JOURNAL OF
ENVIRONMENTAL HYDROLOGY

The Electronic Journal of the International Association for Environmental Hydrology
On the World Wide Web at http://www.hydroweb.com

VOLUME 19 2011

GEOLOGICAL AND GEOELECTRICAL SURVEY OF GROUNDWATER POTENTIAL IN THE ASTANEH-KOUCHESFAHAN PLAIN, IRAN

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The Astaneh-Kouchesfahan Plain, an extensive and productive aquifer system in Iran, is located in the south Caspian Sea basin which is part of the Alborz tectonic range in the Alpine fold belt. A permeable aquifer system provides water for industrial, agricultural and domestic uses. Geological and geophysical studies indicate a number of important facts about the groundwater system. For this reason, detailed regional geological, tectonic and geophysical data were gathered to better understand the behavior of hydrogeological zones in the system. Geological studies show that the area is predominantly covered by recent alluvium, which consists of Pleistocene and Holocene stream deposits, coastal deposits, beach deposits and alluvial fan deposits. The bedrock mainly consists of impermeable clay of the Mesozoic era. Also, based on available geological cross sections, geophysical surveys, and well logs, it is shown that the system contains an unconfined, shallow Quaternary alluvial aquifer which is composed of heterogeneous sequences of relatively coarse grained gravel and sand interconnected with different thicknesses of silt and clay. The final results of this study are extremely useful for geotechnical activities, environmental strategies, and water resource management.

INTRODUCTION

The Astaneh-Kouchesfahan Plain is an important water resource system in Gilan Province, Iran. The socioeconomic importance of the plain is immeasurable and plays a vital role in supporting the rural inhabitants of the area. In the Astaneh-Kouchesfahan Plain, a permeable aquifer system provides water for industrial, livestock, irrigation, commercial, municipal and domestic usages. In the area, however, rapid population growth and low irrigation efficiency in agricultural sector have increased the demand for groundwater resources. Therefore, proper groundwater management is crucial for sustainability of this underground resource. For proper management of groundwater resources, a series of detailed investigations related to geological and geophysical characteristics of each water-bearing zone were conducted. Unfortunately, for many reasons such as lack of data, availability of the unreliable data, and being nonfunctional information, there are no complete data available for rational groundwater management. For this reason, a proper identification and delineation of the hydrogeologic zones has been proposed as a basic prerequisite for well-organized groundwater resource management.

Geographical Location and Climate

The Astaneh-Kouchesfahan Plain, one the largest groundwater systems of Iran, is a conical aquifer which extends reversely from its southern vertex in opening of alluvial fans of Sefîd-Rûd River to its northern base in the coastal line of the Caspian Sea. The geographical location of the plain is 35° 34' 00'' to 35° 48' 00'' North latitude, and 49° 30' 00'' to 50° 15' 00'' East longitude (Zone 39N in UTM System: WGS 1984) and underlies an area of approximately 1343 Km^2 (Figure 1).

The prevailing climate of the area has Mediterranean characteristics. In winter, the area enjoys a moderate temperature and changeable, rainy weather. Summers are more hot and dry, due to the domination of the subtropical high pressure systems, except in the immediate coastal areas.

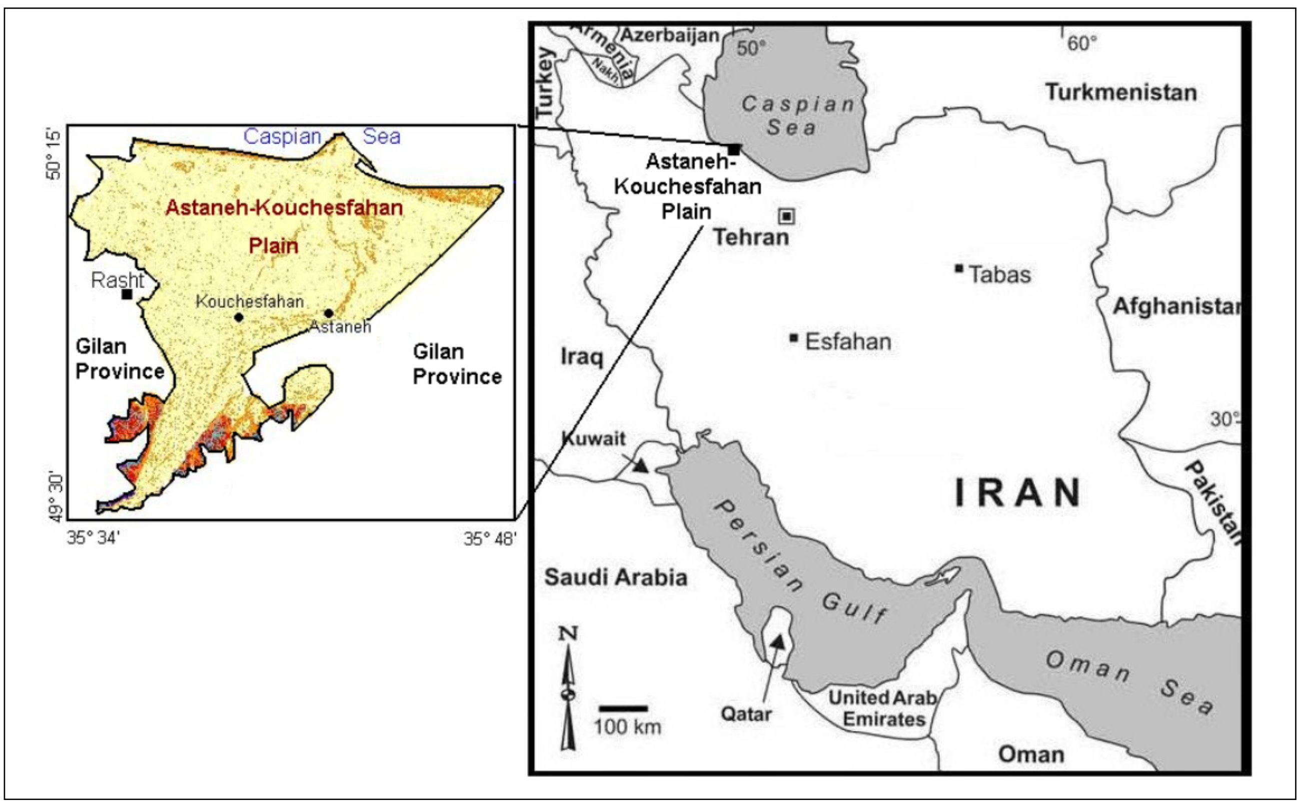

Figure 1. Geographical location of Astaneh-Kouchesfahan Plain in north of Iran.

