

## Integrated Approach for Groundwater Exploration in Wadi Araba Using Remote Sensing and GIS

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### ABSTRACT

Jordan has been recently classified as the fourth poorest country of water resources. Natural and human factors are affecting and increasing the stresses on these resources. Jordan had suffered from the continuous drought periods over the time. Furthermore, unbalanced demand vs. supply is always present as a result of high population growth rate.

This study aims at the exploration of new water resources through the investigation of hydrogeological and groundwater resources in Wadi Araba Basin (Northern and Southern Wadi Araba Basins). The integration of Geographic Information Systems (GIS) and data extracted from earth observation satellites with additional collateral data, coupled with selected field investigations and the geological knowledge of the area under investigation, provides a powerful tool in groundwater exploration.

Weighted overlay modeling technique was used to develop a groundwater potential model with six weighted and scored parameters. The results of this model were calibrated against observed data collected from the existing wells' information. The results obtained from this model show that about 40% of the study area was classified as having a good potential for groundwater exploration. The spatial distribution of these areas is highly correlated with the location of the existing groundwater wells. The generated groundwater potential map shows that there is a lot of unexplored areas that have a good potential for groundwater exploration.

**KEYWORDS:** Integrated approach, Groundwater exploration, Remote sensing, GIS, Wadi Araba, Jordan.

### INTRODUCTION

Jordan is considered as one of the ten most water-scarce countries in the world (Jordan Water Resources (JWR), 2001). The country, dominated by arid and semi-arid climate, suffers from scarcity of natural water resources and increasing population growth. This has caused an increased demand on water resources and resulted in a wide disparity between water supply and

demand (Al-Mimi, 1992). The available per capita water resources are falling as a result of population growth and are projected to fall from less than 160 m<sup>3</sup>/capita/year at present to about 90 m<sup>3</sup>/capita/year by 2025, putting Jordan in the category of an absolute water shortage.

Groundwater is the most important source of water in Jordan, whereas Jordan is divided into 12 groundwater basins. It provides 418.5 MCM/yr (more than half of the total water demand). Groundwater is divided into renewable (275.5 MCM/yr) and non-renewable

groundwater with safe yield of 143 MCM/yr; (JWR, 2001). The majority of renewable groundwater reservoirs are being utilized at rates exceeding their sustainable yield. The combined abstraction rate of all renewable

reservoirs approaches 437 MCM/yr, a rate equals to 159% of their sustainable yield. The over-pumping ratio varies from 146% in minor aquifers to 235% in major ones (Jordan Geography and Environment (JGE), 2001).

**Table (1): Lithological sequence in Jordan (compiled from Natural Resources Authority (NRA), 1995).**

Period	Age	Group	Formation	Lithology	
Quaternary	Holocene (Recent)	Jordan	Fan, Talus, Terrace, River	Sand, Clay, Gravel	
	Pleistocene		Lisan	Marl, Clay, Gypsum, Sand, Gravel	
Tertiary	Pliocene	Valley	Undifferentiated	Conglomerate, marl	
	Miocene				
	Oligocene				
	Eocene	Belqa	Wadi Shallala (B5)	Sandstone	
Paleocene	Umm Rijam (B4)		Chert, limestone		
Upper Cretaceous	Maestrichtion	Belqa	Muwaqqar (B3)	Chalk, Marl	
	Companion		Al Hasa (B2a)	Phosphate	
	Santonian	Ajlun	Amman (B2b)	Silicified Limestone	
	Turonian		W. Ghudran (B1)	Chalk, Chalky marl	
	Cenomanian		Wadi Es Sir (A7)	Limestone	
			Shueib (A5-6)	Marly Limestone	
				Hummar (A4)	Dolomitic Limestone
Lower Cretaceous	Albian	Kurnub	Kurnub Sandstone	White Sandstone, dol.	
	Aptian			Varicolored Sandstone	
	Neocomian			Lst., shale, marl, dol.	
Permo-Triassic		Zarqa	Dardur	Sandstone, marl, shale	
			Ma'in	Sandstone, siltst., clay	
			Umm Irna	Sandstone, siltst. shale	
Silurian		Khryim	Khushsha	Sandstone, shale	
			Mudwwara	Sandstone, shale, mud	
Ordovician			Ram	Dubaydib	Sandstone, shale
				Hiswah Sandstone	Mudstone, sandstone
Cambrian		Safi	Umm Sahn	Sandstone	
			Disi	Sandstone	
			Umm Ishrin	Sandstone, siltstone	
			Burj dolomite	Shale, dol., sandstone	
Pre-Cambrian			Salib	Sandstone, siltstone	
			Saramuj Conglomerate	Conglomerates	

