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Structural Control on Groundwater Distribution and Flow in Irbid Area, North Jordan

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Abstract

This study aims to evaluate geologic and structural influences on groundwater in Irbid area as an essential resource in that area. This importance increases in the light of the rapid increase in human population, industrial expansion, and agricultural activities. The geology of the area is comprised of Upper Cretaceous limestone, silicified limestone and marly limestone, and all overlain by thick layers of soil. Amman Silicified Limestone and Wadi As Sir Limestone Formations form good aquifers in the study area. The influence of faults and joints on groundwater in the study area is two fold. N-S and NE-SW joints and faults act as drainage channels of groundwater flow and also as aquifers in the area. On the other hand, ESE-WNW normal faults, forming a horst and graben system, form a barrier or semi-barrier to the ground water flow. They are responsible for the dryness of wells in Dayr Yusof, Al Husn Camp, and Huwwarah. All these wells are on the down thrown side of these faults.

Keywords: structure, horst and graben, Irbid area, groundwater flow.

1. Introduction

Water is the most important component of the development of any area. Human settlement depends to a large extent on the availability of water resources in close proximity to the settled localities. There has been a tremendous increase in human population in Irbid area. Moreover, there has been a lot of industrial expansion and farming activities within the area. These factors have overstretched water demands in the area.

The present research is important for understanding the factors influencing the distribution, flow, and yield of groundwater. The study area is located in the northern part of Jordan. The area ranges in elevation between 770 m above sea level in the southern part and 480 m in the northeastern part. The area is bounded by latitudes 32° 25' 38" N and 32° 33' 21" N and longitudes 35° 45' 02" E and 35° 57' 20" E, which is equivalent to 221-240 E and 202-220 N of Palestine Grid. It is about 340 km^2 (Figure 1).

Irbid area is located on the northern end of Ajloun dome, which is very close to the Dead Sea rift. Thus, it was affected by subsequent movements during the formation of the Dead Sea rift. The formation of the Dead Sea rift was accompanied by faulting, tectonic movement, and volcanic activity. The rift margins were affected by these events (Abed, 2000). Faults have influenced the occurrence of groundwater in terms of its distribution, flow, and yield. Faults can make rocks excellent aquifers.

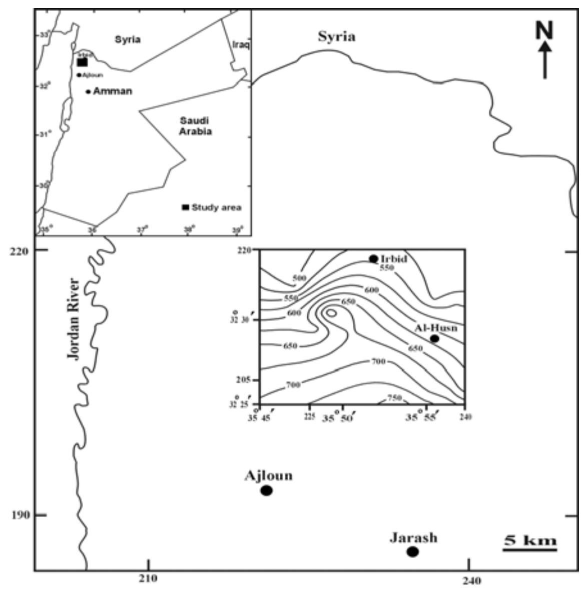

Figure 1: Location and topography of the study area. Contour lines are indicated on the map.

The yield from boreholes drilled into such rocks is thus high. Alternatively, faults act as drains, lowering water table and thus affecting the distribution of groundwater (Mulwa *et al.*, 2005). Further, faults act as barriers to the flow of groundwater if filled with impermeable material such as marl and clays (Kulkarni and Deolankar, 1993). These factors have a strong influence on the aquifer yields through boreholes, static water levels, flow, and hence distribution of groundwater. Therefore the amount of water available in a faulted region would be influenced. A comprehensive understanding of the influence of structures on groundwater is necessary for the selection of drill sites of

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productive boreholes in this area and in other areas of similar geological setting.

