IJES *Iranian Journal of Earth Sciences*
Vol. 11, No. 3, 2019, 205-214

The effect of Tous fault on groundwater resources in northern parts of Mashhad plain

Mohammad Reza Arjmand[1], Abbas Kangi*[1], Naser Hafezi Moghadas[2]

1. Department of Geology, Shahroud Branch, Islamic Azad University, Shahroud, Iran
2. Department of Geology, Faculty of Science, Ferdowsi University of Mashhad, Iran

Received 24 July 2018; accepted 22 January 2019

Abstract

Mashhad Plain affects by a series of active faults in the northern margin of the Binalud and the southern margin of the Kopet-Dagh mountain ranges. The activity of these faults forms the morphology of the stepped bedrock of the Plain. In addition, the faults' activities in the Quaternary period are the main effective parameters in thickness and texture of aquifer deposits in Mashhad Plain. In this regard, one of the active and important faults in Mashhad Plain is Tous fault, which runs from the northwest of Mashhad Plain into the city of Mashhad. The present research aims to analyze the effect of this fault on groundwater resources in the north of Mashhad Plain. For this purpose, ancient geoelectric studies and many well logs data are gathered, interpreted and by the combination of all of the geology information a new model for groundwater resource of the area proposed. The results of this study indicate that activities of Tous fault results to the uplifting of the Neogene Marly bedrock of Mashhad Plain, which such as a barrier prevents the flow of groundwater from the northern plain to the main aquifer of Mashhad Plain, and practically has divided the alluvial aquifer of Mashhad Plain into two parts. The maximum sediment thickness can be seen adjacent to the fault in the north of the Tous region and the tomb of Ferdowsi.

Keywords: *Tous fault, Marly bedrock, Mashhad Plain aquifer, Active Fault*

1. Introduction

Active faulting, have a major role in the quality and quantity performance of the aquifers. In order to determine the fault effects in groundwater flow, we need to know the components of the fault zone structure (Ben-Zion and Sammis 2003, Kim et al. 2004). It was long known that active faults control the pattern of groundwater flow in aquifers (Burbey 2008, Folch and Mas-Pla 2008) and affect the permeability of rocks, which is an important factor in the movement of groundwater (Geraud et al. 2006). Despite, the importance of understanding the fluid flow around fault zones at low depths of the earth's crust, the special efficacy of faults on the flow of groundwater in various geological environments is complex and varied, and it is often not well understood (Mayer et al. 2007: Bense et al. 2013). The fault zones consist of a core surrounded by crushed zone. The core of the fault includes secondary structures such as fractures, minor fault plans drawn inside the footwall and the hanging wall, which are the remainder of post-faulting phenomena but generally, the permeability of the core of fault is not very high. Multiple fields and laboratory experiments have shown that the crushed zone has a greater permeability than the fault core and the permeability in each zone is strongly anisotropic (Forster and Evans 1991). In addition, some field experiments indicate that the groundwater flow in the crushed zone usually has a conduit form along the fault surface, while the fault core (in particular, reverse faults) acts as an impermeable barrier against groundwater flow (Chester and Logan 1986, Caine et al. 1996). Depending on their mechanism, faults have different effects on the hydrological conditions of aquifers, and faults with a tensile mechanism have greater potential for water potential, and, on the other hand, fault plans with a reverse mechanism are not suitable routes for the flow and transfer of groundwater. Normal faults created by tensile stress, so it is possible to reveal a few centimeters of opening; however, these openings may be filled with secondary calcite or fault cutting. Reverse faults and strike-slip faults formed due to compressional stress and can act as impervious material (Goldscheider et al. 2008).

So far, researches being interested in the effects of the faults on groundwater aquifers and groundwater management (Koch and Mather 1997, Rana 1998, Lippmann et al. 2000) and the relationship of faults with groundwater (Cervantes et al. 2004, Hung et al. 2004, Sander 2007, Meijerink 2007, Al-Taj 2008). Travaglia (1988) used tectonic elements and faults as an important information layer in the study of Syria's groundwater and found useful results regarding the relationship between these elements and the potential of water wells. Based on their research, Caine and Forster (1999) stated that the flow of fluids in the upper sections of the crust controlled by the geometry of the fault zones and the permeability of these structures. Al-Taj (2008), studying the effect of structures in the groundwater of the Irbid area in the north of Jordan, showed that joints and faults

