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Investigation of shallow ground water in the Tulul al Ashaqif highlands, Jordan

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Abstract

Perched aquifers in the arid region of Tulul al Ashaqif in northeastern Jordan are an important traditional source of water in this area, and could potentially be a significant contributor to the water resources of this arid region. Despite this, little effort has yet been exerted into understanding the distribution and nature of this resource. The purpose of this paper is to describe the recent research effort, which aimed at understanding the factors controlling the distribution of this water, its quality and renewability as well as the hydrological nature of the aquifers.

A combination of remote sensing and geomorphological analysis was used to determine the locations of potential sites for further investigation. Based on this, detailed geophysical surveys were conducted at nine sites, using both Wenner and Schlumberger geoelectrical arrays. These surveys resulted in the choice of four potential sites for drilling of shallow wells. The wells yielded two locations where shallow groundwater is present.

The chemical characteristics of the water indicate that it is well within the standard guidelines for drinking water in Jordan. The isotopic data from this water indicates that it is renewable. The hydrological characteristics of the aquifer indicate low hydraulic conductivity, ranging from 5.8-9.7cm/day, although the quantity of water is significant (millions of cubic meters). This suggests that numerous wells need to be drilled for optimal extraction.

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Introduction

The importance of finding water resources in arid areas cannot be over-emphasized. Social and economic development and proper stewardship over the environment requires planners to understand the opportunities and limitations imposed by the climate and landscape. Moreover, economic and political realities are often not suitable for large-scale projects involving the importation of water from long distances, which is commonly thought to be the key to social and economic development in such areas. In fact, such schemes are often detrimental to the environment and fail to achieve the desired development of these areas.

The Badia Research and Development Programme was established in 1992 as a tool to encourage research into various aspects of sustainable development in the northern Jordanian badia (northeastern desert). Naturally, evaluation of water resources in the area became a prime concern for the programme. Research has been conducted on both the ground water and surface water resources in the area. This has resulted in the construction of a number of surface water catchment dams in order to harvest the intermittent runoff generated in some of the wadis. The regional aquifer contains high quality water in the western part of the northern badia region, but is less utilized in the eastern part (Tulul al Ashaqif) where the quality is lower (Abu-Jaber et al., 1998). Thus the Tulul al Ashaqif area is sparsely inhabited, largely because of the relatively high salinity of the waters from the upper aquifer.

Modern developments have led to the near-abandonment of the traditional water resources in the Tulul al Ashaqif area. These consist of three known shallow (perched) aquifer sites where water is readily accessible by digging shallow pits. These sites are located at Biyar el (i.e. wells of) Ghussein, Biyar el Mahdath and Biyar el Khudari. The presence of this water at such shallow depths raises a number of questions as to their scientific and practical significance. From a scientific perspective, questions on why these aquifers exist and how does their recharge occur were investigated. Chemical and isotopic data of waters from these sites indicate that the water is young and relatively unevaporated, suggesting rapid recharge (Abu-Jaber, 2001). Recharge seems to occur into the wadi sediments when runoff is generated, although recharge through the desert pavement and the underlying mantle can not be discounted, especially given the absence of vegetative cover over most of these areas. The trapping of the water within the alluvium is probably related to water-rock reaction creating impermeable clay horizons such as the one seen at Biyar el Ghussein (Abu-Jaber, 2001; Abu-Jaber and Kimberley, in prep.). From a water resource perspective, questions relating to the nature and extent of the aquifer as well as the quality of the water are raised. Clearly, there is no reason to assume that recharge and storage occurs exclusively at the three sites mentioned above. In fact, little has been written about the investigation of such aquifers as a potential source of water anywhere in the world, despite the obvious need to understand the potential of any water resource in arid regions. Therefore, we have embarked on this project in order to determine where other such resources in the area may be found, and determine what sorts of yields may be expected from these aquifers and the quality of water in them. This was done using a combination of field reconnaissance, remote sensing, geophysical surveying and drilling of selected sites.

Study area

The Tulul al Ashaqif is an 80 km by 40 km ridge extending nearly NS half way between the towns of Safawi and Ruwaishid (Figure 1), and reaches elevations exceeding 950m. The Amman-Baghdad highway crosses the southern part of the ridge and provides the only major land access into the area.

The climate of the area is arid, with cool winters and hot summers when temperatures can exceed 40^{o}C. Rainfall occurs in the winter and is generally erratic in its spatial and temporal distribution. Average annual rainfall is between 60-100 mm/yr (Kirk, 1998).

The ridge is of volcanic origin and is Neogene in age. According to Ibrahim (1993), much of the ridge is composed of the Safawi Group as part of the Harrat Ash-Shaam super group, whereas the younger Aritain pyroclastics make up the volcanic cones which dot the area (Ibrahim, 1993).

Relief in the area is generally moderate, with distinct topographic features defined by volcanic cones and river valleys (wadis). The ridge defines the boundary between the Azraq and Hammad hydrographic basins in northeastern Jordan. Drainage towards the west flows into Wadi Rajil, and towards the east into the playas of the Hammad basin. Because the basalt flows are rather young and the area is dry, the hydrologic system has not been perfectly developed. There are numerous examples of small internal drainage basins that are terminated by small playas known as *Qa's* (Al-Homoud et al., 1996).