**Table (2): The major faults' names and strikes in Wadi Araba Basin.**

General trend of faults	Fault name	Fault strike
NE-SW trending faults	Southern Wadi Araba fault	N15° E
	Northern Wadi Araba fault	N10° E
	Aqaba-Gharandal fault	NNE-SSW
	Wadi As Siq fault	NE-SW
	Wadi Ghuweiba fault system	N10° E – N18° E
	Wadi Tilah fault system	NE - SW
	Wadi Musa fault	N 35° E
	Wadi Sabra fault	N 30° E in the south, and changes to NNE in the north
E-W trending faults	Wadi Khunyzira fault zone	Begins as WNW – ESE and ends E-W
	Wadi Rakiya fault	E-W
	Dana fault	N60° E to E –W
	Salawan fault	E - W
N-S trending faults	Bi'r Khidad fault	N 10° and N 10° W
	Gharandal Abu-Burqa fault	N-S
	Al Quweira fault zone	N-S
	Jabal Eth-Thuleimate-Wadi el Huwwar-Wadi Abu Khusheiba fault	N 15° W to N 5° E
	Petra-Wadi Eth-Thughra-Wadi Sakakin fault	NNE in the south to NNW – SSE in the north
	The strike-slip faults located between Al-Quwieria fault and Wadi Araba fault	N-S, changes at the western part to NNW-SSE
	Wadi Rahma fault	N 5° E
	Khurayj fault	N 10° E

Groundwater exploration, on the other hand, has many problems such as the paucity of existing data, the high cost of data gathering (subsurface and surface techniques) and relatively remote target aquifer. Therefore, remote sensing techniques and Geographic Information System (GIS) techniques are considered the most appropriate new alternative tools for groundwater exploration (Moore, 1982).

The main advantages of using remote sensing and GIS techniques for groundwater exploration are the

reduction of cost and time needed, the fast extraction of information on the occurrence of groundwater and the selection of promising areas for further groundwater exploration (Toleti et al., 2001).

The objective of this research is identifying prospective areas for groundwater exploration in Wadi Araba area based on the integration of satellite images, topographic, geological and structural data. This integration will be implemented through the use of spatial databases and geographic information systems (GIS).

### Study Area

Wadi Araba lies between the Southern Ghorarea south of the Dead Sea and extends to the Gulf of Aqaba (Figure 1). Only part of Wadi Araba east of the truce line is to be considered. It lies within the Jordan Rift System. Surface drainage in the northern part of Wadi Araba is to the north, toward the Dead Sea, whereas it is toward the Red Sea in the southern portion. Therefore, two sub-basins are distinguished: Northern Wadi Araba Basin and Southern Wadi Araba Basin.

**Table (3): Scored values for mean annual precipitation.**

Annual Precipitation (mm)	Weight
>250	70
200-250	60
150-200	50
100-150	40
<50	30

**Table (4): Scored values for the lithological units (Baharuddin et al., 2006).**

Lithology	Weight
Alluvium (Sand)	55
Sedimentary	36
Alluvium (Clay)	30
Conglomerate	28
Volcanic	21
Granite	17

According to Dames and Moore (1979), the study area lies entirely within the Jordan Rift Valley which consists of Wadi Araba - Jordan Graben System. The wadi Araba and Dead Sea basin represents a northern extension of the East African - North Syrian Fault System. Bender (1974) distinguishes two physiographic provinces which coincide with the geological provinces: Wadi Araba - Jordan Rift, and Mountain Ridge and Northern Highlands, east of the Rift.

The stratigraphy of Wadi Araba is underlain by a Precambrian igneous and metasedimentary basement complex over which is a series of sandstones, limestones, marls, shales and evaporites ranging in age from Cambrian through Pleistocene. Table (1) shows the classification of rock units in Wadi Araba Basin.

### Geological Structures in Wadi Araba

The Wadi Araba-Jordan Rift runs from the Gulf of Aqaba to the Dead Sea in 15° direction (southern graben) and then gradually takes a turn to the north (northern graben). The most fundamental structure of the basin is the Wadi Araba-Jordan Graben, which constitutes 360km of the East African-North Syrian Fault System that extends for about 6000 km (Bender, 1974). The Wadi Araba-Dead Sea-Jordan Rift separates the "Sinai-Palestine micro plate" in the west from the Arabian Plate in the east. However, the Arabian Plate block plunges northward more rapidly than the Sinai-Palestine micro plate in the west. The contrast between the surface geology of the two crustal blocks gradually becomes less towards the north of the Dead Sea until there is no longer any fundamental difference in the position of the Mesozoic and Cenozoic sequences on the two sides of the graben.

The study area is highly faulted and has a complex pattern of fault structures of which three categories of faults and fault zones cut the study area from north to south. The dominant fault zones (known as Border fault) strike north, northeast and north-northwest (Figure 4). The younger rocks down faulted against older rock complexes to the east. The major faults and flexures strike north and northeast at an acute angle into the rift, with some faults striking northwest at wider angle into the rift. The dominant fault zones which border the rift in the east are not parallel to the rift valley but are at different angles to it; they strike north, northeast and north-northwest. The network of faults dissecting the mountain range east of the border faults has the same characteristic trends as the border fault. Table (2) summarizes the major faults within Wadi Araba and their properties.



Figure (1): Location map of Wadi Araba watershed area.

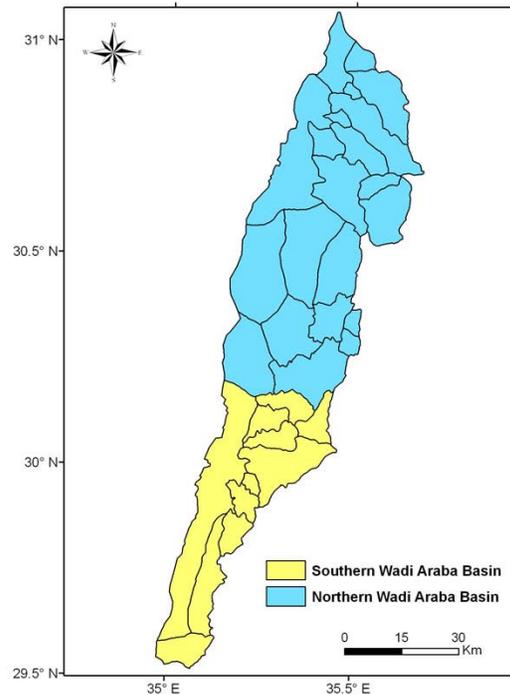


Figure (2): Location map of the northern and southern Wadi Araba basin.