----

*Corresponding author.
E-mail address (es): a.kangi.geology@gmail.com

act as drainage channels for groundwater flow in the region. Zaigham et al. (2003) believe that the fault fracture has an important role in the basin drainage routes from Jeddah, Mecca, Taif cities to the Red Sea. Moreover, Seaton and Burbey (2005) identified the evacuation of groundwater by springs along the Lebanese coastline in the Mediterranean Sea. Cervantes and Armienta (2004) studied the effect of the fault on the quality of groundwater in the Valle dell in Mexico. Williams and Lee (2008) worked on the effect of the reverse fault in the hydrogeology of the Belo Ridge State in the Eastern United States, which shows that the water source depends on an extension of the fault zone. Aydin (2000) and Jourde et al. (2002) stated that in the concept of groundwater storage performance, the effect of fault zones on fluid flow should be determined because the fault zone of the area can behave as a barrier or a fluid channel.

Saba and Skooi's (2011) showed that the faults and the crushed zones in the watersheds of the mountainous areas of northern Tehran in Iran cause the supply of groundwater resources and provide suitable locations for storing water between the joints and fractures. Hashemi (2010) investigated the relationship between large-scale faults and fractures, and the abundance and quality of groundwater resources in Semnan province in Iran. Khorsandi-Aghai et al. (2008) in their study on the interaction between water resources and the fault of Lar valley in the north-east of Tehran shows that the fault has affected 60% of the water of the river in Lar valley and 57.5% of the springs.

The purpose of this study is to evaluate the effect of the Tous active fault on the groundwater resources of Mashhad Plain. Tous faults is a right-lateral and reverse fault with a Northwest-southeast trend that makes the north border of the Mashhad plain.

2. Geology of Study area

From the geological and structural sedimentary basin point of view, the study area is located in the Kopet-Dagh Zone and within Mashhad Plain (Nabavi 1976, Aghanabati 2004). Mashhad Plain is part of Mashhad-Quchan subsidence zone, which lies between two sedimentary basins of Kopet-Dagh (northeast) and Binalud (southwest) (Berberian et al. 1999, Natal'in and Sengör 2005). The northeastern boundary of this subsidence is Kashafrood fault and South Mashhad fault delineates its southwestern boundary (Alavi 1994). The sedimentation of Mashhad Plain is entirely under the control of active tectonics. Young morphotectonic features such as deformed alluvial fan, displacement of the river channel, high sedimentation rates, and young fault scarps are some evidences of the active tectonics of the Plain (Hafezi-Moghaddas et al. 2017).

Tous Fault

Tous fault is a branch of Kashafrood fault that has a northwest-southeastern trend and was first introduced by Berberian et al. (2000) based on geomorphologic evidence. The occurrence of several historical earthquakes in the north of Mashhad assigned to the activity of Tous fault (Fig1), (Ambaseys and Melville 1982).