The area is largely covered by pavement overlying an eolian sedimentary mantle. These pavements are believed to affect the runoff characteristics of the surfaces and prevent the erosion of the underlying eolian sediments (Higgitt and Allison, 1998). In the wadi systems, coarse-grained fluvial sediments are concentrated, and include a number of distinct river terraces in some areas. Towards the termini of these drainage basins, pebble and gravel-sized sediments are deposited and are known as "*marabs*" (Al-Homoud et al., 1996). The *marabs* typically have a relatively rich vegetative cover and are sought after by the shepherds in the area (Dottridge and Abu-Jaber, 1999). In some places, experiments are being conducted in order to grow crops. At the termini of these drainage basins, fine-grained playa deposits define the *qa's*, which are almost totally devoid of vegetative cover. The volcanic cones with a relatively high relief are devoid of pavements or sediment covers, and their plant cover is limited as well.

Previous work has been conducted on the water chemistry and recharge of the regional aquifers in the surrounding area (Abu-Jaber et al., 1998, Dottridge and Abu-Jaber, 1999, Obeidat, in press). These previous studies suggest that recharge in the entire Azraq basin to be on the order of 30 million cubic meters (Dottridge and Abu-Jaber, 1999). Work on the shallow aquifers, however, suggest that significant recharge at localized sites is occurring in the shallow aquifer (Abu-Jaber, 2001).

Shallow ground water

The study area has three previously known areas where shallow (<10m) ground water can be found. These areas are known as Biyar el Ghussein (37°50'E and 32°20'N), Biyar el Mahdath (37°50' E and 32°15'N) and Biyar el Khudari (37°38'E and 32°32'N; Figure 1). All three of these locations are characterized by having notable alluvial deposits, which appear quite clearly on aerial photographs. Alluvial terraces at Khudari indicate at least two stages of fluvial deposition in the area, possibly during more humid stages of climate in the Quaternary. It is not clear whether the occurrence of the shallow aquifers at this site reflects actual distribution of shallow water in the region, or that is an effect of traditional know-how on where it is most feasible to dig and find water. Clearly, the coarse-grained sediments in the alluvium do encourage rapid recharge as water runs through the wadis.

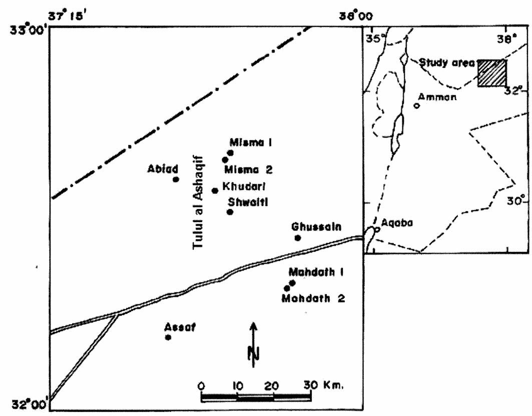


Fig. 1: Location map of the study area and locations of the Biyar and locations of survey points.

Many of the wadis in the area have relatively flat (3-4%) stretches where the river bottom undulates (pool/riffle features). This creates locations where ponding typically occurs, a feature known as a ghadeer locally. Ghadeers are well known features to the local inhabitants as they provide water resources for significant parts of the year. Ghadeers occur in close proximity to Biyar el Khudari and Biyar el Mahdath. It seems likely that their presence encourages recharge at these locations, as they allow ponded water to seep into the subsurface. The wadis themselves show higher gradients (about 9%) on longer ranges, and thus the ghadeers are localized phenomena.

Thus the significant geomorphic features that seem to characterize the occurrence of shallow aquifers in the area are the presence of alluvial terraces and the occurrence of pool/riffle features. These observations were incorporated into the later stages of exploration for more waters resources in the area.

Research strategy and methods

The strategy of this project was to attempt to focus on finding and evaluating new shallow water resources in the area. The vegetative cover density in the area was classified using satellite images, and general slope characteristics were determined using the digital terrain model available for the area. Based on these data, as well as what is known about physiographic features of the known well fields, nine locations were selected for detailed geophysical evaluation. Whereas the remote sensing and DTM were useful for identifying the general locations of the promising sites, further field expeditions were needed for the determination of the exact sites which were to be investigated using geophysical techniques. Based on the results of the geoelectrical surveys, four sites were selected for drilling. Following drilling and finding water, slug tests and chemical and isotopic analyses were conducted in order to determine aquifer characteristics as well as water quality and recharge into these aquifers.

Remote sensing

Landsat TM images of the area were obtained, and the vegetative index was determined. The visible and near-infrared data were rationed to form a "vegetation Index", also known as the Normalized Difference Vegetation Index (NDVI; Campell, 1996).

The Landsat TM map contains seven spectral bands: the blue–green (0.45 – 652µm), the green (0.52 – 06µm), the red (0.63 – 0.69µm), the near infrared (0.76 – 090µm), the mid infrared (1.55 – 1.75µm), the far infrared (10.4 – 12.5 µm) and mid infrared (2.08 – 2.35µm). The chlorophyll absorbs the red in visible light, and the mesophyll reflects the infrared. Based on this, distinguishing plant density from the spectrum was done by calculating NDVI as:

NDVI = IR-V / IR+V

In this work, IR is the near infrared band and R is the red band. Then we calculated the NDVI:

NDVI =TH4 (Low infrared) -TH3 (Red) / TH4+TH3 (Campell, 1996)

And from these calculations we could classify the map to four different classes: high NDVI, middle NDVI, weak NDVI, very weak NDVI.

