability to contamination in the North- River Side Valley.

The objectives of the actual study are: evaluate the Potentiality of the groundwater resources in NRSW; and estimate the ground water vulnerability to contamination in the study area using GOD methodology.

Study area:

North River Side Wadis basin (NRSW) is one of the most developed areas in Jordan. NRSW is locate in the north west corner of Jordan (Fig. 1). The total area of the basin is about 940km^2, with a population of more than 350 thousands its one of the most populated zones of Jordan**.**

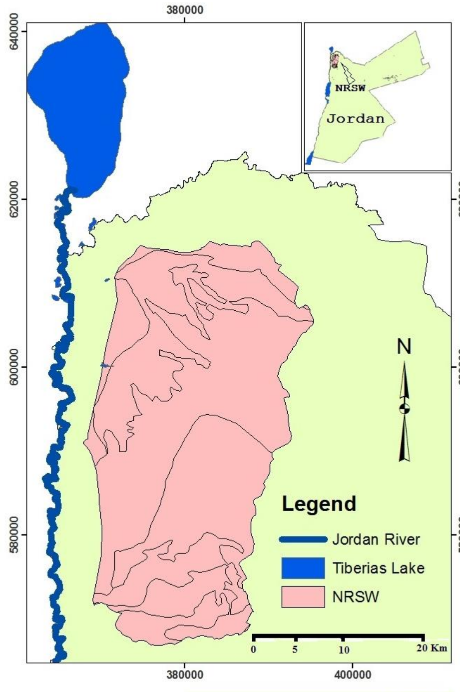

Figure 1: Location map for the North River Side Wadis in Jordan.

Climatological and Hydrogeological Setting:

The amount of rainfall is mainly governed by the topography and the distance to the Mediterranean sea. The precipitation in the study area ranges from 350 millimeters per year (mm/yr) to more than 650 mm/yr, which considered as the highest annual rainfall in Jordan according to the Jordan Meteorological Department (JMD, 2013) (Figure 2).

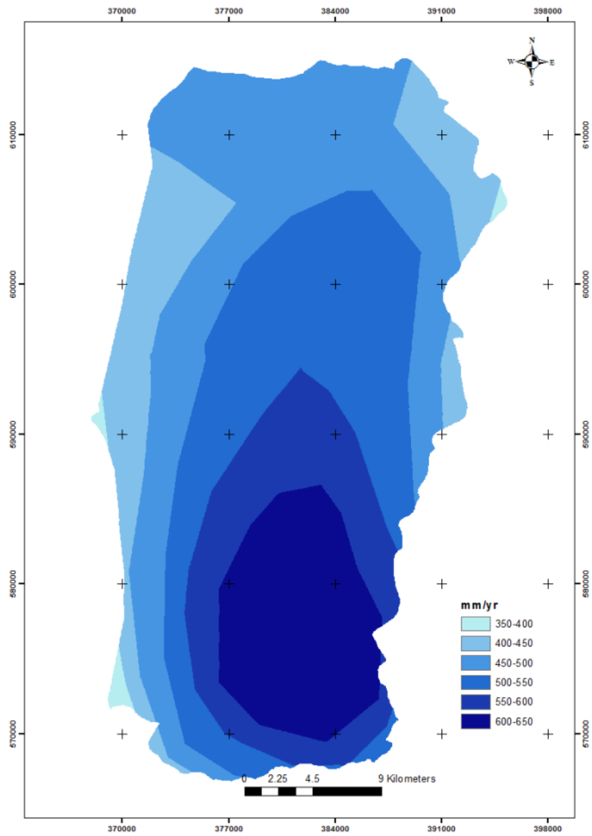

Figure 2: Isohytal map for the rainfall distribution in North River Side Wadis Basin.