Long-term information related to amount, intensity and distribution of monthly or annual rainfall for a period between 1964 and 2003 showed the average annual precipitation was 1430 mm. The maximum annual rainfall was 2236 mm in 1993 and minimum was 864 mm in 1971. Also, during the study period, the heaviest rainfall occurred between September and December. In general, the main precipitation of the area occurs during winter (approximately 40.8%) and the remaining occurs during the three seasons of spring (25.8%), autumn (20%) and summer (13.4%). As shown in Figure 2, maximum and minimum monthly rainfall has been measured to be 230 and 50 mm in October and July, respectively. In the study area, temperatures exhibit a clear annual cycle with mean monthly values being highest during July and August and lowest between December and February. The maximum temperature was 40^{o} centigrade and it has been recorded in August. The minimum temperature in the area was 3^{o} centigrade in February. The climatological data of the study area indicates that the relative humidity in different times fluctuates from 60 percent to 90 percent and minimum and maximum have been recorded in March and October, respectively. It also shows that the mean annual potential evaporation in the plain is around 1800 mm. Monthly potential evaporation reaches a peak over 210 mm in July and August, corresponding with the period of higher winds, longer days, and lower relative humidity. It falls to lower points around 120 mm in January and February, corresponding with the period of slight winds, shorter days, and higher relative humidity.

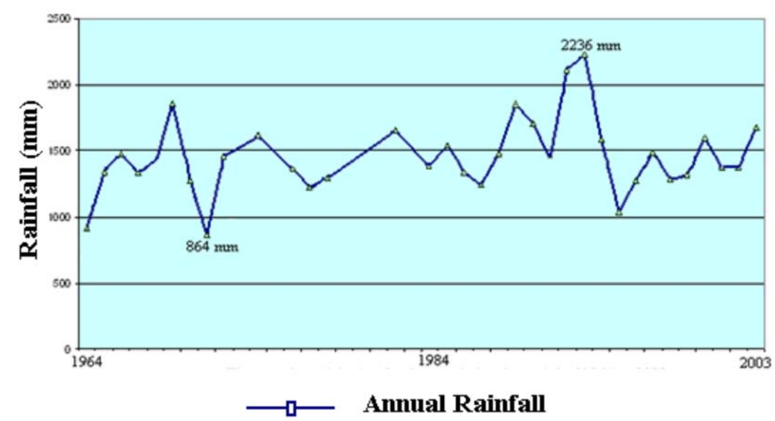

Figure 2. The annual variations of rainfall intensity in the study area during the study period of 1964 to 2003.

RESULTS AND DISCUSSION

Geology of the Study Area

In any groundwater study, the geology of the basin must be known since geological structure controls the occurrence and movement of groundwater. The number and type of water-bearing formations, their depth and thickness, hydraulic properties and outcrop pattern are all the result of the geological history of the basin. A study of the subsurface geology is required to find out the type of materials that make up the groundwater basin; their depositional environment; their age; and their structural deformation, if any.

The geology and structural geology of the study area has been described by Aghanabati (2004), Darvishzadeh (2002) and Berberian (1983) and mapped at the 1:1000000 scales by the Geological Survey of Iran (GSI, 2004). According to Darvishzadeh (2002), the study area lies on the middle and northern end of Alborz Geological Zone and it is defined by small outcrops of Paleozoic-aged formations to spread deposits of recent alluvium. The oldest formations in the area are Paleozoic metamorphic rocks which have a small outcrop south of Rasht city. However, the platform of the area is generally considered to have formed in the late Mesozoic-early Cretaceous back-arc environment (Berberian 1983; Zonenshain and Le Pichon, 1986). The Paleozoic formations consist of carboniferous phyllite and dark-grey limestone of Permian age that have small outcrops in surrounding area. The Mesozoic formations acquire more thickness and outcrops; and mainly construct the major structural features in the southwestern parts of area and include limestone, sandstone, conglomerate and volcanic deposits (GSI, 2004). However, due to the tectonic activities in the study area these sediments were either not deposited or were removed by erosion prior to the latest sedimentary cycle commencing in the early Pliocene (Berberian, 1983). As a result, Cretaceous deposits in the study area are directly overlain by sediments of Pliocene and younger age, with a distinct unconformity (Mousavi-Rouhbakhsh,2001). As shown inFigure 3, the area is predominantly covered by recent alluvium made up of Pleistocene and Holocene stream deposits, coastal deposits, beach deposits and alluvial fan deposits. The geological characteristics of the study area are described in more detail in the following paragraphs.

Paleozoic Formations

The oldest formations in vicinity the study area are creamy-brown to dark-green slate to phyllitic clastic sediments and partly calcareous stones of Mobarak Formation (Rasht- Lahijan phyllitic rocks of early carboniferous period) having unconformity can be seen in south western parts of the study area. In this part, Ruteh Formation consists of the dark, gray, massive to medium bedded recrystallized limestone, locally dolomitized with shale of late Permian where the thickness of limestone ranges from 200 to 500 m northwest of Chashmehsar countryside. They are fossiliferous and contain the fragments of *Nankinella* sp, *Staffella* sp, *Codonofusiella* sp, *Agathmmina* sp and *Vermiporell* sp of late Permian.

Mesozoic Formations

In the surrounding study area, the basement complex of Mesozoic era largely crops out in the south, where they form the backbone of elevated northern Alborz Mountains. The Mesozoic

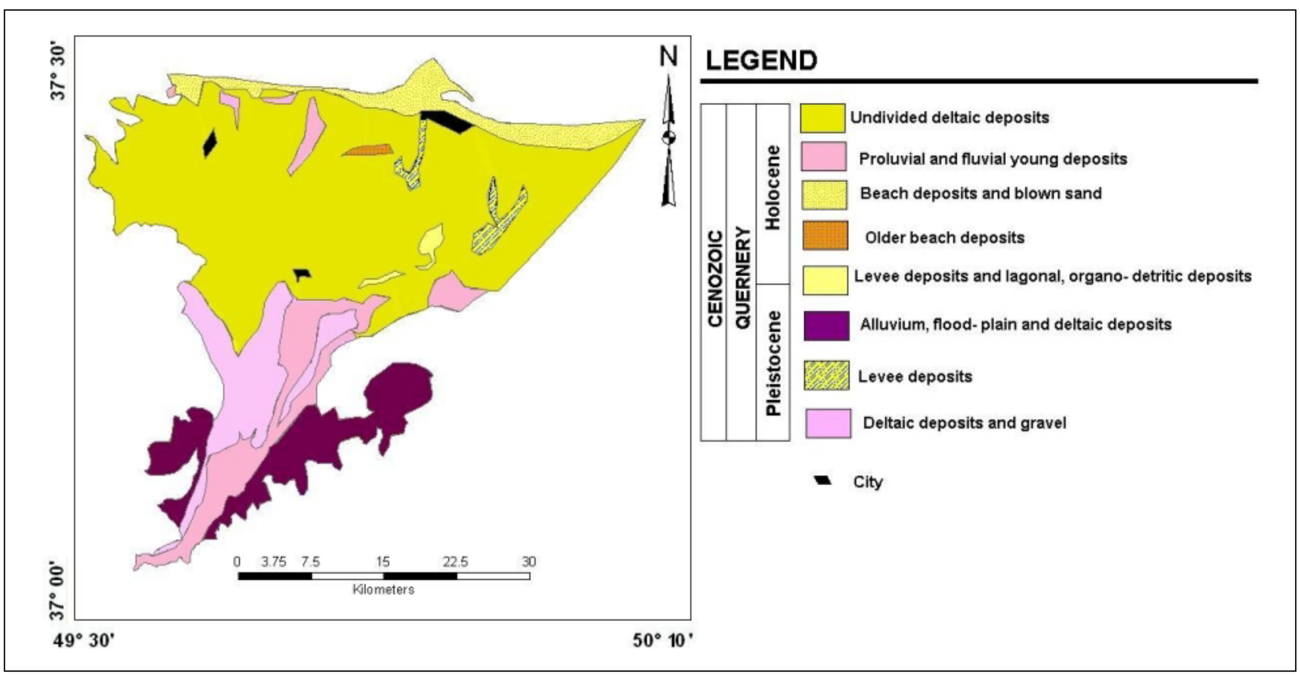

Figure 3. The geological map of the study area.