We used the Thematic Mapper ® for land use classifications that depicts relatively homogeneous areas, which were delineated subject to limitations of scale, resolution, generalization and other constraints. Because of the above we could classify the region into four different areas: No vegetation, weak vegetation, moderate vegetation, and high vegetation. The absolute vegetation density in the entire area is quite low, and thus the classifications that we used are relative to each other.

To get an indication about the soil humidity, we integrated the hyperspectral data (HIS) into the color map and we separated the channels that represent the pure color. This is because the purity of the color can point to humidity and to the ratio of organic material, which lower the humidity.

We made a constructive space image from bands 4,7,2 which allowed us to differentiate types of land cover representing stones and organic matter. These probably reflect soil humidity, organic matter content and surface sediment types.

Integrating terrain data

The DTM used was that adopted by the Royal Geographic Center, which has a horizontal resolution of about 100 m and vertical resolution of 5m. While this resolution is too low to see individual features, such as *ghadeers*, it does allow for a general overview of the general topographic features in the area with better resolution than standard topographic maps. The digital terrain model for the area was obtained and modeled using the ArcInfo® software package. A slope map was obtained in order to find the areas with slopes similar to those seen in the known well areas. The area was classified into four categories:0-3^o; 4-6^o; 7-9^o; and >9^o.

The raster data from the remote sensing outputs was overlaid with the slope data in order to roughly determine which areas can be targeted for more detailed investigation. Criteria for this determination were based on what were considered to be the distinguishing features of the sites known to contain water. The most distinguishing of which are wadis with moderate slopes (4-9^o) and higher vegetative cover, and obvious alluvial deposits. While it might be assumed that the areas with the lowest slope are those that have the higher recharge, this is not true. This is because the areas with the lowest slopes are the playas (*qa's*), which allow very little recharge because to the concentration of fine-grained clay in them. As mentioned earlier, the resolution of the remote sensing data is too low for direct siting of promising locations, and therefore follow up was done using field surveys in order to chose the best sites for further investigation. It should be noted that other areas with very different geomorphic characteristics may also contain shallow aquifers, but such sites were ignored in this exploration effort. Where water has been found may simply reflect limitations in local knowledge as well as technical limitations related to the ability to drill in other types of settings.

Geoelectrical exploration

A detailed study was conducted in the selected locations using geophysical techniques. Field measurements of the VES were represented in graphs, in which the half-length of the configuration AB/2 is plotted on the X-axis and the corresponding apparent resistivity is plotted on the logarithmic Y-axis. The interpretation was done by curve matching automatic techniques. The sounding curves were first interpreted by using partial curve matching of theoretical master and auxiliary curves for two horizontal layers. Such manual curves matching produces a preliminary model showing the distribution of the true resistivity and thickness of the layers. This preliminary model was feted to a computer resistivity program RESIST (Velpen, 1988) as a start model for an automatic technique procedure (inverse modeling) in a least square sense, calculating the best fitting curve with the observed data, then a final model was created. The results were interpreted using a four-layer model, as will be explained later. The soundings were conducted in order to find out the greatest thickness of alluvium, the most permeable areas and low resistivity layers, which may indicate free water. These areas could be considered the best potential areas for drilling shallow groundwater wells. Schlumberger and Wenner arrays were used in this particular study. Seven vertical electrical sounding (VES), Schlumberger configuration, and twenty-nine profiles, Wenner configuration, were conducted (Geonics, 1995). The study covered the following six wadis; Wadi el Assaf, Wadi el Mahdath (two locations), Wadi el Ghussein (4 km downstream from Biyar el Ghussein), Wadi el Shwaiti (two locations), Wadi el Abiad and Wadi Misma (two locations; Fig.1).

The VES are carried out with AB/2 up to150m. The Wenner profiles are executed by fixed electrodes with spacing of a = 5m,10m, 20m and 30m. The equipment used for this study, was an earth resistivity meter, AR-DIGIT ™. The thickness of the alluvium ranged from 50-100m.

Drilling

Based on the previous results, locations for drilling were selected. The wells were drilled by rotary drill and cased with 6 5/8" casing. Samples of cuttings were collected about every meter. Only water was used in the drilling, with no mud added.

Slug tests

Slug tests were conducted both at traditional pit well locations as well as the drilled wells where sufficient water columns were present. The slug tests were conducted using a submersible pump, and rate of water level rebound were determined by monitoring using a water-level indicator. The traditional pits (*biyar*) didn't yield enough data to make any concrete conclusions. In the wells, pumping rate was at the order of $1m^3$/minute. At Wadi Ghussein, the well was pumped for 34 seconds during which time the water level dropped 4.7 meters. Rebound time was about two hours. At Wadi Abiad, the well was pumped for 25 seconds, during which time the water level dropped 1.1 meter. Rebound time was over five hours. The data from the wells were treated using the Hvorslev slug test method (Fetter, 1994). This treatment allows for the determination of hydraulic conductivity of the aquifers under question (Hvorslev, 1951).