In the study area formations from Ajlun group (A) and Balqa group (B) are exposed (fig.3). The rocks of Ajlun Group from Cenmanian to Santonian Epoch are overlayd by Balqa Group formations of Santonian to Eocine Epoch (fig.4). The end aim of vulnerability study is keep groundwater quality. So the special interest in such studies is given to formation that forms an aquifer. In Ajlun group only Humar Formation (A4) and Wadi Assier Formation (A7) form productive aquifers. The most important aquifes of Balqa group are Amman Selicified Limeston (B2) and Rijam formation (B4). Gudran Formation (B1) is lays between the formations B2 and A7. The formation B1 is formed of low permeability chalk. But as it's of low thickness and highly fractured its consider as a part of an important aquifer which include also A7 and B2. This aquifer is widely known in Jordan as B2/A7 aquifer (Abed 2000; WAJ 1997).

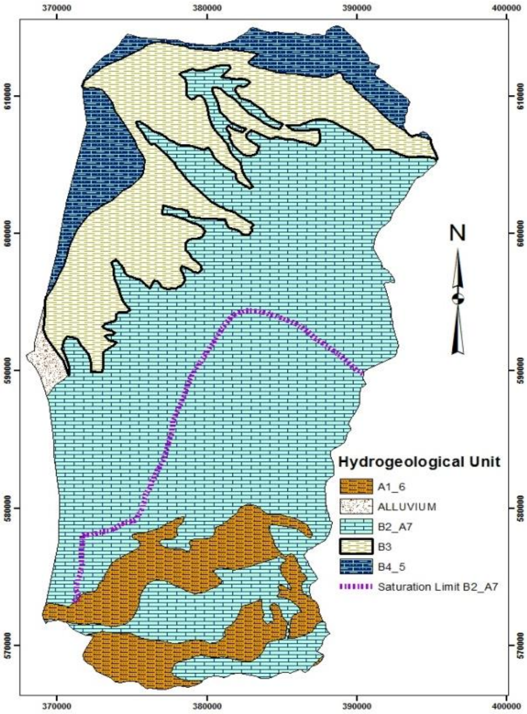

Figure 3: Hydro-geological distribution of aquifer and aquitards outcropped in the study area.

Gological time scale			Quennel,1951		Parker,1971
Era	Period	Epoch	Group	sympol	Formation
Cenozoic	Tertiary	Eocene	Balqa	B5	Shalalah
		Paleocene		B4	Rijam
Mesozoic	Cretaceous	Mastrichtian		B3	Muagar
		Campanian		B2	Amman
		Santonian		B1	W. um Gudran
		Turonian	Ajlun	A7	Wadi Es Sir
		CENOMANIAN		A6	Shuaib
				A5	
				A4	Hummar
				A3	Fuhais
				A2	Na-ur
				A1	

Figure 4: Stratigraphic Column of the study area.

METHODS

a: MAR Evaluation

Potentiality of the groundwater refers to expected value of the aquifer to yield groundwater. Aquifer recharge projects are important for arid to semi-arid areas because of their ability to increase the amount of stored groundwater and to recover the over-exploited groundwater in addition to ability to improve quality of groundwater during recharge and self purification process, (Mohammad, 2016). Reducing loss of fresh surface water, as a result of exposure to evaporation is of vital importance to MAR. Ismail, I., Othman, A., Abd El-Latif, R. & Ahmed, A. (2010).

In order to evaluate MAR potential for the aquifer on a detailed scale within the study area, four thematic layers are important and they interact with each other to produce the final MAR map; which are: hydrogeological characteristics (which controls the presence or absence of aquifers to be recharged), Topographic classification of the targeted area (which is an important factor as the slope is one of the most effective factors that drives the recharge process), urban area distribution (which is another factor that must be taken into consideration during the building of MAR projects - a buffer zone around the urban area must also be taken into consideration) and finally the proximity to the water resources (which will be collected and used for the recharge process).

According to Hobler & Subah (2001), the major distribution of the hydro-geological units in Jordan was modified by the Natural Resources Authority in 1:50000 geological maps and used to evaluate the primary potentiality. This map shows that the study area was subdivided into two main hydro-geological layers (Figure 3): the aquifer unit composed of B2/A7 and the B4/5 aquifer. These are considered as the main aquifers in the study area and the aquitard units, which are composed of impermeable rock units, B3 and A1/6. MAR only has a potential along aquifer outcrops.