2. Hydrogeological Setting

The study area forms part of the Yarmouk basin, which is the major source of groundwater in north Jordan (Al-Ta'ani, 1989). The rocks outcropping in the study area are mostly of Late Cretaceous age. Wadi As Sir Limestone Formation (WSL) (A7), of Turonian age, is the oldest exposed rock unit and covers most of the area (Figure 2). It consists of limestone and dolomitic limestone. It is exposed as a result of the folding in the area (Atallah and Mikbel, 1992). The total thickness of this formation is about 100 m. It is overlain by Wadi Umm Ghudran Formation (WG) (B1) (Santonian). The Formation is 40 m thick and consists of laminated and bedded chalk. The overlying Amman Silicified Limestone (ASL) (B2) (Campanian-Maestrichtian) consists of chert beds, limestone, and laminated and fossiliferous chalk (Moh'd, 1997). It is about 80m thick. Soil covers the eastern part of the study area (Figure 2). Aquifers in the area are replenished by the precipitation that infiltrates into the underground. WSL and ASL are the main aquifers in the area. They are highly permeable and have secondary porosity due to jointing, faulting, karstification of limestone beds, and brecciation of chert.

Due to large portion of chalk WG acts as an aquiclude separating the WSL and ASL aquifers. WSL and ASL in north and central Jordan are considered as one aquifer system that has high potentiality. Table (1) summarizes the characteristics of the Late Cretaceous Formations.

Forty six boreholes were used in this study. The boreholes data were available at Ministry of Water and Irrigation. Generally, the hydraulic gradient decreases toward the north. According to Momani *et al*. (1989), groundwater in the southern part moves toward the northeast, changing its direction in the northern part to move toward the north. In the western part, it moves to the northwest. Numerous wells drilled in the area and penetrated this aquifer system. In the southern part, they are high yield (24-91 m^3/hr); examples are AB1375, AD1219, AB1441and AD1234 wells. While in the north, they aren't high yield (producing 1-5 m^3/hr). Examples of such wells are AD1220, AD1206, AE1032 and AE1006 wells.

3. Structures in The Area

Fracturing and folding result in a high degree of inhomogeneity in the hydrogeological characteristics of different aquifers. This inhomogeneous character causes aquifer yields and ground water flow direction to vary over a whole area (Mulwa *et al.*, 2005).

Bender (1968) considered the study area (i.e., the Irbid area) a part of the fault block mountain east of the rift. Later, Atallah and Mikbel (1992) and Atallah (1996) studied north Jordan in detail, and explained that the study area is a part of Halawa-Al Husn fold belt. It extends from Wadi El Yabis in the west to the basalt plateau in the east. Faulting, folding, and jointing are clear in the area (Figure 2).

Black and white aerial photographs at the scale of 1:10,000 were used in the identification and relocation of faults and fractures in the study area. A mirror stereoscope was used in the interpretation of structural data. The data was plotted on transparent sheets at the same scale as that of the aerial photographs, and the structural data were then transferred onto a topographic map (scale 1:50,000). Consequently, the main structural features such as faults, folds, and joints in the study area were identified (Figure 2).

3.1. Faults and Joints Analysis

Lattman and Parizek (1964) established a relationship between the occurrence of groundwater and fracture traces for carbonate aquifers, particularly in lineaments underlain by zones of localized weathering, increased permeability, and porosity. Researchers' interest in this relationship has grown most rapidly since the introduction of aerial photographs into geological studies (Caran *et al.*, 1982).