Chemical analysis

Chemical analyses were conducted in the laboratories of the Department of Earth and Environmental Sciences at Yarmouk University. Water resistivity and pH were determined using standard electrodes. Chloride and dissolved inorganic carbon were determined using standard titration techniques. Nitrate was determined using spectrophotometery, as was sulfate. Sulfate was determined using the absorption caused by the turbidity initiated by the precipitation of $BaSO_4$. The major cations Ca^{2+} and Mg^{2+} were determined using atomic absorption spectrophotometry, whereas Na^+ and K^+ were determined using flame photometry.

Isotopic analysis

Tritium contents were determined by beta scintillation counting after isotopic enrichment. Errors associated with this technique are estimated to be ± 1 Tritium Unit (TU). Stable isotopic composition was determined using a Finnigan-Mat 251 Ratio mass spectrometer. Both the tritium and stable isotopic compositions were determined at the Water Authority of Jordan laboratories in Amman.

Results

Remote sensing and site selection

Nine sites were chosen for detailed geophysical study based on field reconnaissance and remote sensing data. The remote sensing work was particularly useful because it allowed for a large-scale survey for specific features in which we considered germane to the exploration effort. As a practical matter, it would be extremely time consuming to explore for specific features for such a large area in relatively difficult terrain. These sites are listed in table 1 and include locations and notable physical attributes of each location. In general, the vegetative covers of the sites are relatively high. A mixture of locations with marabs (Shwaiti I and II), locations with ghadeers (Assaf, Mahdath II, and Ghussein) as well as with wadi termini where surface water flow is expected to splay, spread over the alluvium and infiltrate (Mahdath I, Misma I) were chosen. In addition, regular wadi bottoms where apparently thick alluvium seemed to be present were also chosen (Abiad and Misma II).

Table 1: Locations of the geophysical surveys. Locations in Palestine grid.

Site	Lat. (N)	Long. (E)	Geomorphological characteristics
Assaf	183,633	388,620	Wide wadi flowing SW, bound to the south by basalt cliff. Ghadeers present
Mahdath I	194,010	416,884	Near terminus of wadi (marab), ghadeers. Old water wells present but water is below the bottom of wells.
Mahdath II	196,250	418,214	Wide wadi flowing SW, series of Ghadeers in the area. Old pits present but no water in them.
Ghussein	205,847	414,200	Wide wadi flowing SE. Bound by basalt cliff. Ghadeers present. About 4 km downstream from the known well field.
Shwaiti I	216,253	401,728	Wide wadi flowing East. Marab (downsteam).
Shwaiti II	216,171	402,028	Wide wadi flowing east. Marab. About 2km from Shwaiti I.
Abiad	226,636	389,775	Deep wadi incised into the basalt. North flowing. No ghadeers.
Misma I	231,169	402,473	Terminus of a N flowing stream, before reaching a marab.
Misma II	230,495	401,620	Center of a tributary leading to Misma I. Basalt cliff bounds the west of the wadi.

Geoelectrical surveys and well siting

The vertical electrical soundings (VES) for the nine sites chosen for study revealed a number of promising locations. Interpretation of the data was based on a model whereby there are four types of lithologies: dry alluvium, wet alluvium (saturated zone), weathered basalt and fresh basalt. The data was interpreted using the RESIST software package (Velpen, 1988). Because many factors may affect the apparent resistivity of the dry alluvium, it is generally assumed that the top layer consists of such material, regardless of the apparent resistivity. The presence of a saturated zone was surmised from any drastic fall in apparent resistivity with depth. This was seen at five of the nine sites surveyed. Mahdath I showed an apparent resitivity of 13Ωm at about 5m depth (see Figure 2); Ghussein showed an apparent resistivity of 32Ωm at about 18m depth; Shwaiti II showed an apparent resitivity of 55Ωm at about 12m depth; Abiad showed an apparent resitivity of 26Ωm at about 12m depth and Misma I showed an apparent resitivity of 2Ωm at about 12m depth (Table 2). All five of these sites could be considered potential drilling locations.