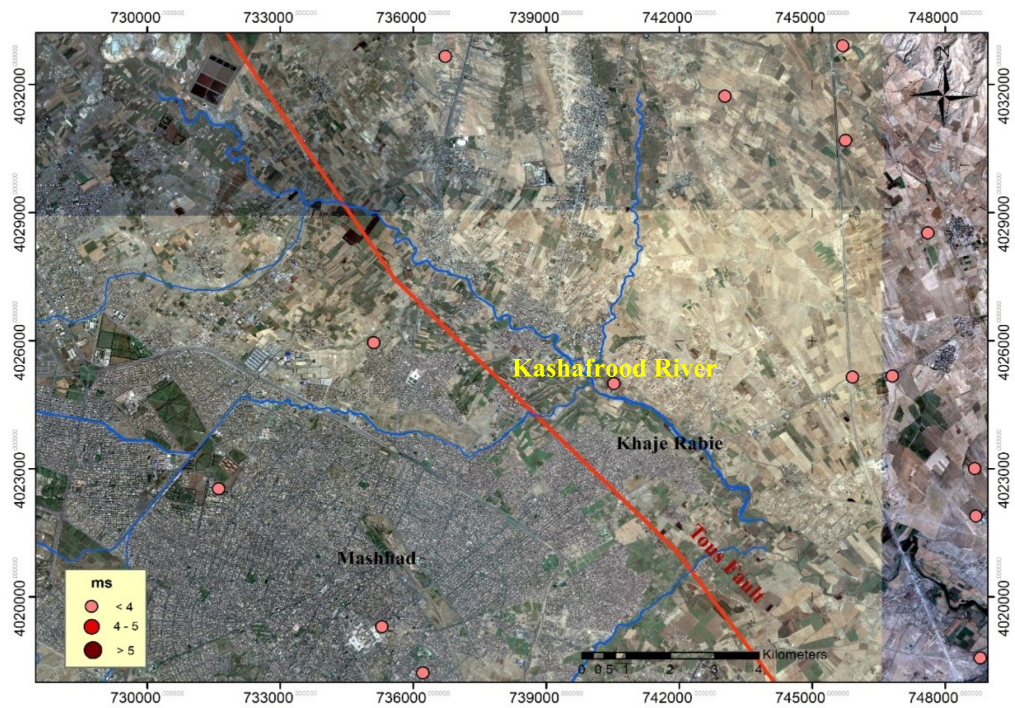

Fig 1. The trend of Tous fault and epicenter of earthquakes in the aerial photograph

The trend of fault in the Southeast of area is not quite visible in Quaternary alluvial sediments. Therefore, there is a controversy regarding the exact location and existence or absence of this fault in North of Mashhad. However, some evidences, for example a fault scarp in the near of Khaje-Rabi area, confirmed the fault continues toward the North of the city (Fig 2 ,3). Also in the aerial photograph can easily see that the river originating from the foothills of the south and southwest of Mashhad has been diverted to eastward after reaching Tous fault (Fig 4). Investigating the position of fault geometry with geoelectrical study in the Khaje-Rabi area, Tous fault has been introduced a reverse fault dip to the southwest (Azadi et al., 2009), while the other study showed that the fault dip toward the Northeast.

Fig 2. A view of Tous Fault trend between Ferizi-Khajerabie area, (Naderi and Sharifi 2018)

Fig 3. About 2 m subsidence in northern part of Tous Fault in khajerabie area, (Naderi and Sharifi 2018)

3. Resistivity studies

The resistivity method involves injecting electrical current into the ground via a pair of electrodes (electrodes A and B shown in fig. 5), simultaneously the potential difference between the other pair potential electrodes (electrodes M and N) is measured. This method of the probing the earth is called electrical sounding and geoelectrical investigations refer to the survey based on the resistivity measurements to study the subsurface layers. In practice, many several different arrays are used. But Schlumberger and Wenner arrays are most used.

Apparent resistivity can be estimated by the ratio of the potential difference (ΔV), electrical current (I) and electrodes positioning (k) with the following formula:

$$\rho = k \, \Delta V / I$$

As by increasing the AB spacing in Schlumberger configuration, the current goes deeper into the ground the apparent resistivity will be changed. This change relates to electrical features into the sub-layers. Such a configuration is called the symmetric array of electrode pairs (A, B) and (M, N) are coaxial and MN<<AB. In such a configuration AB spacing is expanded symmetrically for deeper penetration of the current.