### Hydrogeology of Wadi Araba Basin

The Wadi Araba basin is divided into a northern sub-basin and a southern sub-basin. The drainage divide between the two coincides with the groundwater divide and lies to the north of Qa' es Sai'diyeen on the western side of Jabal Ar-Risha, about 75 km to the north-northeast of Aqaba. The southern sub-basin drains into the Gulf of Aqaba while the northern one drains into the Dead Sea (National Water Master Plan (NWMP), 2004). The lithological composition of the aquifer is very heterogeneous, with conglomerates, gravels, sands, silts and clays in some places mixed together, interbedded and/or intercalated. The following aquifer systems exist within Wadi Araba area (NWMP, 2004). The major aquifers can be summarized as follows:

1. Water-bearing sandstones of Cambrian and Ordovician, constituting Disi Group aquifer system; The Ram Group Aquifer (Disi) forms a large aquifer

system in Jordan, which underlies the entire area of the country. It crops out only in the southern part of Jordan and along Wadi Araba-Dead Sea Rift Valley. (NWMP, 2004);

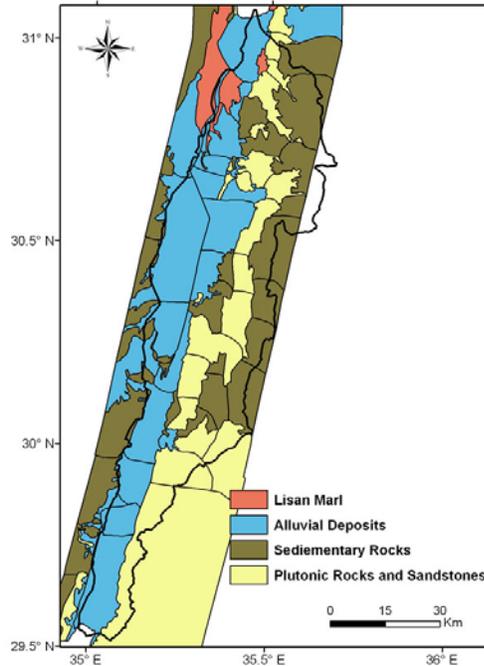
2. Kurnub Group aquifer, consisting of Low Cretaceous sandstones;
3. Water - bearing carbonate rocks of Upper Cretaceous age constituting the so-called Amman - Wadi Sir (or B2/A7)) aquifer system;
4. Alternating water-bearing and water-confining/supporting Upper Cretaceous and Tertiary undifferentiated strata;
5. Shallow aquifer system occurring in the Quaternary deposits, i.e. the valley fills of Wadi Araba.

### Modeling Groundwater Potential

Groundwater constitutes an important source of water supply for various purposes such as domestic, industrial

and agricultural needs. Groundwater forms the part of the natural water cycle, which is present within underground strata. The principle sources of groundwater recharge are

precipitation and stream flow (influent seepage) and those of discharge including effluent seepage into the streams, lakes, springs, evaporation and pumping (Gupta, 1991).



**Figure (3): Generalized geological map of Wadi Araba basin.**

The modeling approach followed to model groundwater potential is summarized in the flow chart in Figure (5). This chart also shows the different inputs and outputs used to generate the final groundwater potential map.

A GIS model was applied using Spatial Analyst™ to derive the groundwater promising areas suitable for exploration. The method used here has been modified from the well-known DRASTIC model, which is used to assess groundwater pollution vulnerability by the Environmental Protection Agency of the United States of America (Aller et al., 1985). The formula of the Groundwater Potential (GP) model is shown below:

$$GP = Rf + Lt + Ld + Lu + Te + Ss + Dd + St \dots\dots\dots(1)$$

where:

- Rf: Annual rainfall,
- Lt: Lithology,
- Ld: Lineament density,
- Te: Topography elevation,

Ss: Slope steepness, Dd: Drainage density.

A spatial database was generated using ArcCatalog™ to store the different data sets needed to implement the model shown in Equation (1). A description of these parameters is given in the next sections.

**Annual Rainfall**

Rainfall is one of the major factors that contribute to groundwater recharge. The long term mean annual precipitation ranges between 50mm/year in the western areas where the elevation reaches -400m below MSL and 250mm/year in the eastern highlands area (Figure 6). These precipitation values were scored to reflect the influence of perception on groundwater. As we have more precipitation, more water will be available for surface runoff and infiltrations will naturally recharge the

groundwater. Table (3) shows the scored values of mean annual precipitation, and Figure 7 shows the generated thematic map for the scored values of mean annual

precipitation. As this figure shows, areas with high scoring values are located in the western parts of the basin.