Topography plays a major role in MAR through infiltration, as the slope determines the residence time of surface water over a specified area. According to Rapp (2008), the most effective slope for MAR is 0–5 %, under which proper infiltration process can take place without any enhancement for runoff. Regarding slopes, the area was subdivided into two slope classes: from 0 to 5% (which is suitable for MAR) and greater than 5% (which is unsuitable for MAR).

According to Gale (2005), the water sources suitable for MAR are: perennial streams, rivers or canals, intermittent streams, wadis and flood flow water, treated and reclaimed water and desalinated water. Maps for these components are drawn, with a buffer zone of 5 kilometers around dams and waste water treatment plants included. The drainage system for the area under study was designed using Arc Hydro tool under the environment of Arc GIS. Then a buffer of 250 meters around these lineaments (which is considered an economic distance for MAR) was drawn.

Urban areas and small settlements distributed over the study area represent a limitation for MAR, as MAR requires an appropriate area and some construction works. However, other types of land use such as farms do not restrict MAR constructions. A map for the urban areas as obtained from the

Ministry of Water and Irrigation MWI was used in order to determine the thematic layer with a buffer of 250 meters around urban areas.

For processing of the MAR map, Table 1 shows the potentiality of the area under study to be used for aquifer recharge. Applying data in the pattern shown in table 1, resulting map is shown in Figure 5.

In Jordan, several vulnerability studies were conducted using different indices. In Azraq basin, the area bordering NSRW from the east, DRASTIC index and MAR were applied separately. The results show that the areas are with different ranges of vulnerability rates according to the environmental settings, as described by AlRaggad & Jasem (2010), while the MAR within the same basin defines the area with the high potentiality of recharging the groundwater as shown by AlRaggad & Jasem (2010). From the two studies, it is clear that there are some high recharge potential areas with a range of high groundwater vulnerability rates, which must be removed from the potentiality map because of its ability to pollute groundwater.

Table 1: Combination of classified slope and hydro-geological classes and potential zones (Rapp, 2008)

Combination of classified slope and hydro-geological classes		
MAR parameters	**MAR Potential**	
Aquifer and slope <5%	High	
Aquifer and slope >5%	Medium	
Enhanced aquifer and slope <5%	Very high	
Enhanced aquifer and slope >5%	Medium	
Aquitard and slope <5%	Low	
Aquitard and slope >5%	Low	
Parameters combination and the resulting potential zones		
MAR parameters	**Proximity to water sources**	**MAR potential**
Aquifer and slope <5%	No	High
Aquifer and slope <5%	Yes	Very High
Aquifer and slope >5%	No	Medium
Aquifer and slope >5%	Yes	High
Enhanced aquifer and slope <5%	No	Very High
Enhanced aquifer and slope <5%	Yes	Excellent
Enhanced aquifer and slope >5%	No	Medium
Aquitard and slope <5%	No	Low
Aquitard and slope >5%	No	Low

b: GOD Methodology

GOD is an acronym of the three factors that the methodology consider. These factors are:

Groundwater occurrence, Overall aquifer class, and Depth to groundwater (foster 1987). The GOD index is obtained by multiplying indices of each of these three variables according to the following equation:

$$IGOD = G_r * O_r * D_r \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where:

G,O,and D are GOD Parameters

r is the rating of each parameter

The range and ratings for the three GOD model parameteres are listed in the table (2). The GOD vulnerability map is generated by reclassifying the I GOD map according to the criteria explained in the table (3)

Table 2: range and ratings of the three parameters of GOD model (modified after Foster, 1987)

Parameter	Range	Rating
G	No aquifer to unconfined aquifer	0 to 1
O	Clay to karstified limestone	0.3 to 1
D	>100 to 0 (m)	0.4 to 1

Table 3: GOD Index and corresponding vulnerability category of GOD model.