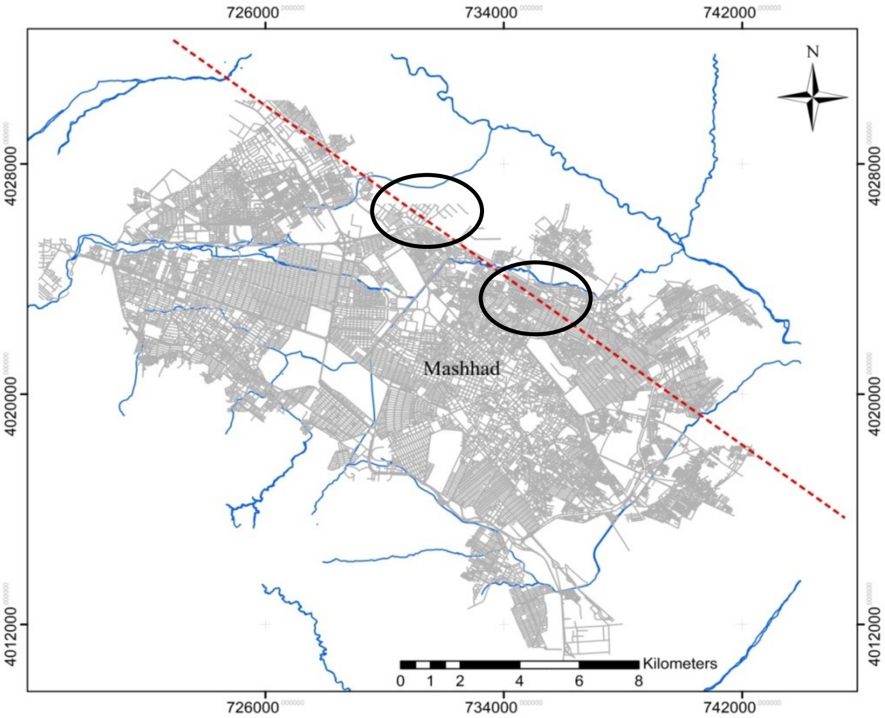

Fig 4. The main river channel of Mashhad (continuous blue lines) originating from the southern and southwest highlands of Mashhad are diverted to the right after reaching Tous fault line (red line).

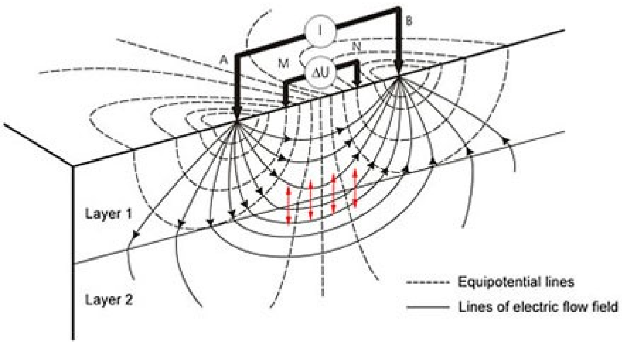

Figure 5-Calculating method, Current lines and equipotential surfaces of apparent resistivity for Schlumberger arrays

In the present study, the approximate position of Tous fault was derived on the map and three geoelectric profiles (AB=1000m) were taken along the vertical perpendicular to the fault. In addition, the results of two geoelectric profiles taken in Upper and Lower Tous regions have also been studied. Also detailed data of 20 deepwater wells, including location, discharge capacity, surface water table and depth of impact on plain bedrock, were produced. Then geoelectric studies and log data were compared and the results were analyzed.

4. Discussion

4.1. Geoelectric studies in Zak-Marian alluvial zone and adjoining regions

Three geoelectric profiles I-I, J-J and K-K were carried out normal to Tous fault in Zak-Marian region (Fig.6). Figs 7-9 show the apparent resistivity and geological sections of these profiles. Figure 7 draw based on the 10 soundages, soundages I1 to I5 are far from the fault plane; therefore, withdrawal wells are well fed and have a good quality. Soundages of I6 to I9 are near the fault zone and alluvial thickness in these soundages are relatively low and soil texture is fine grain. In the northern part of the cross-section, I9 to I10 soundages are located east of Tous fault zone and the aquifer layer was found to be relatively deep and relatively high thickness.

Figure 8 shows the interpretation results of 10 soundages, from which soundages J1 to J5 are located in the south of Tous fault in the main aquifer area. The proper condition of groundwater at J3 soundage is due to the sedimentation and nutrition of the Kashafrood River. Around the Tous fault zone near station J4 to J5 alluvial thickness and groundwater quality is low. In the northern part of the fault zone, J8 to J10 soundages show a relatively high alluvial thickness with good groundwater potential. In figure 9, K1 to K3 and K9-K13 stations show a good condition but the soundages near the fault zone have inadequate potential of groundwater due to uplifting the marly layer.

4.2. Specification of the withdrawal wells

Table 1 show the information of 20 drinking and agriculture wells in the study area. As can be seen, the depth of wells in the south of Tous fault (e.g. the villages of Akbar-Abad, Kalate-Barfi, Shams-Abad etc.) is more than 240 meters, and the wells in these areas have high discharge capacity.