formations are prominently found in south parts of the study area and can be categorized in three subdivisions as follows:

- **Late Triassic - Jurassic Formations**

The Triassic - Jurassic deposits are alterations of gray to greenish, fine grained arkozic sandstone, grey to black shaly mudstone, locally with thin calcareous, basalt and spilitic in base. Such deposits are mainly belonging to Shamshak Formation and can be seen in adjacent south and southwestern parts of the plain.

- **Jurassic - Cretaceous Formations**

The Jurassic - Cretaceous deposits are represented by detrital limestone and calcareous silty-sandstone (Shall Formation), gray medium to thick bedded limestone and alteration of light gray dacite-andesite tuff, dark-gray andesitic lava and agglomerate which are located nearby south and southeast parts of study area. These fossiliferous strata are including *Calpionnella* alpine, *Capionella*, *Elliptica*, *Ermata*, *Radiolaria*, *Textullaria* sp and *Tintinnopsell* sp of Neocomian and Thitoinian age.

- **Cretaceous Formations**

The Cretaceous series is subdivided to early and late Cretaceous era. The early Cretaceous formations can be observed close to south and southwest parts of the plain and are composed of calcareous conglomerate, gray to dark calcareous sandstone, dark-gray basaltic-andesite lava and dark-gray medium to thick bedded limestone. They are compact and indurated and have primary and secondary porosity. The late Cretaceous formations are distributed in southwest and southeast parts of study area and consist of light-gray limestone, light-gray to green silty limestone and siltstone, and alteration of lapilli tuff, agglomerate with intercalation of calcareous sandstone.

Cenozoic Deposits

Cenozoic deposits are widespread in the study area, and they extend continuously from 37° 10' 00'' North latitude to the coast of the Caspian Sea. Most of the Pleistocene and Holocene deposits of the area consist of river deposits, coastal and beach sediments, and loess deposits of windblown sediment. River deposits are mainly created in the flood plains of Sefîd-Rûd River, where large alluvial deposits can be found such as random cobble and gravel beds with coarse grain sand. Such facies can be seen in the centre of the plain around Sangar area. In the centre of the plain, the study area has been mainly covered by undivided deltaic deposits, alluvium, flood plain and deltaic deposits of Holocene age. The Holocene deposits generally consist of gravel, coarse and fine sand and in some parts silty sands, silt and clay.

Geomorphology of the Study Area

The geomorphology of the study area is the result of Paleozoic to resent deposition; lithospheric strength subsidence between continental crust and oceanic crust; tectonic forces such as compressive folding and faulting; and a variety of superficial processes causing by weathering, wind and water erosion, gravity and water transport (Alaee, 2004). Tectonic forces have resulted in a variety of surface forms and geological structures in the southern part of the area (Aghanabati, 2004). Dominant ridges of this area are anticlines, hogbacks and questas (steeply to gently strata of Mesozoic, mainly Cretaceous age) which have resulted from folding and faulting processes (Darvishzadeh, 2002). Major valleys follow synclinal structures; occur as strike valleys parallel to hogbacks, or are the result of Cenozoic erosion along normal faults. Synclinal valleys often contain a dendritic drainage system. Such drainage systems in the recharge area can easily be recognized by aerial photographs in the field (GSI, 2004). In the centre of the plain, the alluvial fan of Sefîd-Rûd River has been formed where a fast flowing stream flattens and becomes slow and spreads onto a flatter plain. In this area, the delta of Sepidroud has been formed where the mouth of Sefîd-Rûd River flows into the Caspian Sea. In the deltaic area, the size of the particles decrease as the flow slows and the larger particles are deposited. This deposition goes on continually in a cyclic fashion, creating alternating sediment beds of coarse and fine grain deposits. In available dendritic system, the main branches of Sefîd-Rûd River act like the trunk of a tree, which was joined and formed by many smaller tributary rivers. They develop where the river channel follows the slope of the terrain.

In the study area, topography has been investigated based on Digital Elevation Model (DEM) and topographic maps of 1:50000 and 1:100000. From southern boundary of the study area to northern boundary along the coast of the Caspian Sea, the elevation of the top layer ranges between 32 meters above sea level (m.a.s.l) and -25 m.a.s.l. According to Davis (1987), the slope values have been extracted from digital elevation map of the area and classified into six classes to form the slope classifications (Table 1). The slope classification map indicates that general slope in the plain is almost less than 2% and the area is predominately classified as flat to almost flat, as shown in Figure 4.

Structural Geology of the Study Area

As noted before, the study area is located in the south Caspian Sea basin and known as a part of the Alborz tectonic range in Alpine fold belt. The area is structurally bordered by Attari Fault Zone in east, Lahijan Fault Zone in west and Mosh-Fasham Fault Zone in south (Darvishzadeh, 2002). The area was classified by Stocklin (1968) as northern part of Alborz tectonic zone and considered to be a tectonically active area.

The south Caspian basin has undergone many major tectonic events that led to widespread deformations. At present, many studies have been reported in the literature about lateral and vertical lithospheric strength contrasts between the north Iranian continental and the south Caspian oceanic crusts (Berberian, 1983; Mousavi-Rouhbakhsh, 2001; Darvishzadeh, 2002; Aghanabati, 2004). Where compression from the collision is applied across the region, the strong south Caspian oceanic crust, buried under nearly 10 kilometers of pre-middle Miocene sediment, interacts with the bottom of the mechanically strong continental upper crust of northern Iran, resulting in upward buckling of the continental crust and downward buckling of the oceanic crust. During the Pliocene and Pleistocene ages, an unusually rapid subsidence of the south Caspian basin occurred that coincided with the uplift of the Great Caucasus, Kopet-Dagh and Alborz mountains, as a result of large horizontal forces and loading of the basin edges associated with a syn-

Table 1. Criteria for evaluating slope (after Davis, 1987).