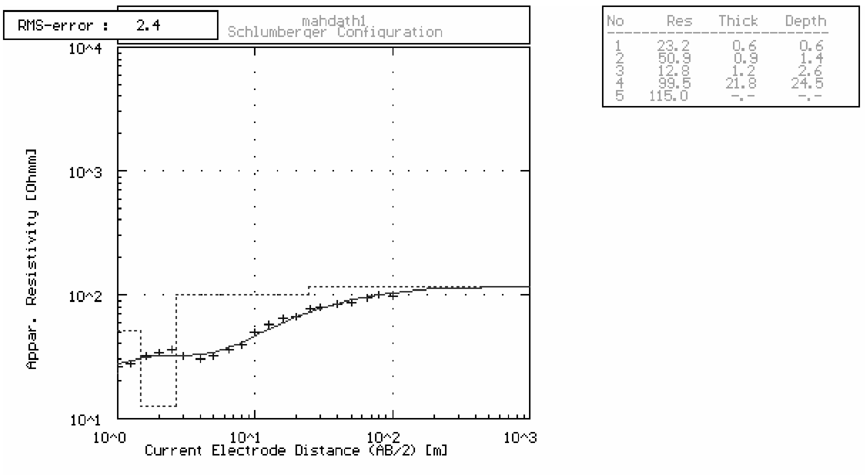


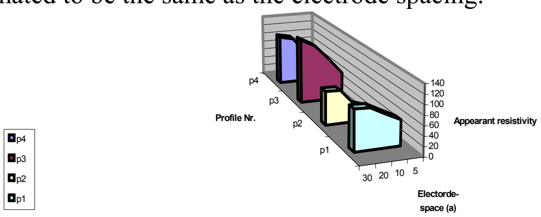
fig. 2: Model results from the Mahdath I Schlumberger array.

Table 2: Results of the geoelectrical surveys (Schlumberger method). Data was interpreted using the RESIST software package (Velpen, 1988).

Location	Layer No.	Resist. Ωm	Base depth (m)	W.L (m)	Lithology	Total Thick. (m)
	1	23	0.6		Alluvium	
	2	51	1.4	?	/	~25
Mahdath1	3	13*	2.6		/	
	4	100	24.5		/	
	5	115		24	posb. highly weathered rock	

Location	Layer No.	Resist. Ωm	Base depth (m)	W.L (m)	Lithology	Total Thick. (m)
	1	60	0.7		Alluvium	
	2	115	1.1		/	
	3	72	1.8	1.1	/	~ 15
Ghussein	4	32*	15.2		/	
	5	233	26.1		posb. moderately weathered	=11
	6	100			rock	
					posb. highly weathered rock	
	1	762	0.8		Alluvium	
	2	231	1.4		/	~ 10
	3	55*	9.7	1.4	/	
Shwaiti II	4	195	13.8		pos. moderately weathered	
	5	454	44.5		rock	= 33
	6	232			pos. slightly weathered rock	
					pos. moderately weathered	
					rock	
	1	110	0.6		Alluvium	
Abiad	2	26*	11.4	11.4	/	~ 62
	3	53	61.6		/	
	4	1502			pos. fresh bedrock	
	1	625	1.3		Alluvium	
	2	174	1.5		/	
	3	119	4.6		/	~ 12
Misma1	4	2*	6	4.6	/	
	5		11.9		/	
	6	21			possibly slightly weathered	
		604			rock	

The Wenner profiles conducted in the Wadi Mahdath I site suggest that there is lateral continuation of the saturated zone at this site (Figure 3). This can be seen both at the 20 and 30 m spacings, which show similar profiles. The same can be said of the Wadi Ghussein and Wadi Abiad. The situation is different at Misma I, where there appears to be some heterogeneity in the subsurface distribution of the various units, as is the case in Wadi Shwaiti I (Haddadin, 2001). Penetration depths are estimated to be the same as the electrode spacing.



	30	20	10	5
p4	109	103	65	41
p3	140	124	92	57
p2	71.5	70	36	26
p1	84	83	67	52

fig 3: Model results from the Mahdath I Wenner array.

Based on this information, four sites were chosen for drilling. The location at Mahdath was excluded from the drilling program because of financial constraints, and because it is already well known by the local community that shallow water exists at the site.

Drilling results

Thus, the wells were drilled at Shwaiti II (depth 17m), Misma I (Depth 14m), zGhussein (depth 17m) and Abiad (depth 55m). Water was encountered at the Ghussein well at a depth of 13m and in the Abiad well at a depth of 18 m. No water was encountered at Misma I or Shwaiti II. Descriptions of the core cuttings and their relative match with the geophysical results are summarized in figure 4.

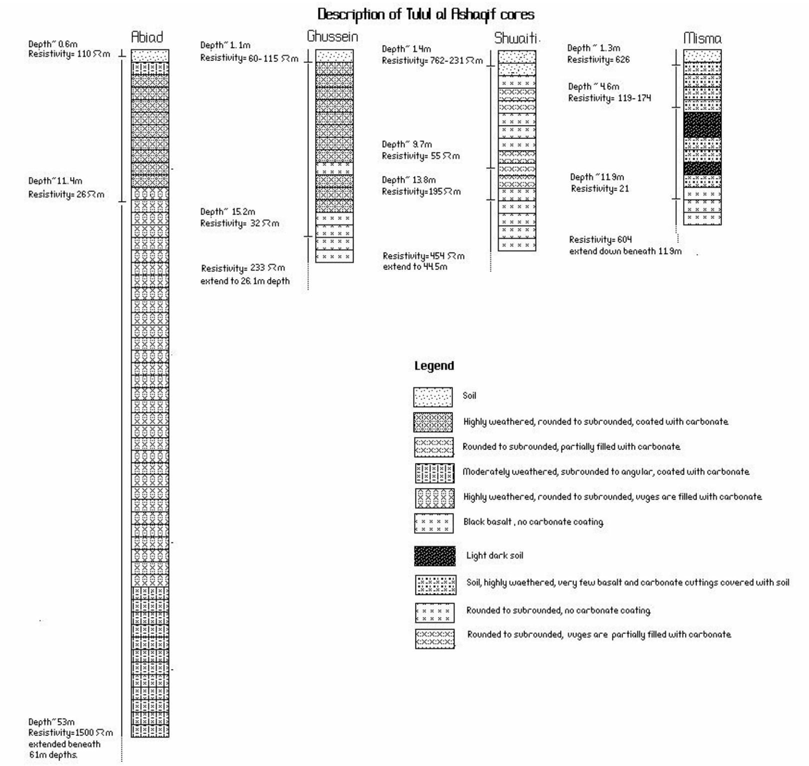


Fig 4: Core descriptions and corresponding geophysical data.