The faults in the study area are grouped into two sets. The first set consists of normal faults strikes NW-SE to WNW-ESE, while the second strikes E-W, and they are strike-slip faults. Faults are of Late Tertiary in age (Abdelhamid, 1995). The major fault of the study area is Dayr Yusof fault. It strikes WNW-ESE and can be traced for 6 km before being covered with soil (Figure 2). A fault breccia zone up to 1 m wide was found. The breccia consists of limestone fragments cemented by coarse crystalline calcite (Mansoor, 1998). Geophysical studies showed that it extends east to Al Husn Camp (Azmy Al Mufty Camp) (Al-Bis, 1994). The down thrown block is the northern one. Based on boreholes data, its throw is estimated to be 50 m (Figure 3). Also, there are two remarkable faults; the first lies near Juhfiyeh, 1 km south of Dayr Yusof fault. While the second lies just north of Al Mazar (Figs. 2 and 3). Juhfiyeh fault strikes WNW-ESE and can be traced for about 4 km (Figure 2). In several localities, it is detected due to the truncation of the Wadi As Sir Limestone strata (upthrown) in the south against the Wadi Umm Ghudran (downthrown) in the north. In addition, topographic change between the step-like steep cliffs of the upthrown block and the gentle slopes of the downthrown block is clear evidence of the fault (Mansoor, 1998). Al Mazar fault strikes WNW with a remarkable throw (Figure 3). Dayr Yusof, Juhfyeh and Al Mazar faults represent the horst and graben system extending from Dayr Yusof to the north of Kitim (Figs. 2 and 3). This system is associated with several high angle minor faults, which are of N-S direction, almost perpendicular to the major faults (Figure 2).

The joint system in the study area consists of four sets (Figure 4). The first set, which constitutes the major set, trends WNW-ESE (120º). The other sets trend: N-S (10º), NNW-SSE (150º) and ENE-WSW (70º) (Figure 4).

3.2. Folds Analysis

Folds are obvious in the central and northwestern parts of the area. The fold axes are of two trends; the first is NNE-SSW, and the other is ENE-WSW. Generally, they are plunging to the north. The first trend is formed due to WNW-ESE compression related to Syrian Arc system, while the second trend is younger than the first; and is caused by NNW-SSE compression; and is related to Dead Sea system (Eyal, 1996, Diabat *et al.*, 2004 and Al-Khatib, 2007).