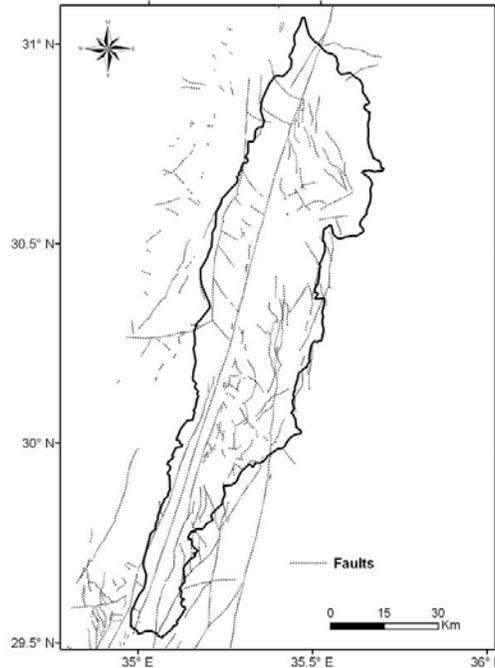


Figure (4): Major structural faults in Wadi Araba basin.

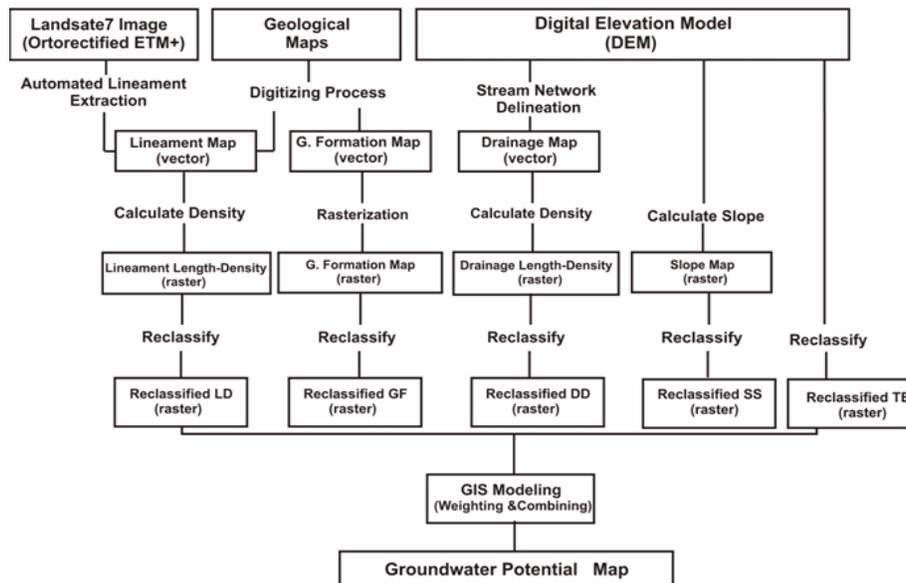


Figure (5): Flow chart of the processes followed to implement groundwater potential model.

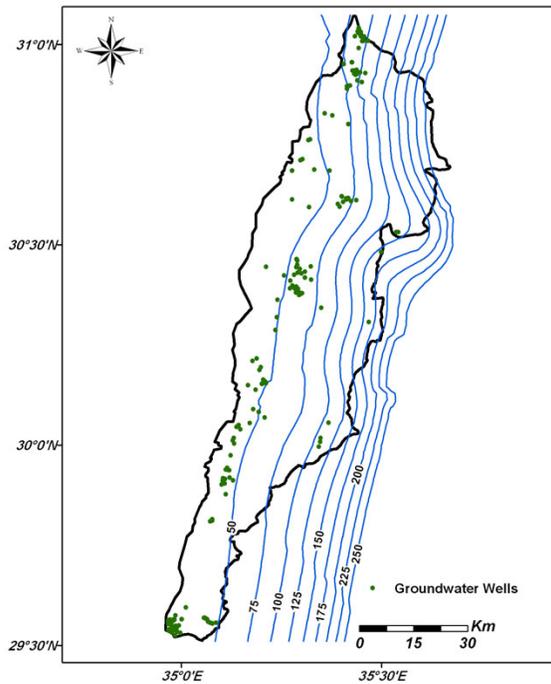


Figure (6): Isohyantal map for Wadi Arab basin.

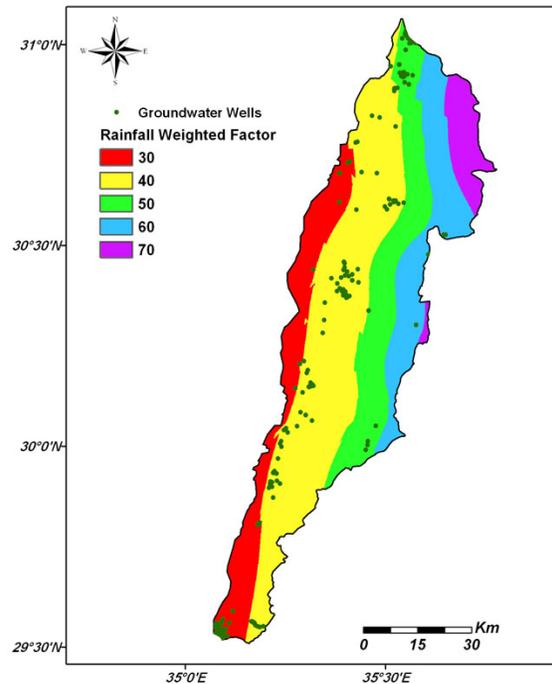


Figure (7): Scored values for the mean annual precipitation.