GOD Index	Vulnerability Category
< 0.1	Very low
0.1-0.3	Low
0.3-0.5	Moderate
0.5-0.7	High
>0.7	Extreme

RESULTS AND DISCUSSION

The drafted situation of the groundwater resources in the basin requires the adaptation of integrated water resources management concept, MAR mapping using a GIS environment showed that around 10% of the total basin area possess high potential to MAR, due to the presence of superficial deposits, low slope, aquifer conditions and proximity to water resources. medium potential zones formed more than 40% of the total area. It is concentrated in the parts of water drainage through the targeted area where the depth to water is very low, therefore enhancing the MAR processes, low MAR potentiality areas formed 55% of the total Azraq basin area. This part was found to be restricted to the high slope areas and absences of good aquifer rocks (figure 5), table 4.

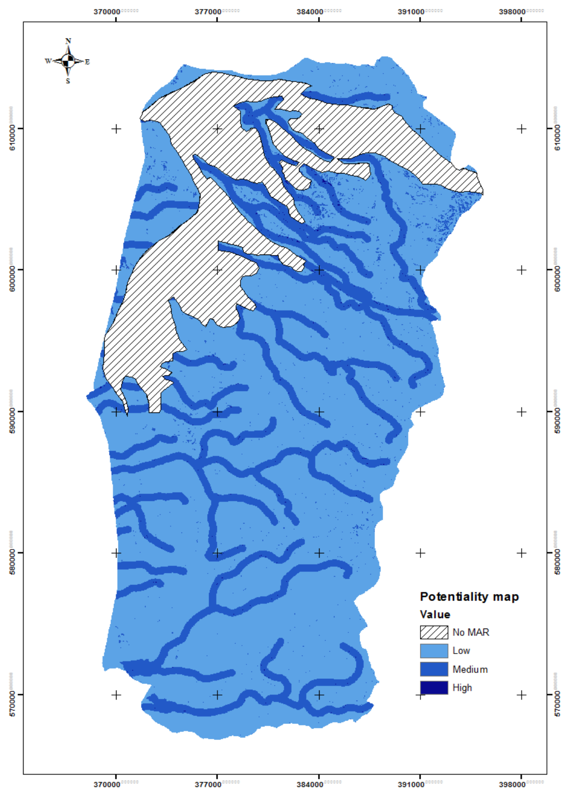

Figure 5: Managed aquifer recharge final map for NRSW.

Table 4: Percentages of MAR classification within the study area

MAR potentiality	Area %
High	10
Moderate	35
Low	55

Each of GOD model parametes has been evaluated separately. Consequently, a thematic map has been elaborated for each variable to describe its spatial variability. Figure 6 shows the rating distribution for G factor, O factor, and D factors.

GOD Index map shows values ranging from 0.06 up to 0.54, reclasifiation this map using the criteria indicated in table 3 produced the GOD vulnerability map (fig. 7). GOD vulnerability map shows a clear influence of hydrogeological map. Rijam aquifer area represents the unique high vulnerability zone in the study area. That's becuas Rijam aquifer is relatively shallower than B2A7 aquifer and both of them are calcerous. The area underneath the B2A7 aquifer is saturated and evaluated as moderate vulnerability zone. However this aquifer is more carstic than Rijam aquifer and its transivity is also higher than Rijam, the water table of B2/A7 is very deep (water resourse north Jordan). The area which cavered by alluvial is also of moderate vulnerability. The rest of study area where the aquifers is confined or not saturated, the vulnerability is identified as low. Calculating the sapatial distribution of each vulnerability class, 49.5 %, 43.1%, and 7.4& of study area are belong to very low, moderat, and high vulnerability.