Slope Class	Slope Description	Slope Range
1	Flat	0-2
2	Slight	2-8
3	Gentle	8-15
4	Moderate	15-25
5	Steep	25-45
6	Very steep	> 45

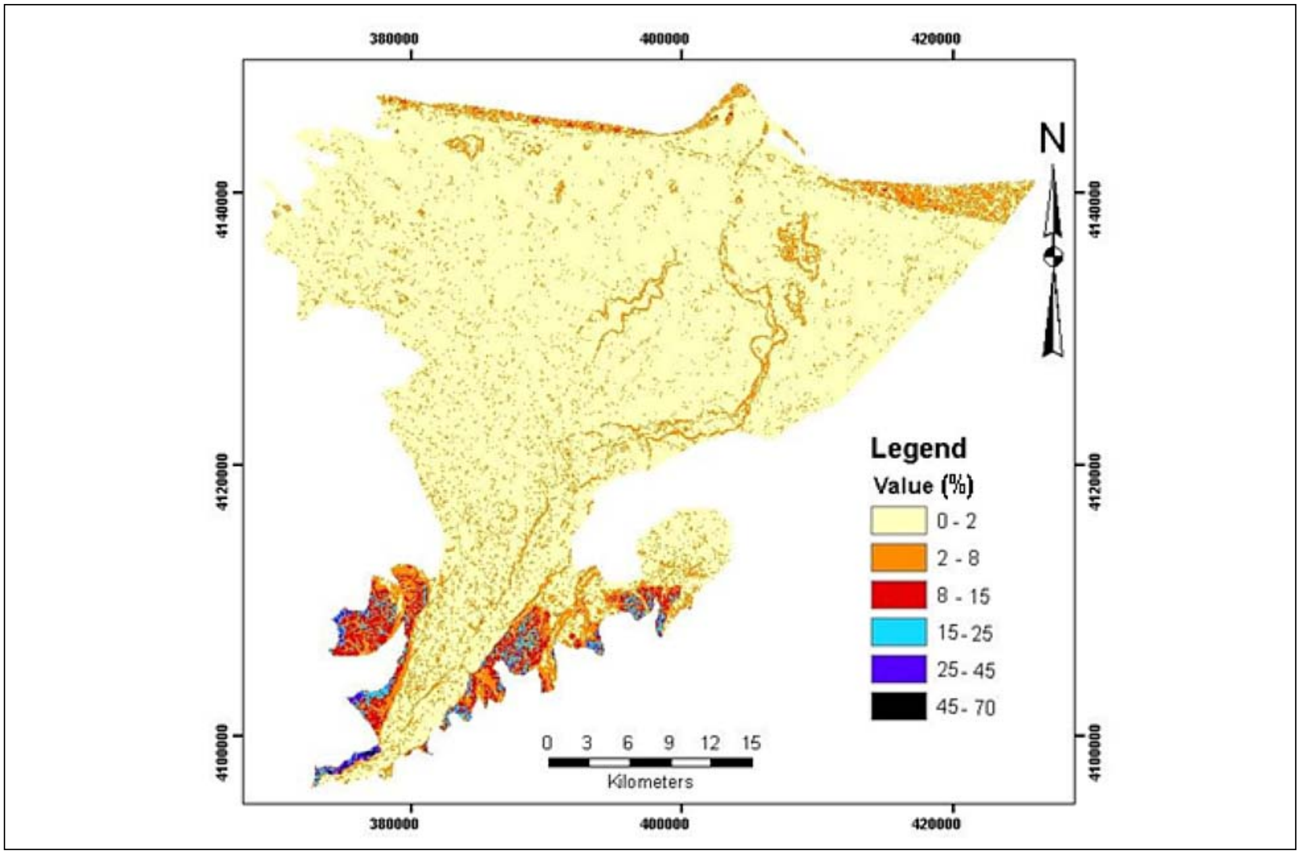

Figure 4. The ground slope classification of the plain.

compressional down-flexing of the entire area (Brunet et al. 2003). Rapid subsidence may also have been promoted by the large Tallish and Khazar faults, which are located to the west and south of the south Caspian Basin (Berberian, 1983; Mousavi-Rouhbakhsh, 2001).

Locally, morpho-tectonic and structural properties of the study area are largely controlled by Khazar Fault. The Khazar Fault is an active thrust fault in the northern part of the Alborz Range, which is associated with folding (the Khazar anticline) in its hanging-wall (Berberian, 1983). Regional geological studies indicate that the fault from the early Cenozoic has been active (Darvishzadeh, 2002). Because of its activities on 20 January 1990 in Gilan, the study area has been considered as a high risk zone (GSI, 2004). The Khazar Fault with approximately 40 kilometers long crosses the area in the east-west direction and separates the folded southern parts from northern coastal parts of the plain where the elevation of area sharply changes from hundreds meters to -25 meters.

Other major faults in the study area are Lahijan Fault and Sefîd-Rûd Fault. The strike of Khazar Fault is E-W but the Lahijan Fault has a strike of NE-SW. The Sefîd-Rûd Fault length is 25 kilometers and it is north-dipping and its orientation is N75NE (Darvishzadeh, 2002). As shown in Figure 5, the Sefîd-Rûd River pathway is mainly controlled by Lahijan Fault and Sefîd-Rûd Fault. The other major faults in the area are Galesh Zamin Fault and Vajargah Faults in southeastern parts, and Mianeh khaneh Fault in south western parts of the area, as shown in Figure 6.

In the folded area, the movement of groundwater is predominately controlled by dip of strata and orientation of folded layers, open fractures and subsurface structures associated with folding systems. In the study area, dominant folds have been found in Paleozoic and Mesozoic formations including Kah Kooh Anticline in southwest of Siahkal, Peale Sara Anticline in south of Siahkal,