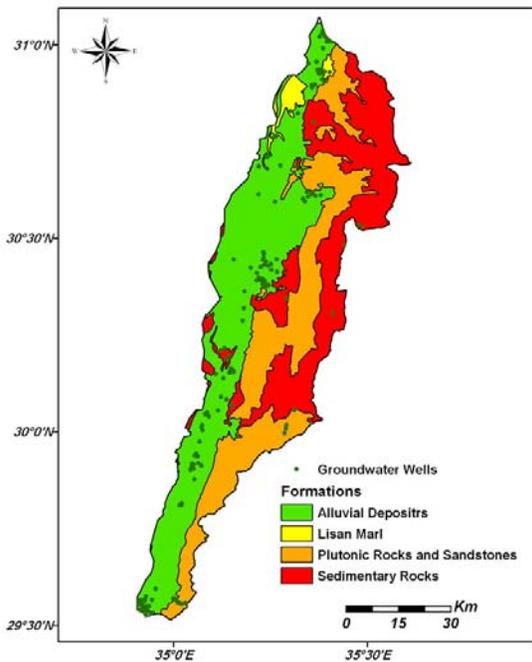


Figure (8): Main rock units exposed in the study area.

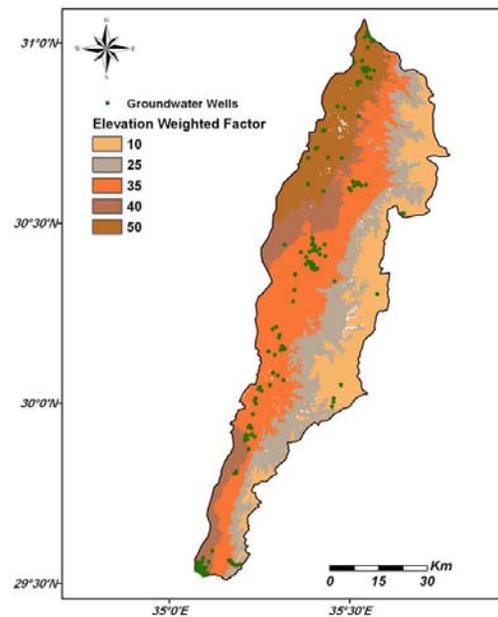


Figure (9): Thematic map for the scored values of lithology.

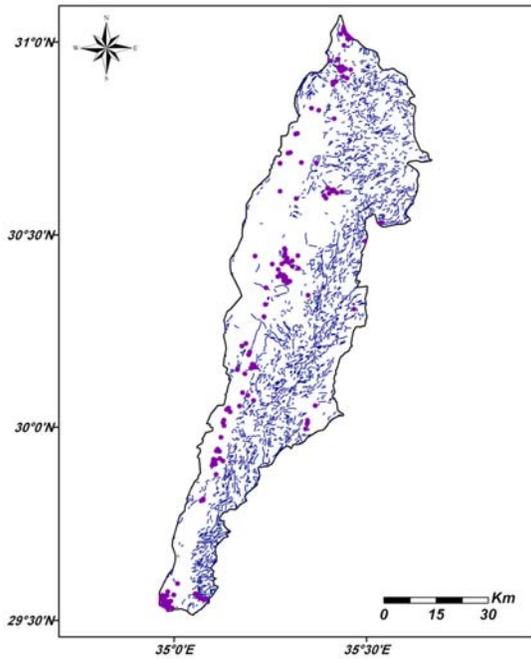


Figure (10): Lineaments map generated by PCI Geomatica LINE module.

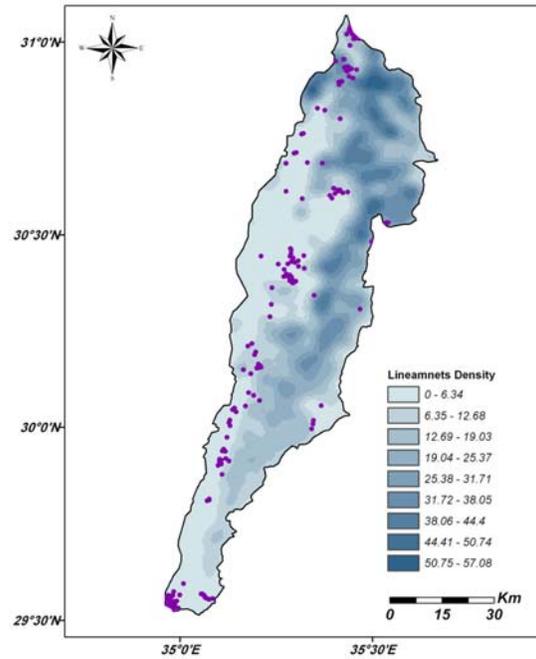


Figure (11): Lineaments density generated by ArcGIS Spatial Analyst.