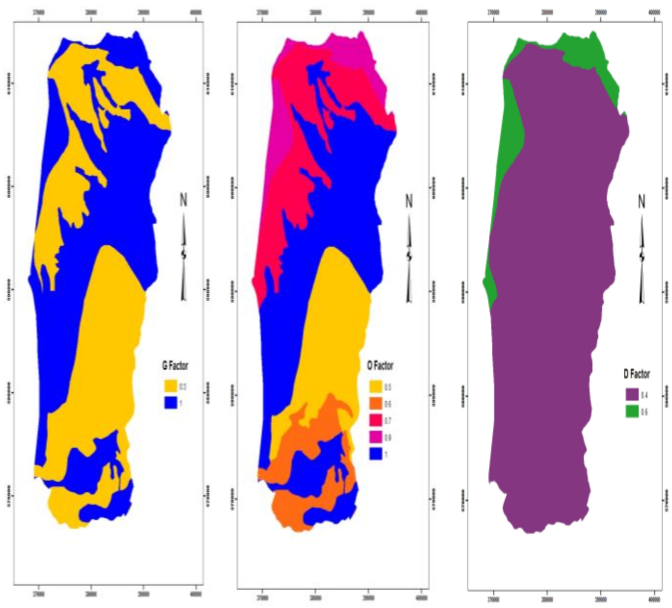

Figure 6: Distribution of the G, O and D factors ratings in the study area

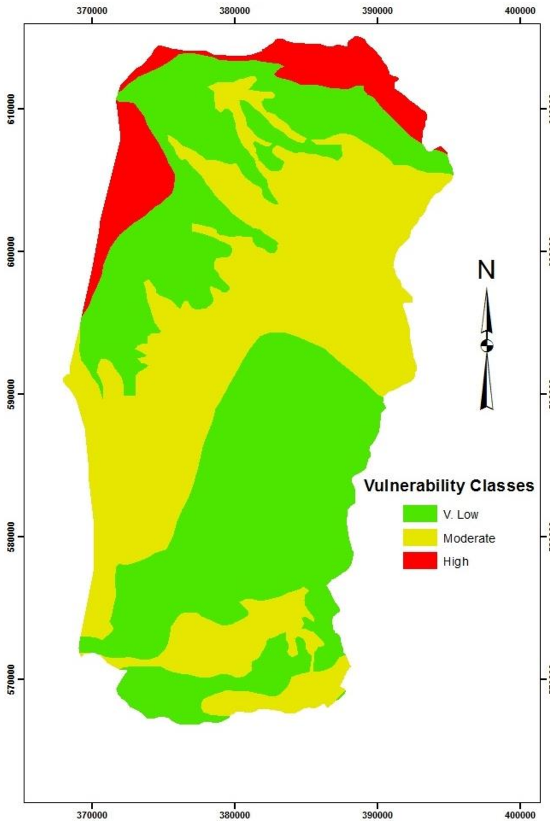

Figure 7: GOD Vulnerability of groundwater to contamination in the study area

CONCLUSION

Both, managed aquifer recharge and vulnerability concepts are very important to be applied for arid to semi-arid areas. The importance comes from the significance of groundwater as the main resource of water in these areas. Jordan, being one of the countries, poorest in water resources, puts more pressure on these groundwater resources. The need to save existing water resources highlights the value of the groundwater vulnerability concept, and the importance of providing renewable groundwater resources increases the importance of managed aquifer recharge concept.

GOD model was able to classify the study area to different vulnerability categories, applying this model resulted in about 50% of study area is belong to very low vulnerability and about 7% of study area is belong to very high vulnerability class which is the areas overlying Rijam aquifer due to relatively shallow water table.

Merging both these concepts together is a new procedure to limit areas that should be considered as potential areas for applying and building national water projects to save and enhance existing water resources in Jordan. This article shows that combining MAR and vulnerability map together reduces potential areas of groundwater resources that might be used for such projects. Also, this will save existing resources from pollution. Areas that show high and very high potentiality for managing aquifer recharge concept without vulnerability mapping were a total of 10% of the study area, while this figure was reduced to 8% of the total area from the basin, after eliminating areas classified as high vulnerability.

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