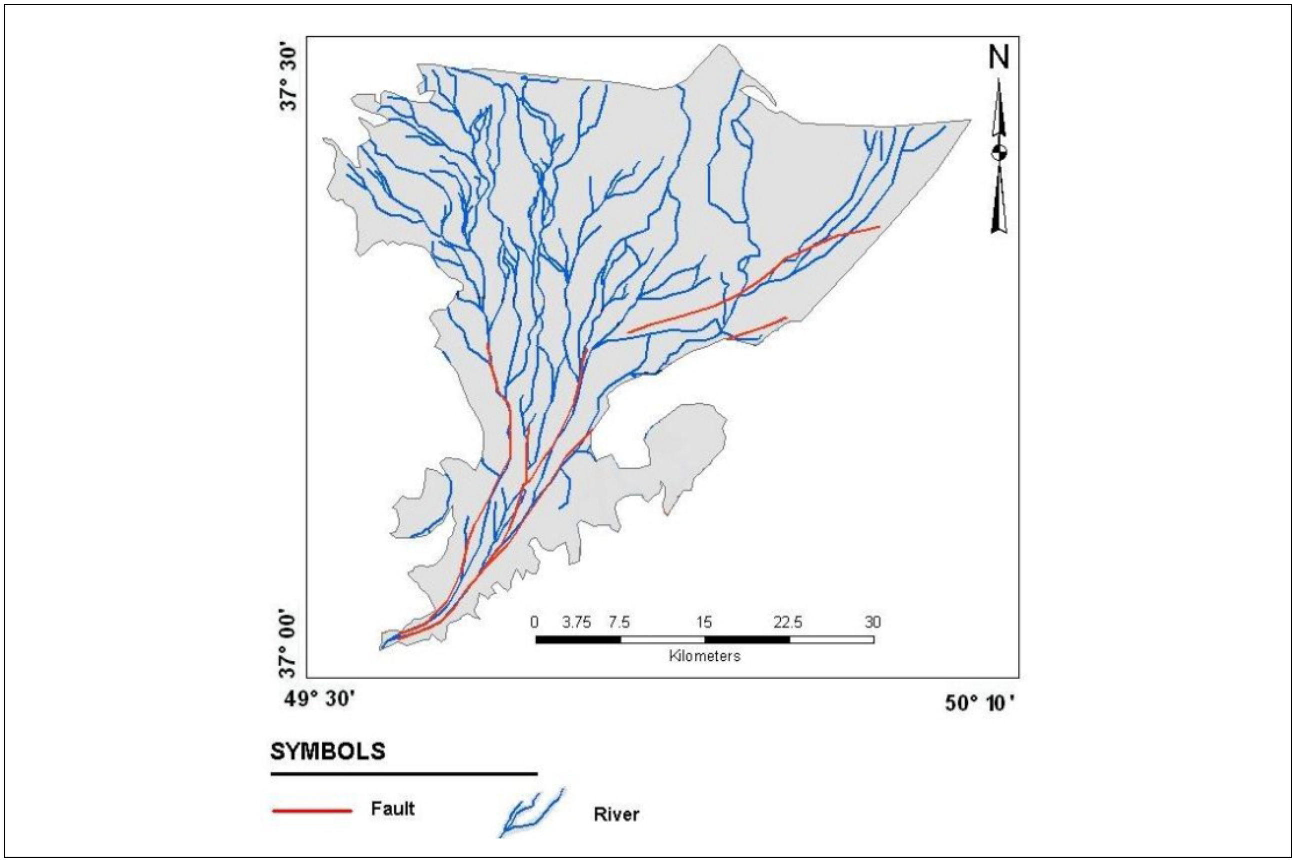

Figure 5. The close relationship between river pathways and the available fault systems in the study area.

Modjdehi Anticline and Kacha Anticline in southwest parts of the plain. The Kah Kooh Anticline and Peale Sara Anticline are sub-parallel folds which have a strike of E-W. Bedding dips of above folds are characteristically gentle. These folds have been intermittently active since the early Cretaceous period. Modjdehi Anticline and Kacha Anticline are dominant structural features for a distance of about 10 kilometers south from Rasht. Both of them are double plunging fold and the axes of two folds are parallel and have a strike of NE-SW. These are asymmetrical which northwest limbs of them have a dip of 30 to 45 degrees. These folds have been intermittently active since the late Jurassic period (GSI, 2004).

Geophysical Survey

In order to determine the lithology and thickness of alluvial deposits, many geophysical surveys using geo-electrical resistivity techniques have been carried out by Gilan Regional Water Organization (GRWO, 2005). Geo-electrical resistivity techniques which measure the electrical resistivity variation with depth are one of the most popular techniques for groundwater study (Barker, 1980). In this study, the Vertical Electrical Sounding (VES) method using a Schlumberger array with a maximum current electrode separation of 1000 m was used along three N-S profiles which covered a total distance of 98.5 kilometers of the area. However, the data has not been officially published. In this study, analysis of the geophysical survey data has produced cross sections that enable interpretation of contrasts in the lithology and thickness of the underlying layers and bedrock.

Figure 7 illustrates a geological cross section covering a distance of 37 kilometers from the south of Siahkal to the north of Lasht Nesha. Based on this N-S geological cross-section, the aquifer can be divided to eight hydrogeological zones from top to bottom of aquifer. These

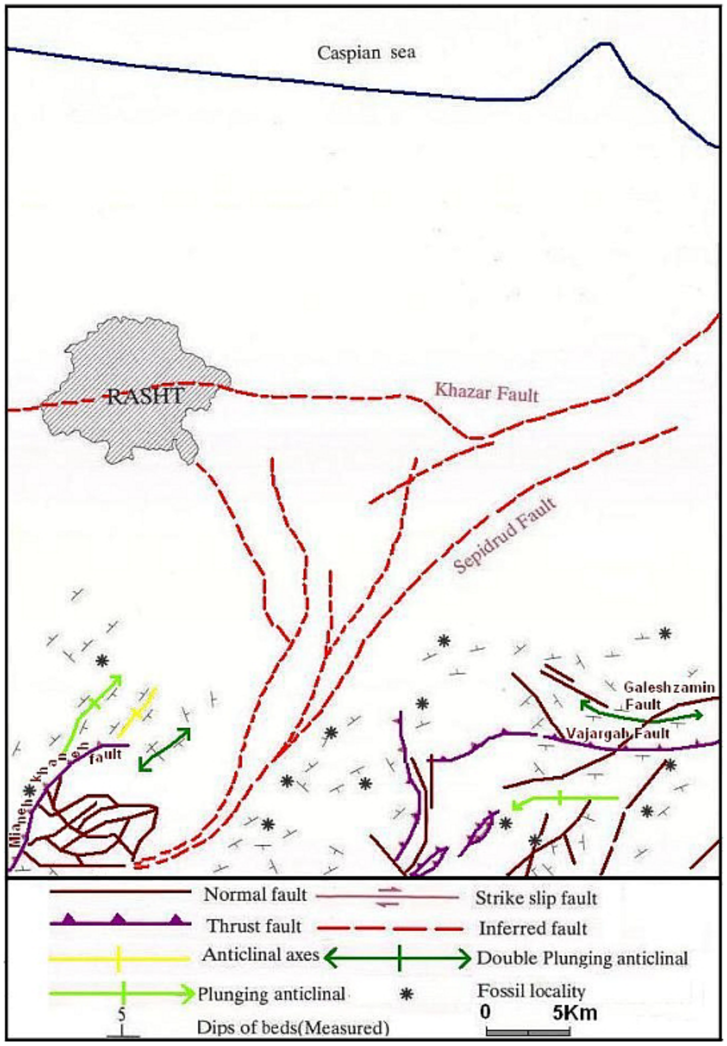

Figure 6. The structural geology map of Astaneh- Kouchesfahan Plain (after GSI, 2004).

sections are successions of relatively saline water-bearing layers and fresh water-bearing layers which are different in grain size and thickness. The thickness of the surface layers is less than 50 meters of unconsolidated gravel, sand, silt, or clay. Based on available cross section, there is a medium to coarse grain size, a fresh water-bearing zone, and thick layer between surface layers and bedrock that play an important role in transmitting the majority of groundwater flow. The bedrock predominately consists of impermeable clay of Jurassic age.

Another geological profile has been carried out to determine the character of the shallow and deep layers in a N-S trend, covering a distance of 23 Kilometers from the south of Kouchesfahan to the north of Khoshke Bijar (Figure 8). The upper 30 m of the profile illustrates some of the variation in the shallow stratigraphy as successions of poor fresh water- bearing layers, fresh water-bearing, and relatively brackish layers. The shallow layers towards the north of Kouchesfahan are relatively the same in thickness and vary in transmissivity. The presence of relatively brackish water- bearing layers in the south and north of section have caused an increase to the electrical conductivity of water with increasing salinity. This property is due to the concentration of minerals dissolved in water. Also the cross section shows that the aquifer contains a deeper layer extending approximately 30 to 200 m below the surface with low to intermediate resistivity. This transmissive layer overlies the bedrock of Shamshak Formation.