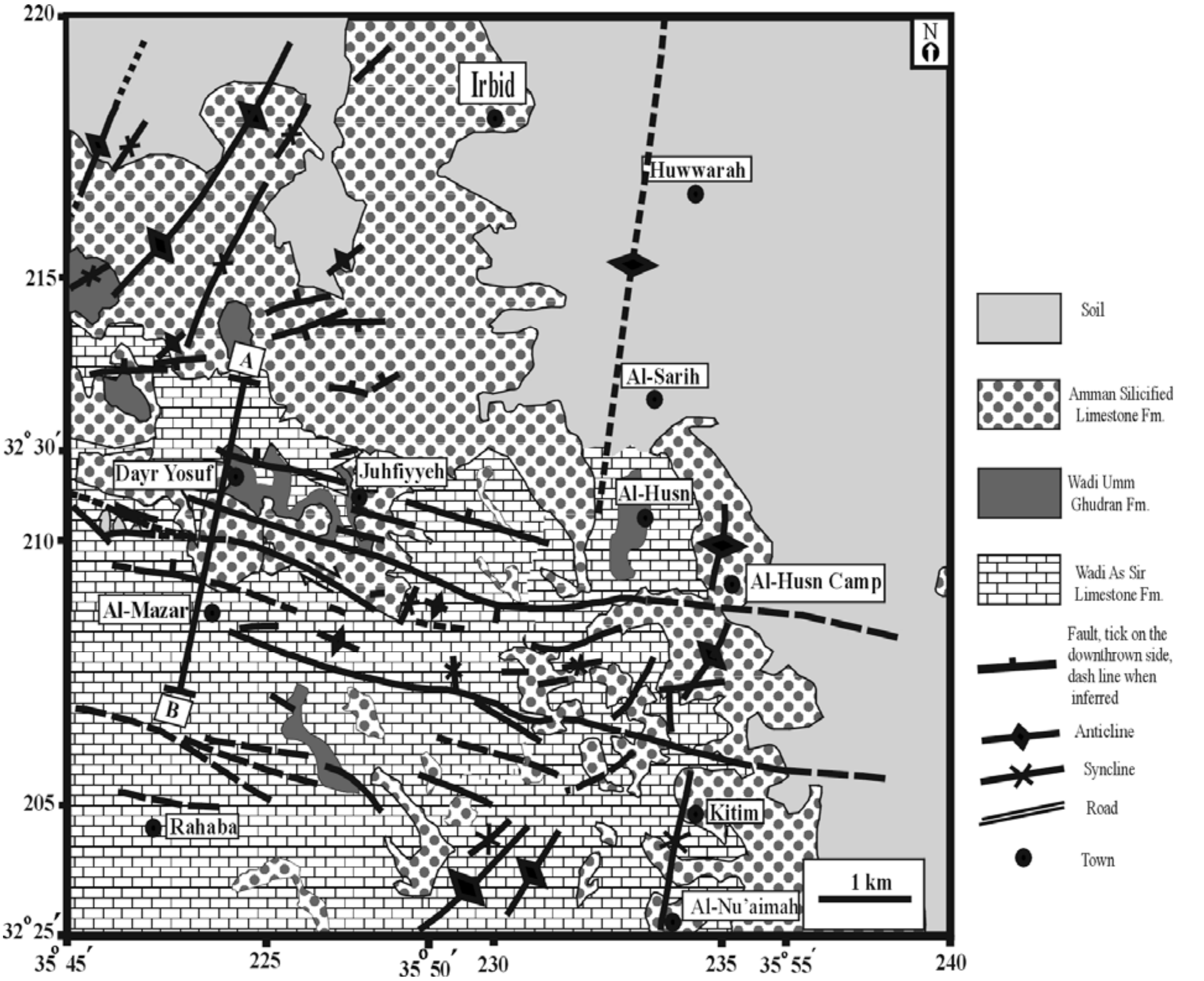

Figure 2: Geology of the study area.

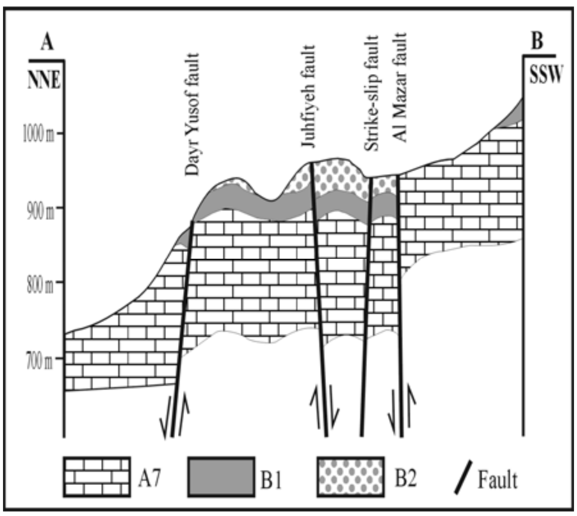

Figure 3: N-S cross section in the area (based on boreholes data). The location is shown on the map of Figure 2.

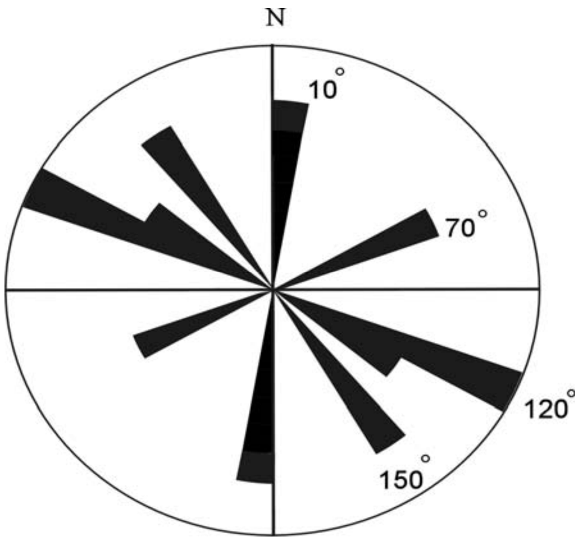

Figure 4: Rose diagram representing main trends of joints in the area.

Table 1. Geological and hydrogeological classification of the Upper Cretaceous rocks (Abed, 2000).