The fact that two sites failed to yield any water despite the promising geophysical evidence can be attributed to a number of potential causes. At Wadi Misma, the soil layers encountered during drilling may have been wet at the time of the geophysical survey, which may have yielded a low resistivity horizon. Because the drilling process used water, it is difficult to determine how wet this clayey layer was prior to drilling. A similar phenomenon may have occurred at Wadi Shwaiti, where weathered basalt was encountered at the depths where water was expected. In both the Abiad and Ghussein wells, water lies beneath a layer of highly weathered alluvium whose rounded to sub-rounded pebbles are largely coated with a carbonate layer. In the case of the Abiad wells, water is stored in highly weathered alluvium with sub-rounded to rounded particles. The weathering is probably largely facilitated by the presence of water in the area (Abu-Jaber and Kimberley, in prep.). At the Ghussein well, the water seems to be stored in alluvium with relatively fresh basaltic particles.

The similarity in the geophysical and lithological similarities between the sites where water was found and the Shwaiti II well suggest that similar geochemical processes are at work at these sites. There is no highly weathered zone seen in the non water-bearing wells, contrary to what is seen in the water-bearing wells. The geophysical data shows no evidence of a deeper level in the surficial alluvium of the non water-bearing sites, which might be serving as an aquifer.

In the Misma I well, the cuttings are more reminiscent of a soil horizon. The lithological differences between this well and the others drilled indicate that the aquifer potentiality and recharge at this site are not promising.

The drilling results thus indicate that geophysical data should be read with some caution. Although it is reasonable to assume that a negative geophysical result should be used to discount a particular site, a positive result may simply imply the presence of a soil or clay layer with no free water. The consistent presence of highly weathered basalt above the saturated zone may provide for a useful indicator in future exploration efforts. The weathering is probably why water is trapped at these locations as clay may be impeding the movement of water to deeper levels.

Water potential

The processed Landsat images suggest that the lateral extent of Wadi Ghussein aquifer is about three kilometers (width about 50m) and the Wadi Abiad aquifer is about five kilometers (width also about 50m). According to the geophysical surveys, the thickness of the saturated zone at Abiad and Ghussein are about 50 m and 15 m, respectively. Assuming a minimal porosity of 25%, the waters stored in the Ghussein and Abiad aquifers are probably on the order of $0.56*10^6$ m^3 and $3.1*10^6$ m^3, respectively, assuming that the aquifers do not extend into the neighboring basalt and that the assumed thicknesses of the saturated zone extend throughout the aquifer. It should be noted that there are numerous sites which can be considered as being potential shallow aquifers in the area.

Water quality

The chemical characteristics and evolution of the waters of the Ghussein and Khudari well fields has been discussed at length by Abu-Jaber (2001). The waters from the traditional biyar and wells are considered here. For this purpose, the chemistry of the waters at these sites was analyzed before and towards the end of the pumping tests conducted on these wells. This was done to ensure that the samples are representative of the aquifer. The Biyar at Ghussein and Khudari were sampled in July 2001 and the wells at Ghussein and Abiad in October 2001. The results of the chemical analyses are listed in Table 3. The waters range from Ca-HCO_3 to Ca-Cl waters (Figure 5).

Table 3: Chemical composition of water from the biyar and wells before and after pumping. Concentrations in mg/l

Sample	EC	pH	Cl^-	HCO_3^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	Na^+	K^+
Main farm (before pumping	700	7.97	55	240	1.9	19.5	69.4	17.1	27.2	10.4
Main farm (After pumping)	715	7.91	61	250	0.7	19.7	76.2	17.3	27.1	10.4
Middle Valley (Before pumping)	1158	7.86	124	236	29.1	34.7	69.4	27.2	98.0	8.4
Middle Valley (After pumping)	1163	7.85	130	260	23.7	36.1	66.4	27.2	100.0	8.3
Khudari A (Before pumping)	313	8.02	130	142	n.d	6.7	42.4	6.0	5.9	4.4
Khudari A (After pumping)	314	7.95	150	150	n.d.	6.7	40.4	6.0	5.9	4.3
Khudari B (Before pumping)	333	7.64	140	170	n.d.	6.0	244.8	6.9	7.4	5.5
Khudari B (After Pumping)	335	7.62	170	180	n.d.	6.1	242.0	6.0	5.9	4.3
Ghussein well (Before pumping)	546		28.4	162	2.8	9.0	42.1	10.8	13.9	6.7
Ghussein well (After pumping)	353	7.53	33.3	105	17.4	0.5	35.9	10.7	18.2	7.6
Abiad Well (Before pumping)	416		54.6	196	9.8	4.5	52.8	11.7	28.5	5.5
Abiad well (After pumping)	438	7.41	41.4	180	6.0	15.6	41.8	11.4	29.0	5.8