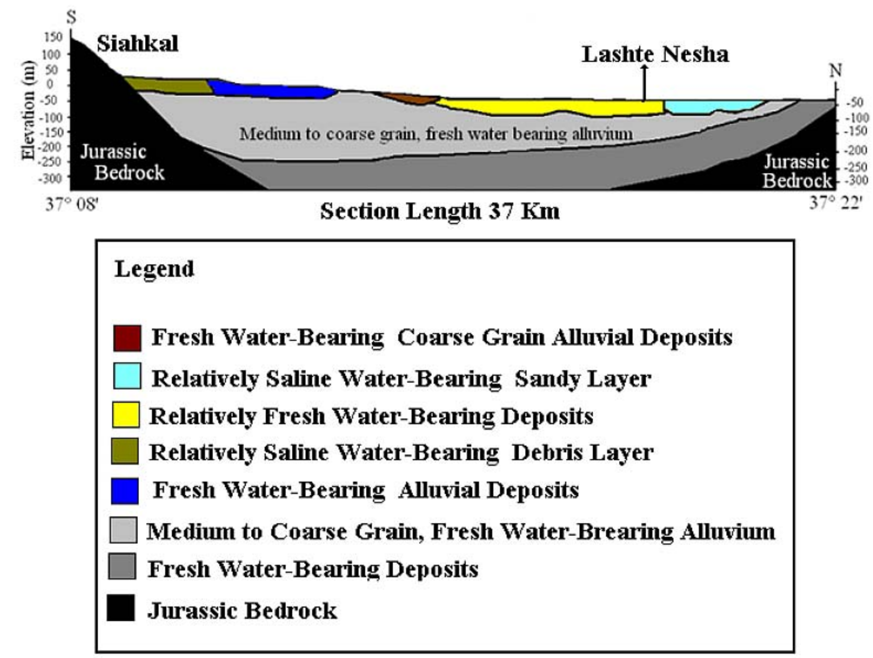

Figure 7. The geological cross section from south of Siahkal to north of Lasht Nesha (after GRWO, 2005).

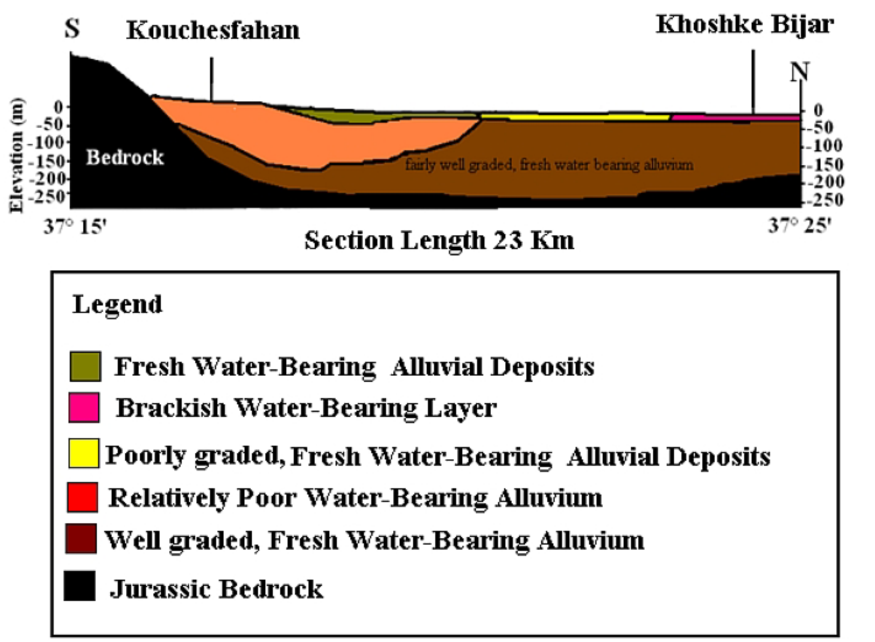

Figure 8. The geological cross section from south of Kouchesfahan to north of Khoshke Bijar (after GRWO, 2005).

The third geological section has been utilized to gain additional subsurface information from surface zones to bedrock. High-resolution resistivity surveys, approximately 38.5 kilometers in length have been completed in N-S orientation from south to north of Astaneh to provide a better understanding of the overlying units and depths and configurations of these layers and the bedrock (Figure 9). This survey identifies the aquifer in this section as characterized by two fresh water-bearing surface layers, one small lens of coarse grain deposits and one transmissive layer which has higher conductivity and overlies the impermeable bedrock.

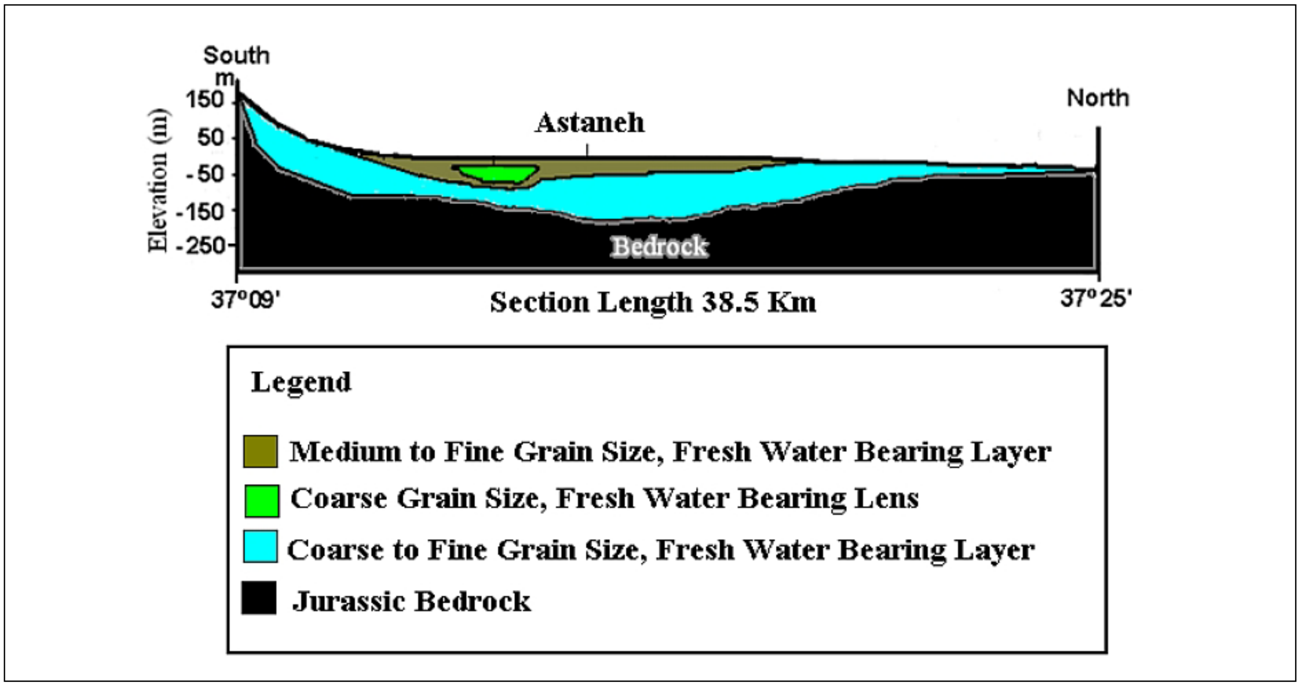

Figure 9. The geological cross section from south to north of Astaneh (after GRWO, 2005).