Period	Epoch	Group	Formation	Symbol	Lithology	Thickness (m)	Aquifer Potentiality	Permeability (m/s)
Late Cretaceous	Maestrichtain	Balqa	Muwaqqar Chalk Marl	B3	Chalk, marl and chalky limestone	80	Poor	Permeable
	Campanian		Al Hisa Phosphorite and Amman Silicified Limestone	B2	Chert, limestone with phosphate	80	Excellent	Permeable
	Santonian		Wadi Umm Ghudran	B1	Chalk, marl and marly limestone	40	Poor	Impermeable
	Turonian	Ajlun	Wadi As Sir Limestone	A7	limestone; dolomitic and some Chert	100	Excellent	Permeable
	Cenomanian		Shu'ayb	A5-6	limestone interbeded with marls and marly limestone	60	Poor	Impermeable

4. Results and Discussion

In order to understand geological and structural influence on groundwater, two maps were prepared as described below:

4.1. The groundwater flow map

The groundwater flow map (Figure 5) was prepared based on the boreholes in the area and contouring at 25 m interval. The map shows recharge and discharge zones in the area. It also shows how groundwater flow is influenced by faults, or hidden structures, or divides (Figure 5). This water divide coincides with the trend of some fold axes. So, it may be explained as resulting from a hidden fold. Moreover, the map shows that groundwater flows from elevated regions (Ajloun area in the south) to low lying discharge areas in the northern part of the area (Figure 1). Joints trending N-S may facilitate this movement.

Faulting is an outstanding phenomenon in the area, and the flow model is modified by the presence of major faults and folds. As a result, flow in the northern side occurs laterally (NE and NW). A characteristic feature of aquifers tapped through boreholes located along or close to faults, which divert the lateral flow of groundwater, is that all of them have water yield in excess of 20 m^3/hr, and can be considered a reasonably good yield. Such boreholes include AB1375, AD1219, AB1441, AD1234, AD1305, AD1221, AD1235 and AD1220 (Figure 6). Therefore, faults and joints act as conduits through which groundwater flows.

4.2. Aquifer yields map

A second map showing aquifer yields of boreholes was prepared by contouring the water yield at intervals of 2 m^3/ hr (Figure 7).

This map is important because it relates water yield from aquifers to geology and structures. The aquifers yielding more than 20 m^3/ hr are located in the southern region of the area, on the upthrown block of the fault system (Figure 3). The high yield from these aquifers can be explained by a correlation of the location of wells (Figure 6), and aquifer yield (Figure 7) maps. The regions with aquifers yielding over 20 m^3/hr are those immediately close to joints and faults. The discharge regions to the north have low yields, less than or equal to 5 m^3/hr, except in very few areas with anomalous high yield ranging between 5 m^3/hr and 10 m^3/hr. All wells with low yield are located on the downthrown block of the main faults.

Aquifers close to fault zones have a mean yield of 46 m^3/hr, and boreholes sited on such fault zones are quite deep with an average total depth of 300 m. However, the respective aquifers were struck at relatively shallow depths. The average aquifer depth is 130 m below ground surface.

Aquifers yielding more than 50 m^3/hr of water are only located on or near fault zones in the study area. Such aquifers, for example, are those tapped by boreholes AB 1375, AD1219 and AB1441 and their mean yield is 63 m^3/hr (Figure 6). These aquifers occur in the central part of the study area where jointing and faulting are dominant.

The water yield in Irbid area therefore depends on the location of an aquifer, whether on the upthrown or downthrown block of the faults. However, the occurrence of multiple aquifers in boreholes does not always guarantee high water yield. Some boreholes associated with multiple aquifers have low water yield (i.e. AD1266), whereas other yields that are associated with only a single aquifer have high water yield (i.e. AD1234).