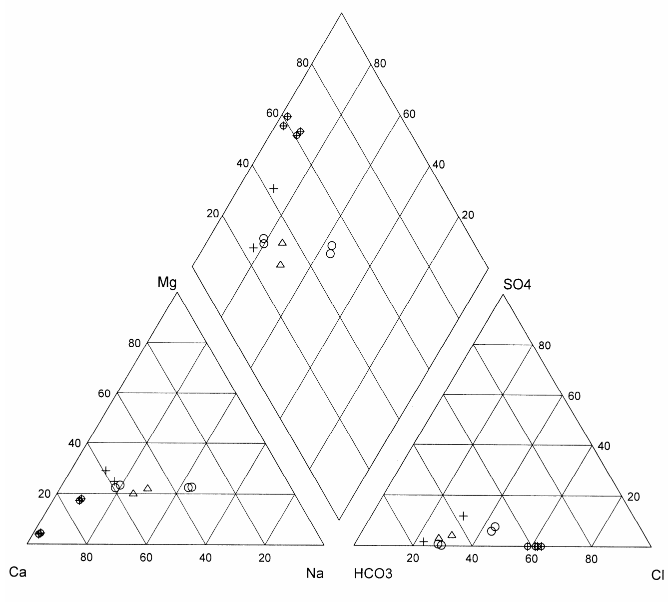


Fig 5: Piper diagram of waters from the aquifers. Crossed circles are from Khudari, triangles are from Abiad, crosses are from Ghussein well and circles are brom *biyar* Ghussein.

The waters in the drilled wells meet the optimal WHO (1996) and Jordanian standards (1990) for total dissolved solids, whereas the waters in the dug wells are within the maximum permissible levels prescribed by the WHO and the Jordanian Standards. The total hardness of the samples ranges from 125-630 mg/l, and thus the waters are classified as being moderately hard to very hard. The very hard waters are present in the pits at Khudari. Water from the drilled wells have hardnesses ranging from 150-180 mg/l, which is above the optimal standards of Jordan and the WHO, but significantly below the maximum permissible limit of 500 mg/l. All other major chemical constituents are well within the permissible levels for domestic water consumption in Jordan. Anomalous nitrate concentrations seem to be natural, due to the lack of any human sources. High nitrate concentrations in arid areas have been attributed to increased nitrogen fixation in plants or to atmospheric input (Böhlke et al., 1997).

Recharge

The results of the isotopic analyses are presented in Table 4. The tritium concentrations in the waters of the Abiad and Ghussein wells are similar to those of local rainwater as well as those of Biyar el Ghussein and Biyar el Khudari (Abu-

Jaber, 2001). This indicates that the waters are recent and renewable.

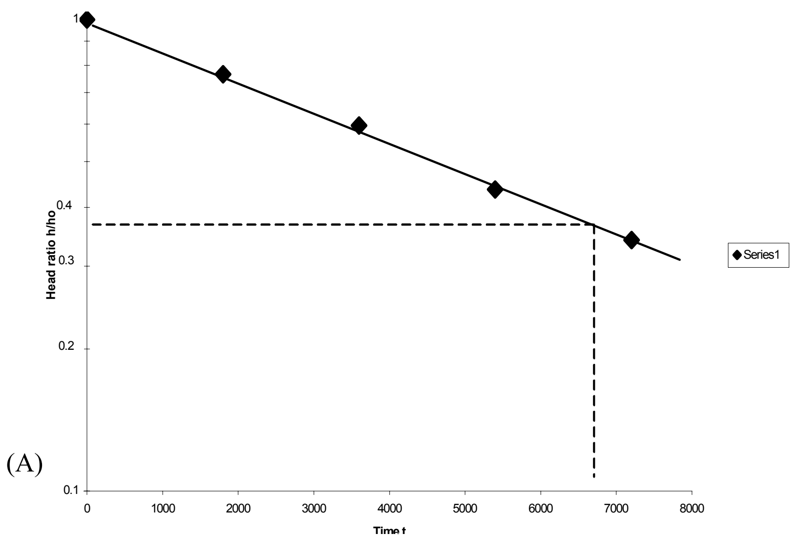
Table 4. Isotopic composition of the well waters.

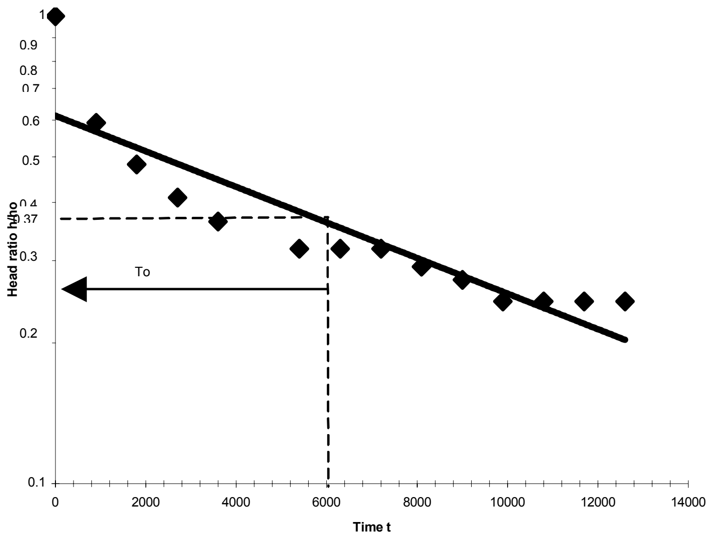
Well	Date	Tritium (TU)	$\delta\ ^{18}O \pm 0.15$ vs. SMOW	$\delta D \pm 1.0$ vs. SMOW
Ghussein	01/10/01	7.10	-0.42	-7.1
Abiad	01/10/01	7.90	-3.42	-17.2