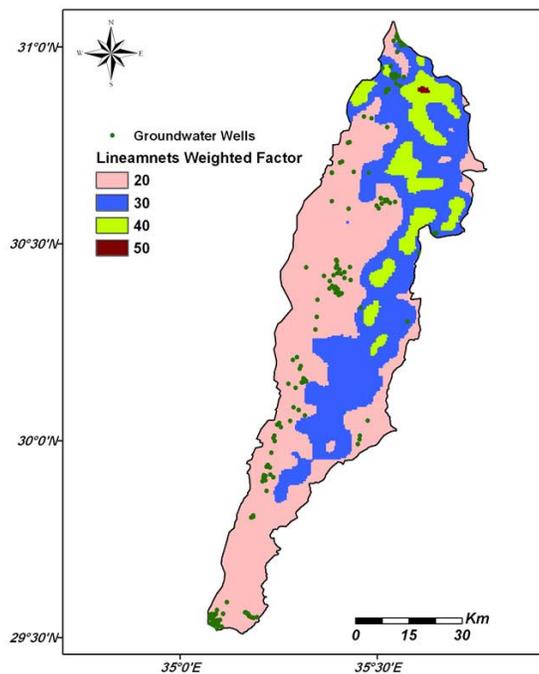


Figure (12): Thematic map for the scored values of lineaments density.

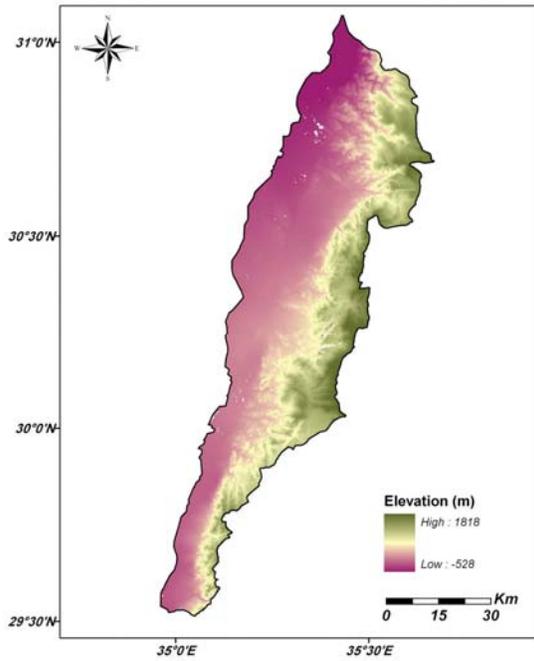


Figure (13): Digital elevation model (DEM) for the study area.

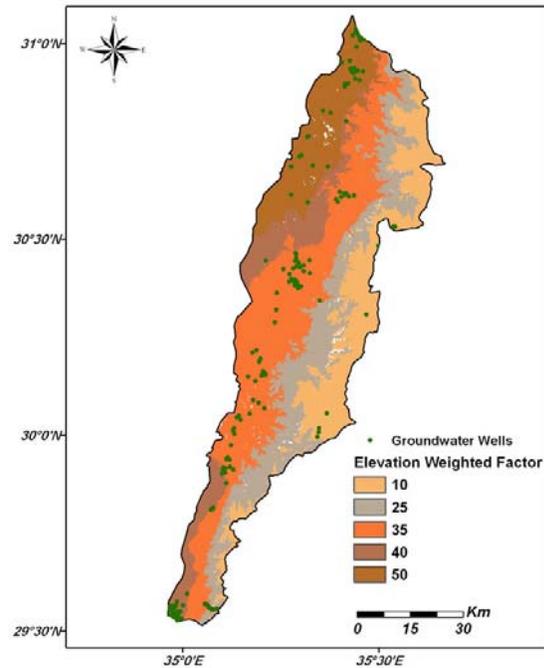


Figure (14): Thematic map for the scored values of topographic elevation.

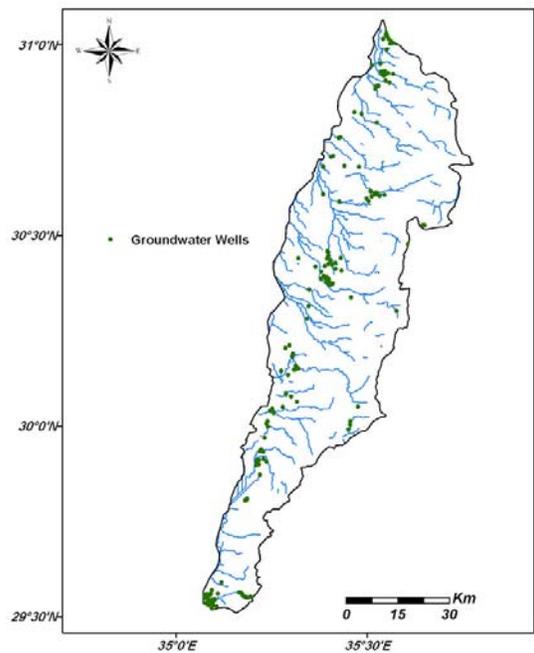


Figure (15): Extracted drainage network for the study area.

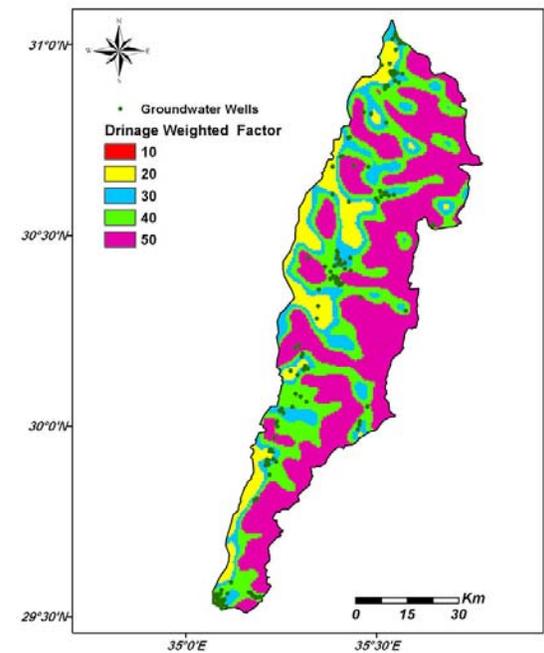


Figure (16): Thematic map for the scored values of drainage density.