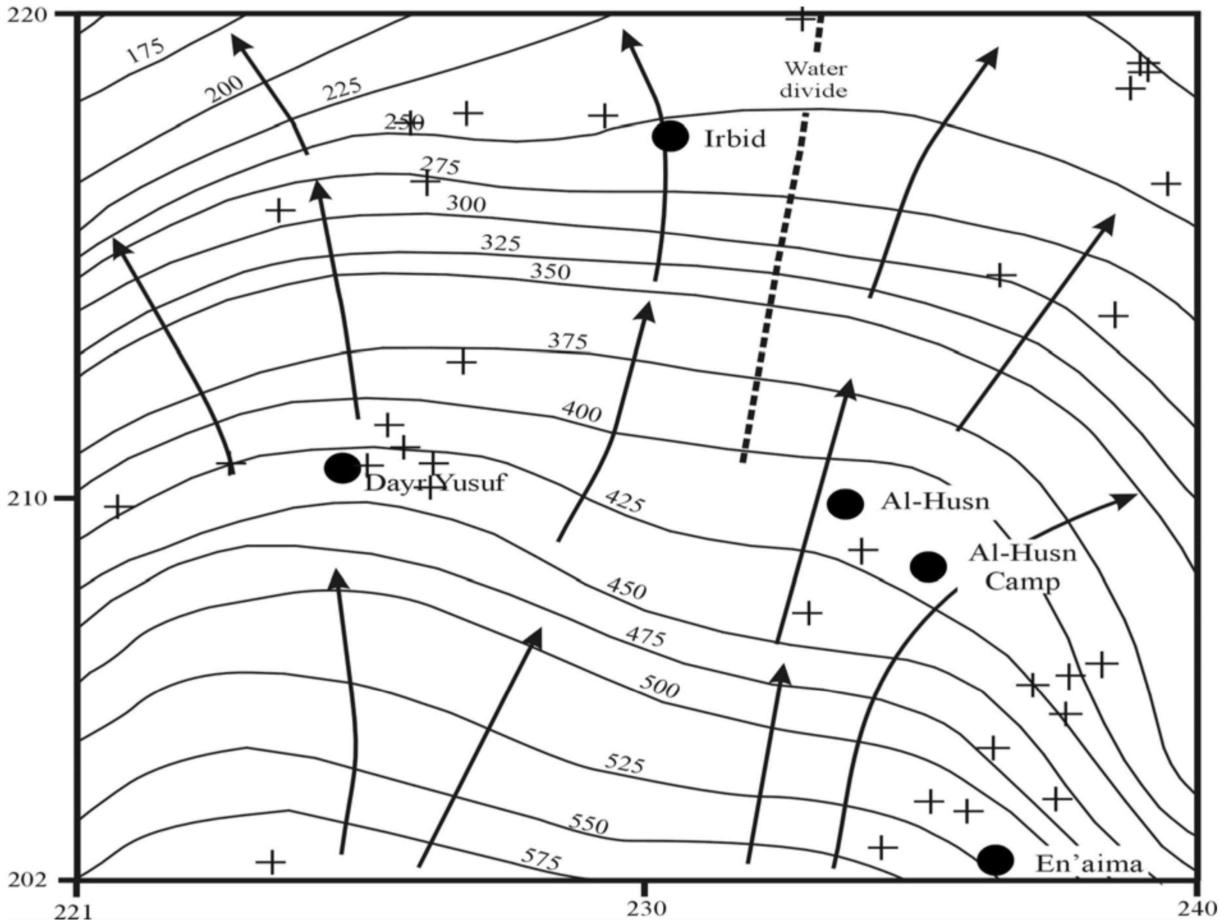

Figure 5: Groundwater flow in Irbid area. Contour lines represent the groundwater level. Crosses represent boreholes locations.