Well Log Analysis

In order to gain additional information, the study of well logs has been carried out in many parts of the plain. Well samples can provide information on the aquifer sequence, depositional strata, geological age, paleoenvironment for depositional history, and geological correlations. Figure 10 shows the location of logged wells maintained by Gilan Regional Water Organization (GRWO, 2005) and Table 2 and 3 summarize the analyses of 10 well logs used in the study area.

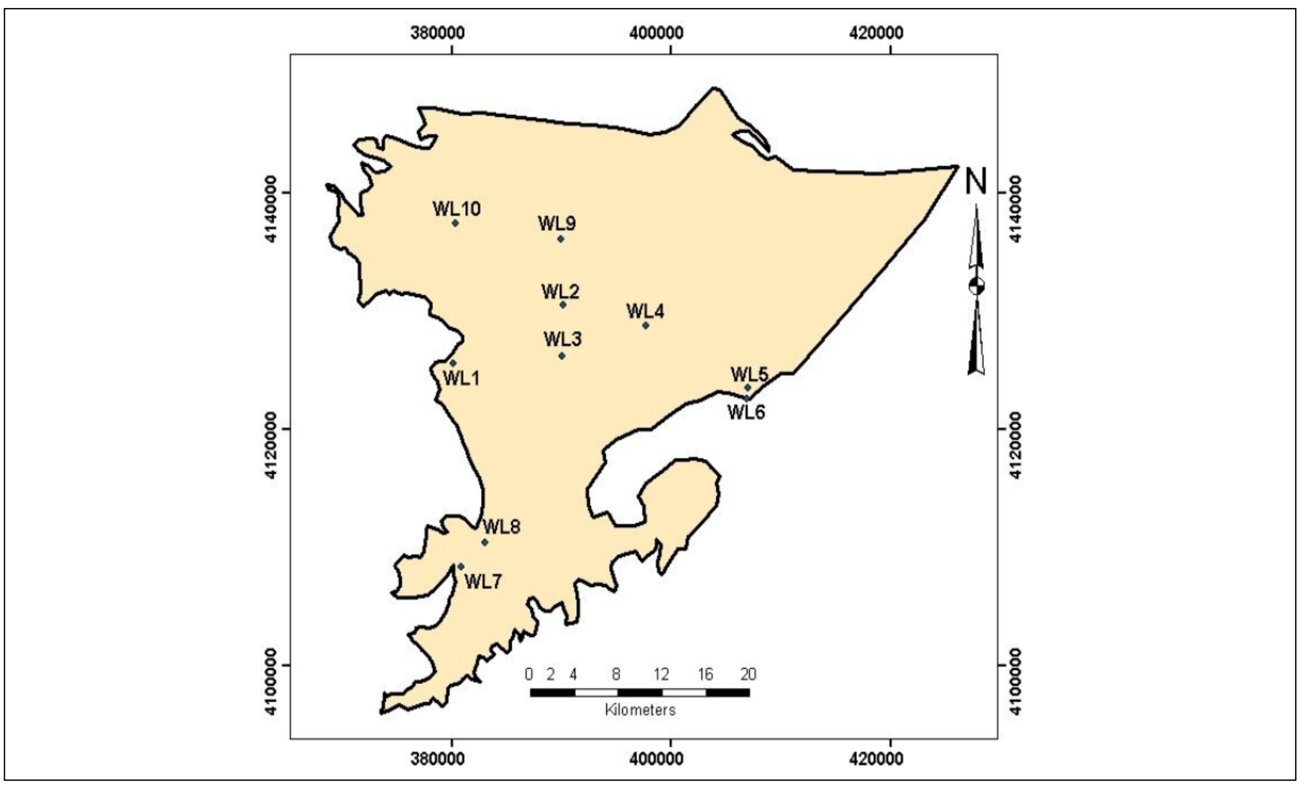

Figure 10. The location of logged wells for well log analysis.

Table 2. Summary of the analysis of log wells in the study area.

No	Well Location	Well Name*	Coordinate (UTM)		Logged Depth (m)	Top Layer	Percentage of layer thickness in the sampling thickness of well			
			(X)	(Y)			Clayey layers	Silty layers	Sandy layers	Gravely layers
1	Dolat Abad-Rasht	WL1	380173	4125617	73	Clay+ Sand+Gravel	0.15	0.40	0	0.45
2	Khast Masjed-Kouch-esfahan	WL2	390146	4130614	37	Sand+ Silt+Clay	0.22	0	0.56	0.22
3	Gilva-Kouch esfahan	WL3	390064	4126214	31	Clay+ Sand+Gravel	0.68	0	0.32	0
4	Rasht Abad-Astaneh	WL4	397691	4128884	56	Clay+ Sand+Gravel	0.55	0	0	0.45
5	Pole Jadid-Astaneh	WL5	406949	4123592	58	Clay+Silt	0.24	0	0.76	0
6	Nioka- Astaneh	WL6	406830	4122631	155	Clay+Sand	0.30	0	0	0.70
7	Shaghaji	WL7	380866	4108397	198	Gravel	0.47	0	0.05	0.48
8	Deh Band-Saravan	WL8	383052	4110444	181	Clay+ Sand+Gravel	0.16	0.43	0	0.41
9	Khoshke Bijar	WL9	389991	4136147	45	Silt+Clay	0.42	0.28	0.08	0.22
10	Khavajkin-homam	WL10	380400	4137552	105	Clay+ Sand+Gravel	0.42	0.10	0	0.48

Table 3. Summary of the aquifer media assessment of the log wells in the study area.

No	Well Name	Well Depth (m)	Aquifer Media (Based on total thickness of each layer in meters)												
			Clay Layers								Silty Layers				
			C	C+Si	C+Si+S	C+Si+G	C+S	C+S+G	C+G	C+B	Si	Si+C	Si+C+S+G	Si+C+G	Si+G+B
1	WL1	73	9	-	-	-	-	-	2	-	-	16	13	-	-
2	WL2	37	-	3	5	-	-	-	-	-	-	-	-	-	-
3	WL3	31	6	3	-	-	12	-	-	-	-	-	-	-	-
4	WL4	56	31	-	-	-	-	-	-	-	-	-	-	-	-
5	WL5	58	-	7	-	7	-	-	-	-	-	-	-	-	-
6	WL6	155	17	-	-	-	11	19	-	-	-	-	-	-	-
7	WL7	198	23	-	-	-	-	47	12	10	-	-	-	-	-
8	WL8	181	30	-	-	-	-	-	-	-	-	15	27	4	31
9	WL9	45	-	3	4	3	-	-	8	-	-	13	-	-	-
10	WL10	105	8	-	-	-	5	31	-	-	11	-	-	-	-

Table 3. (continued) Summary of the aquifer media assessment of the log wells in the study area.