The stable isotopic signatures of the well waters are also similar to those seen in the local waters. The Abiad well is significantly lighter isotopically than the Ghussein well. The Ghussein well shows a clearly evaporated signature. The evaporated signature seen in the Ghussein well confirms the assumption that *ghadeers* contribute to the recharge of shallow ground water in the area. This is because the well is adjacent to a *ghadeer*, as mentioned earlier. The exposure of the *ghadeer* water to evaporation would lead to the heavy signatures. This, in turn, is seen in the waters of the adjacent well. It is clear that infiltration is not confined to the *ghadeers*, given that not all shallow water is found near these features. The water at Wadi Abiad is near to the isotopic signature of local rain and runoff measured in the area. The hydrological, geochemical and isotopic explanations for the local rapid recharge occurring in these areas are given by Abu-Jaber (2001).

Slug tests

The results of the slug tests are given in figure 6. The treatment of the Hvorslev slug test method indicates low hydraulic conductivities, despite the apparent high permeability indicated by the lithology of the aquifer. The hydraulic conductivity in the Ghussein well was about 5.8cm/day, and in the Abiad well it was 9.7cm/day.





(B)
Fig 6: Pumping test data from Ghussein (A) and Abiad (B) wells

In the traditional *biyar* locations, there are a large number of pits dug in close proximity to each other. The low hydraulic conductivity deduced here suggests that the reason for the high density of pits at the *biyar* is due to the need to extract more water from the area than a small number of wells can accommodate.

Conclusions

The results of the exploration effort clearly show that there are other shallow water resources in the area. The waters in these aquifers are of good quality and are renewable. Moreover, available evidence suggests significant volumes are present. The exploration for more of this water requires the use of available remote sensing and geophysical techniques, which both help accelerate the exploration effort and eliminate sites where water is absent. While the drilling effort resulted in finding two new locations of shallow groundwater, the experience gained here will allow for a more refined approach in the future for exploration of water in the area. For example, the significant weathering seen in the alluvium above the aquifer can be used as a research indicator, as well as the presence of ghadeers and moderate valley slope. Marabs have not yielded any water resources and should be eliminated in any future research effort, despite the high vegetative cover seen there.

It is worth emphasizing that the renewable nature of this resource gives it an advantage over the use of the more plentiful, but non-renewable waters in the deeper aquifers (Abu-Jaber et al., 1998; Bajjali and Abu-Jaber, 2001).

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التحري عن المياه الجوفية الضحلة في مرتفعات تلول الأشقف، الأردن

نزار ابو جابر، نبيل عبدالرحمن، وائل عزايزه

حسان العمري، خالد السخني، جورج حدادين

مفيد حمزه، خلدون القضاه

ملخص

إن الخزانات المائية المعلقة في منطقة تلول الأشقف الجافة في شمال شرق الأردن هي من المصادر التقليدية الهامة للمياه لسكان هذه المنطقة، ومن الممكن أن تكون مصدراً هاماً للمياه لتطوير هذه المنطقة. ولكن حتى الآن لم يتم التحري عن هذا المصدر من ناحية توزيعه أو خصائصه.

تهدف هذه الورقة إلى وصف مجهود بحثي هدف إلى دراسة العوامل المتحكمة في توزيع هذه الخزانات المائية وخصائصها هذا، بالإضافة إلى كميات المياه ونوعياتها. ولقد تم استخدام دراسات الجيومورفولوجيا والصور الفضائية لتحديد تسعة مواقع واعدة لدراسات مفصلة، وبناء على هذه الدراسات تم إجراء مسوحات جيوفيزيائية تفصيلية باستخدام توزيعات فنير وشمبلرجير للمسوحات الجيوكهربائية. وبناء على هذه المسوحات تم اختيار أربع مناطق واعدة لحفر آبار ضحلة، وعند الحفر تم اكتشاف مياه ضحلة في موقعين من هذه المناطق الأربعة.

إن الخصائص الكيميائية للمياه المكتشفة هي ضمن مواصفات مياه الشرب الأردنية، وتشير المعطيات النظائرية بأن هذه المياه متجددة . وبالرغم من أن الموصلية المائية للخزانات قليلة وتتراوح من 5.8- 9.7 سم/ يوم، فان

الكميات المتوقعة للمياه في هذه الخزانات هي كميات كبيرة نسبياً وتقدر بملايين الأمتار المكعبة، وتشير هذه النتائج إلى أهمية حفر المزيد من الآبار للاستفادة من هذه الخزانات.

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