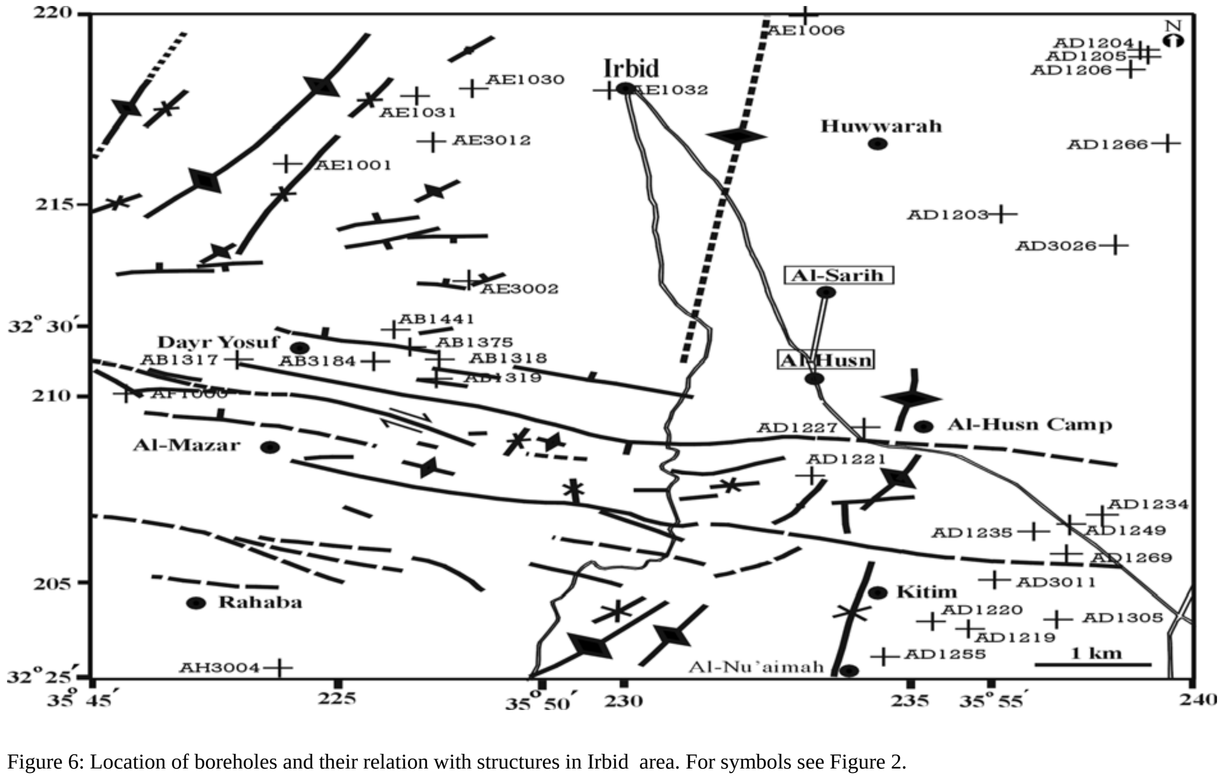

Figure 6: Location of boreholes and their relation with structures in Irbid area. For symbols see Figure 2.