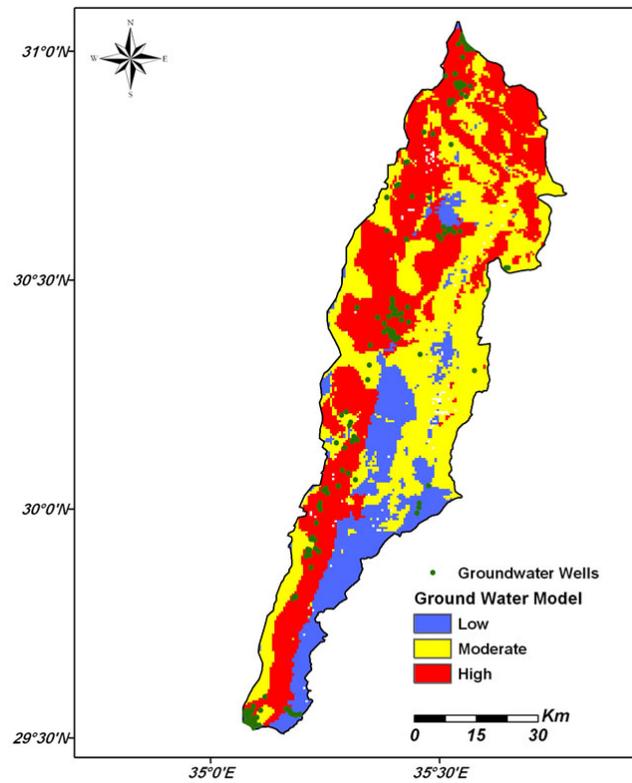


Figure (17): Groundwater potential model.

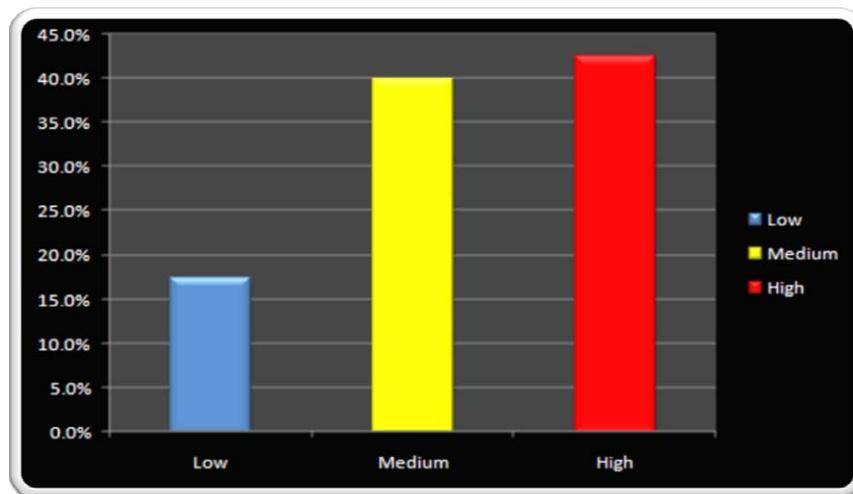


Figure (18): Histogram of the classified categories obtained from groundwater potential model.

### **Lithology**

The lithologic character of the exposed rocks is significant in governing recharge. Some studies neglect this factor once they use the lineament and drainage (El-Shazly et al., 1983; Edet et al., 1998). This is because they consider the lineaments and drainage characters as a function of primary and secondary porosity, thus providing information on the lithology. However, others (Salman, 1983; El-Baz and Hamida, 1995) incorporate the lithology factor because of its strong influence on water percolation. Lithology characterized by massive rock has little influence compared with topography in the control of availability of groundwater. The rocks become aquifers through development of weathering and fracturing by secondary porosity (Sener et al., 2005).

The outcropping rock units can be summarized as follows (Figure 8):

- 1) Alluvial Deposits;
- 2) Lisan Marl;
- 3) Plutonic Rocks and Sandstones;
- 4) Sedimentary Rocks.

Table (4) shows the scored values for the different lithological units and Figure (9) shows the thematic map of the scored values for lithology.

### **Lineament Density**

Lineaments are extracted from satellite images using automated extraction techniques in order to increase details of existing data of the available geological structure map. The main advantages of automated lineament extraction over the manual lineament extraction are: its ability to uniform approach to different images (processing operations are performed in a short time) and its ability to extract lineaments which are not recognized by the human eye. Available software provides different algorithms for automated extraction. The most common algorithms are Hough transform, Haar transform and Segment Tracing Algorithm (STA) (Koçal, 2004).

In this study, the automated lineament extraction is performed by the LINE module of PCI Geomatica 9.1 software. The logic of this method is similar to STA.

Further information about this algorithm are found in PCI Geomatica users' manual (2003). Figure (10) shows the resultant lineaments map.