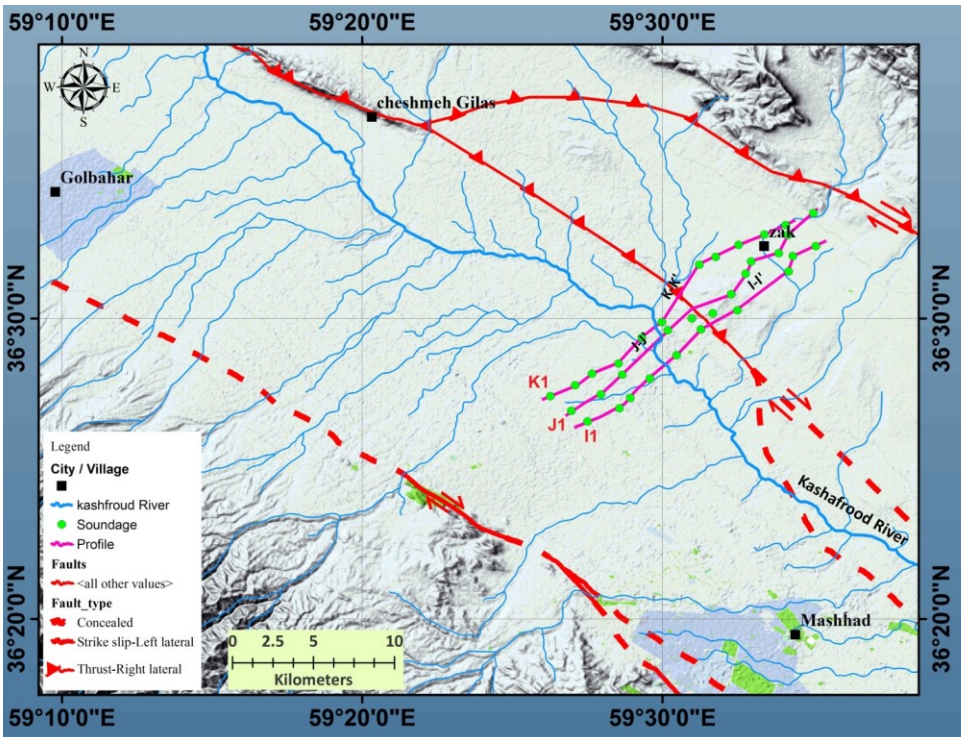

Fig. 6- Location of the study area and profiles and soundages under study (Mighan and Sharifi 2018).

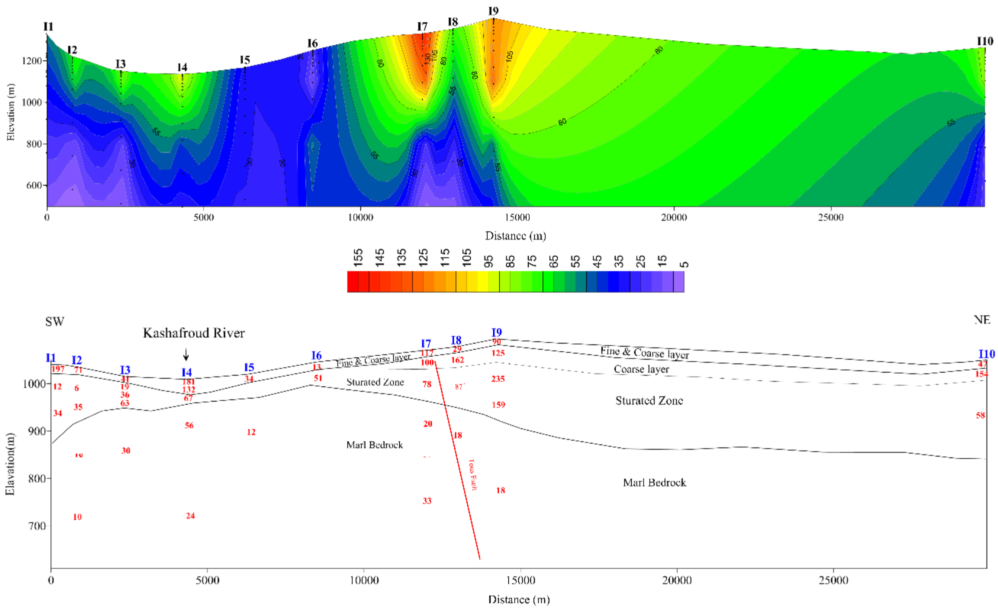

Fig 7. The reverse cross-section of the I-I profile and the geological layers showing the position of Tous fault and location of Kashafrood River.