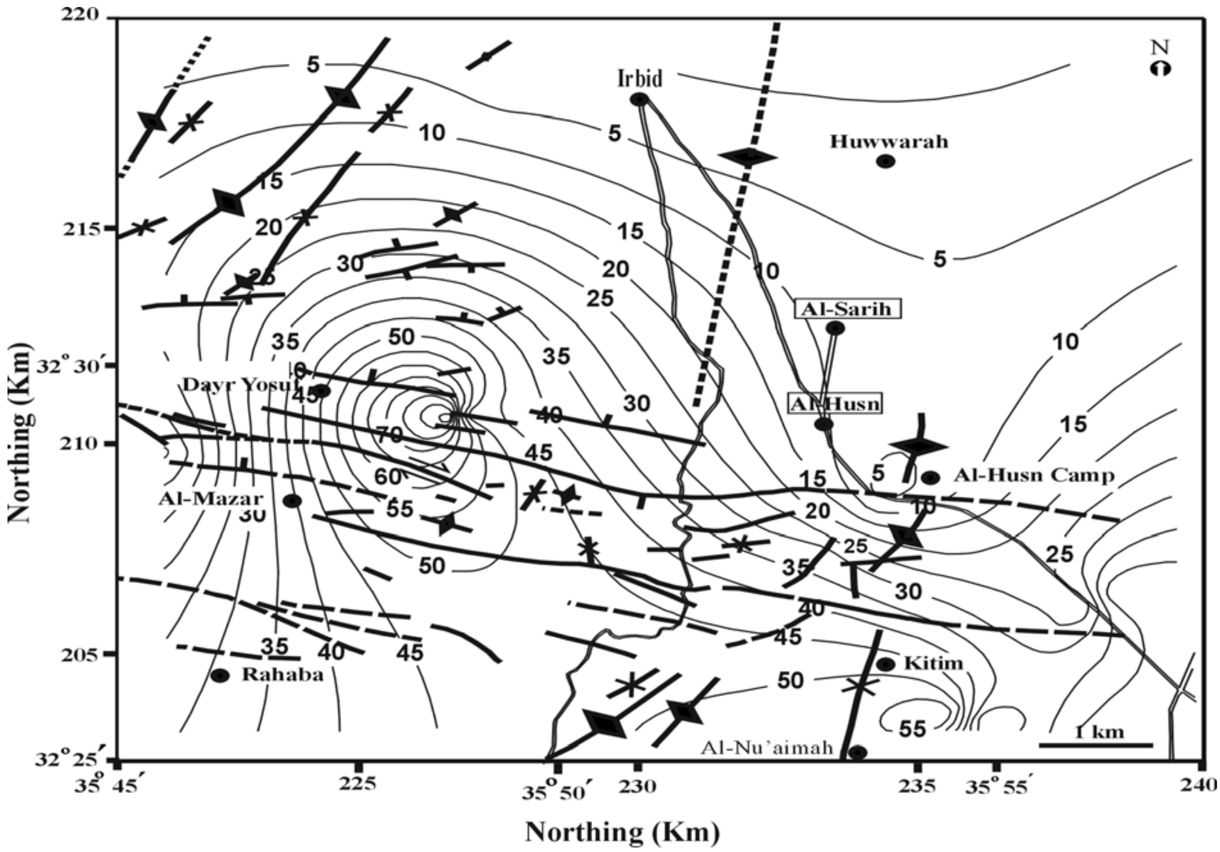

Figure 7: Contour map of boreholes yield and their relation with structures. For symbols see Figure 2.

In the southern region on the flanks of Ajloun dome, recharge is excellent due to high rainfall, which favors infiltration of a good quantity of rainwater (Al-Ta'ani, 1989). Aquifers in the area tend to be modified by structures, both on a small scale by creating local fracture systems which comprise many aquifers and, to a large scale, forming regional hydraulic barrier (Garza *et al.*, 1986, Kulkarni and Deolankar, 1993).

5. Conclusions

Groundwater in Irbid area occurs within Amman Silicified limestone and Wadi As Sir Limestone Formations. The groundwater potential in the area is generally acceptable since the mean yield of all aquifers is about 21 m^3/ hr. Aquifers on fault zones have the highest water yield; and are very deep as depicted by the depths of boreholes tapping water from such aquifers. The depths of these boreholes signify that faults have drained groundwater to deeper levels. Generally, clay layers and dense compact rock units underlying aquifers often act as controls to the downward migration of groundwater. Their absence in the study area (Abdelhamid, 1995) has contributed to migration of groundwater to deeper levels, especially along the joints and faults. The faults in the area are excellent aquifers and excellent conduits to the flow of groundwater.

The groundwater flow direction which is determined by the groundwater flow map (Figure 5) shows that the recharge zone is the southern region, and the discharge zone is the northern region. High water yield from aquifers (>20 m^3/hr) in the recharge zone is due to an immediate recharge by joints and faults or rainwater infiltrating into the subsurface. Aquifers with high water yield are located on the upthrown side on the WNW-ESE normal faults system. The discharge region is characterized by aquifer yields either less than or equal to 5 m^3/hr, and all these wells are located on the downthrown block of the main faults. The water yield from these aquifers is less than 5 m^3/hr and has an average of 3 m^3/hr. The excessively high yield from aquifers tapped through boreholes in the central region of the study area, mean 46 m^3/ hr, is due to the influence of the numerous faults in this region. The WNW-ESE faults and joints act as barriers or semi-barriers to the groundwater flow, while joints trending N-S facilitate the groundwater flow. The permeable rocks in the upthrown block (B2/A7) in the south face impermeable rocks of the down thrown block in the north (B1). The lateral flow of groundwater along the fault zones has led to deeper flow paths.

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