Lineaments density map was generated using ArcGIS Spatial Analyst Tool (Figure 11). Lineament density values were scored according to (Musa et al., 2006) (Table 5). The resultant thematic map for lineaments density appears in Figure (12).

### **Topography Elevation**

Generally, flat and gently sloping areas promote infiltration and groundwater recharge, and steeply sloping grounds encourage run-off and little or no infiltration. The area has a gentle slope; it supports low discharge of overland flow and high rate of infiltration. Therefore, groundwater potentiality is expected to be greater in the flat and gently sloping area (Solomon 2003; Subba, 2006). Flatter topography then will give more chance for groundwater accumulation (Solomon, 2003). Topographic data is a vital element in determining the water table elevations (Sener et al., 2005). The combination of fractures (lineament) with topographically low ground can also serve as the best aquifer horizon (Subba, 1992).

Figure (13) shows the Digital Elevation Model (DEM) with spatial resolution of 20m, used to build the topographic elevation factor values (Figure 14).

### **Drainage Density**

Drainage pattern is one of the most important indicators of hydrogeological features, because drainage pattern and density are controlled in a fundamental way by the underlying lithology (Charon, 1974). In addition, the stream pattern is a reflection of the rate that precipitation infiltrates compared with the surface runoff. The infiltration/runoff relationship is controlled largely by permeability, which is in turn a function of the rock type and fracturing of the underlying rock or surface bedrock (Edet et al., 1998). When comparing two terrain types, the one that contains the greatest drainage density is usually less permeable (Edet et al., 1998). Many workers combined only the lineament map with drainage

map to presume the target areas of groundwater potential areas (Tomes, 1975; Edet et al., 1998). It is well known that the denser the drainage network is, the less is the recharge rate and *vice versa* (Edet et al., 1998).

Figure (15) shows the drainage map for the study area which was created using ArcHydro Tool™ and Digital Elevation Model (DEM) with 30m cell size. Figure (16) shows the scored values of drainage density layer based on the scoring values of Table (6).

**Table (5): Scored values for the lineaments density (Musa et al., 2006).**

Lineament Density (km/km <sup>2</sup> )	Weight
> 0.0075	60
0.0055 - 0.0075	50
0.0035 - 0.0055	40
0.0015 - 0.0035	30
< 0.0015	20

**Table (6): Scored values for the drainage density (Musa et al., 2006).**

Drainage Density (km/km <sup>2</sup> )	Weight
> 0.0055	10
0.0040 - 0.0055	20
0.0025 - 0.0040	30
0.0010 - 0.0025	40
< 0.0010	50

**Table (7): Categories of groundwater potential zones (Baharuddin et al., 2006).**

Category	Lower and Upper Weight Values
Excellent (E)	395-420
Very Good (V)	365-390
Good (G)	345-360
Moderate (M)	330-340
Poor (P)	Less than 330

### Groundwater Potential Map

To obtain the groundwater potential map described in

equation (1), a GIS model was applied using weighted overlay technique to derive the groundwater promising areas suitable for exploration.

Determination of the groundwater potential value for a given area involves multiplying each scale value of reclassified layer (parameter) by its weight (or percent influence). The resulting cell values are added to produce the final output raster that represents potential groundwater areas. Higher sum values represent greater potential for groundwater. For a particular area being evaluated, each parameter class was scaled on an evaluated scale according to their importance to other classes in the layer. The values were assigned in terms of their importance with respect to groundwater occurrences. Once each parameter has been assigned a scale value (suitable value), it is weighted. Weight values, from 1 to 100, express the relative importance of the parameters with respect to each other to groundwater occurrences.

The result of groundwater potential model appears in Figure (17). Figure (18) shows the histogram of the classified categories obtained from groundwater potential model.

The obtained values from the groundwater potential model were classified according to (Baharuddin et al., 2006) (Table 7).

As Figures (17) and (18) show, it was found that:

- 1) About 17% of the study area was classified as low potential areas and concentrated in the southern western parts of the study area.
- 2) About 40% of the study was classified as moderate potential areas.
- 3) The rest of the study area (about 40%) was classified as high potential areas and concentrated in the northern, northeastern part of the study area.
- 4) A great correlation can be noticed between areas assigned as high potential areas and the location of groundwater wells.
- 5) These areas are considered promising sites for further groundwater explorations.

## CONCLUSIONS

In this study, an integrated approach using GIS and remote sensing was adopted to find new potential sites for groundwater exploration in the alluvial aquifer. A weighted overlay model was implemented using eight different effective weighted parameters including; annual rainfall, lithology, lineament density, topography, slope and drainage density. The groundwater potential map was obtained by algebraic summation of these effective parameters being multiplied by their effective weights. This was classified into three different classes reflecting the potential of groundwater exploration. The final map of groundwater potential model shows that about 40% of Wadi Araba was classified as high potential areas for

groundwater exploration. These areas are concentrated along the valley floor and are parallel to the major Dead Sea transform fault system. Furthermore, about 20% of the study area falls within the class of low potential for groundwater exploration. These areas are located in the eastern southern part of Wadi Araba, where the basement rocks are outcropping. The rest of the area was classified as moderate potential for groundwater exploration.

## Acknowledgment

The authors would like to express their gratitude to the Abdul Hamid Showman Foundation for funding this project and for their help and commitment for supporting scientific research projects.

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