No	Well Name	Well Depth (m)	Sandy Layers						Gravel and Boulder Layers										
			S	S+Si	S+Si+C	S+Si+G	S+G	S+B	G	G+C	G+S	G+S+C	G+S+B	G+B	G+B+S+C	G+B+S+Si	B	B+G	B+G+S
1	WL1	73	-	-	-	-	-	-	33	-	-	-	-	-	-	-	-	-	-
2	WL2	37	9	7	3	-	2	-	-	-	-	-	-	-	-	-	8	-	-
3	WL3	31	-	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-
4	WL4	56	-	-	-	-	-	-	-	-	7	-	-	-	-	18	-	-	-
5	WL5	58	13	6	-	11	14	-	-	-	-	-	-	-	-	-	-	-	-
6	WL6	155	-	-	-	-	-	-	-	-	22		53	21	12	-	-	-	-
7	WL7	198	-	-	-	-	11	-	-	12	2	9	-	61	7	-	-	4	-
8	WL8	181	-	-	-	-	-	-	-	-	8	-	-	32	25	-	-	-	9
9	WL9	45	-	-	-	-	-	4	-	-	-	-	-	4	-	6	-	-	-
10	WL10	105	-	-	-	-	-	-	-	-	-		9	16	-	25	-	-	-

Note: C=Clay; Si=Silt; S=Sand; G=Gravel; B=Boulder

The well logs indicate that the surficial zone in most parts of the plain has been covered by uppermost layers of clay, sand and gravel. The thickness of the top layer ranges approximately 2 to 20 m. The availability of low-permeability zones of clayey sediment in uppermost layers can be misleading in well placement process where main-producing zone with coarser materials of boulder, gravel and sand are available in depth.

The body of the aquifer is formed by a mixture of gravel, boulders, sand, silt and clay. Considering borehole analysis, it can be deduced that the aquifer is heterogeneous-unconfined system which has different thickness of alluvial deposits. Figure 11 illustrates the geological column of logged wells in selective parts of the plain.

In this study, the layers in each geological column have been categorized in four groups; clayey group, silty group, sandy group and gravely group. Locally, where gravel and sand dominate the sediments, high-permeability zones exist which act as main water-producing zones in the study area. On the other hand, where clay, silt dominate the sediments, low-permeability zones exist. After classification, the geological texture of each well was evaluated by quantifying the percent of total thickness of each group in the sampling thickness of well. The results show that (Table 2) the total thickness of clayey and silty layers in the logged wells are relatively the same as sandy and gravely layers. Maximum thickness of clayey and silty layers (minimum thickness of sandy and gravely layers) in the geological column occurs in the logged wells of Khoshke Bijar (WL9) and Gilva- Kouchesfahan (WL3) and it reaches to about 68% sampling thickness. Maximum thickness of sandy and gravely layers was seen in sampling wells of Khast Masjed-Kouchesfahan (WL2), Pole Jadid-Astaneh (WL5) and Nioka-Astaneh (WL6), where total thickness of clayey and silty layers falls to lowest point, about 25% of the sampling thickness.

In order to better understand the aquifer texture, each group (including clayey, silty, sandy and gravely groups) has been investigated in detail by compound analysis. The lithology and total thickness of each layer in the geological column of sampling wells were calculated, as presented in Table 3. The results indicate that low permeability and main-producing zones are discontinuous

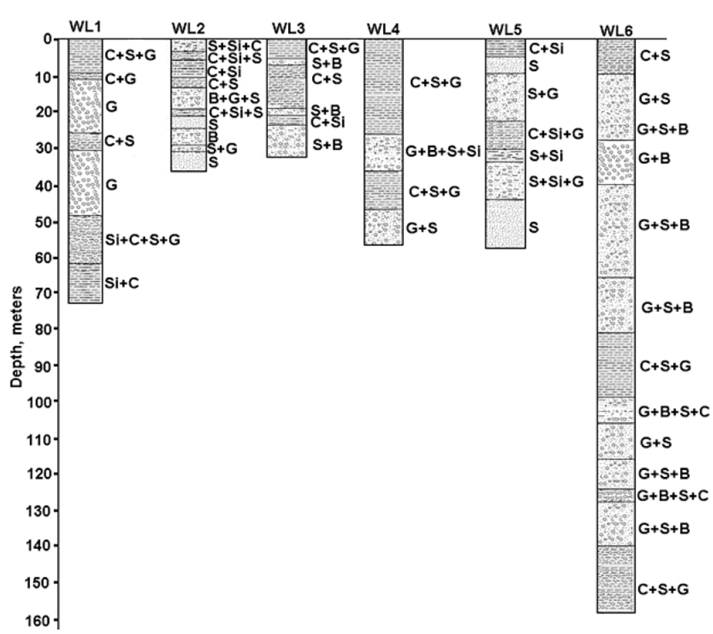

Figure 11. The geological column of the logged wells in the study area. Note: C=Clay; Si=Silt; S=Sand; G=Gravel; B=Boulder.

and they are variable in depth and thickness. In most vertical profiles of the aquifer, sandy and gravely layers have been interbedded with various mixtures of lower permeability silt and clay sediments. In some parts, the low permeability layers of clay and silt are lithologically inconsistent and include various mixtures of higher permeability sand, gravel sediments. Thus, in these areas, the low-permeability layers are very leaky, porous and hydraulically interconnected throughout.

CONCLUSIONS

Estimation of the geological and geophysical characteristics of water-bearing layers is an essential part of groundwater studies. In this study, detailed regional geological, geomorphological, tectonic and geophysical investigations were carried out in order to identify and characterize the different water-bearing zones in Astaneh-Kouchesfahan Plain, in the north of Iran. Such studies are extremely important in estimation of pumping rates, well placement, wellhead protection, remediation, site location and land use strategies .The interpreted data shows that the aquifer is heterogeneous-unconfined system which has different thicknesses of alluvial deposits. The aquifer mainly consists of recent alluvial successions which have been deposited on the eroded surface of the Paleozoic and Mesozoic-aged basement. The grain size distribution is very variable ranging from clay to boulders. Based on the analysis of 10 well logs, it can be concluded that the total thickness of clayey and silty layers in the logged wells are relatively the same as sandy and gravely layers and have a overall composition of 36% clay, 12% silt, 17% sand and 35% gravel. However, in low producing zone the permeability varies considerably due to the variation in the matrix and the percentage of the sand-gravel content. This study finally suggests that future quantitative works in Astaneh-Kouchesfahan Plain should be focused on main productive zones that have more thickness and high permeability. Also, from qualitative point of view, the area with narrow thickness of alluvium on the top must be considered as more vulnerable area to pollution where groundwater protection or monitoring is critical.

ACKNOWLEDGEMENTS

This paper was reviewed by Professor Saied Eslamian, Department of Water Engineering, Collage of Agriculture, Isfahan University of Technology in Iran, and Associate Professor Kourosh Mohammadi of the Department of Irrigation and Drainage Engineering, Tarbiat Modares University of Tehran in Iran.

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