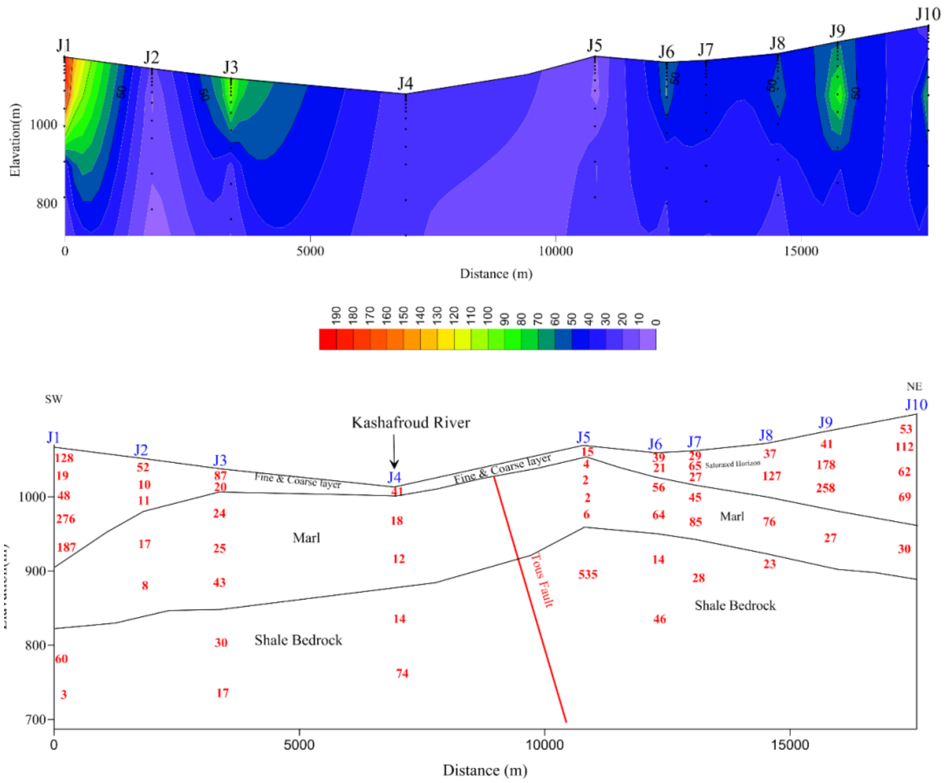

Fig 8. The reverse cross-section of the J-J profile and the geological layers showing the position of Tous fault and location of Kashafrood River.

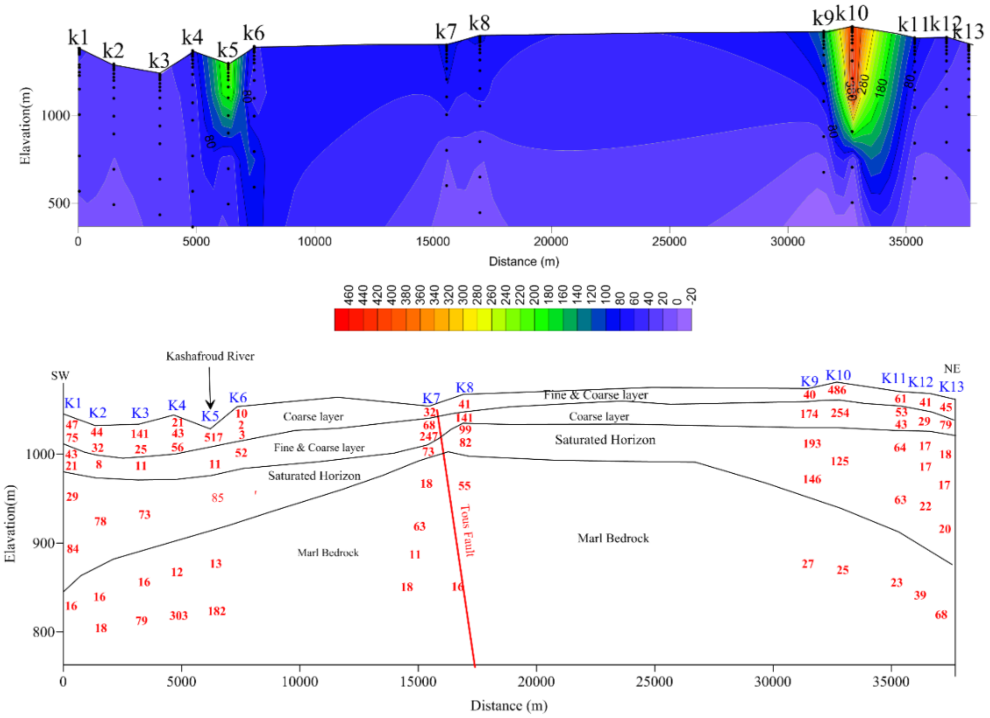

Fig 9. The reverse cross-section of the k-k profile and the geological layers showing the position of Tous fault and location of Kashafrood River.

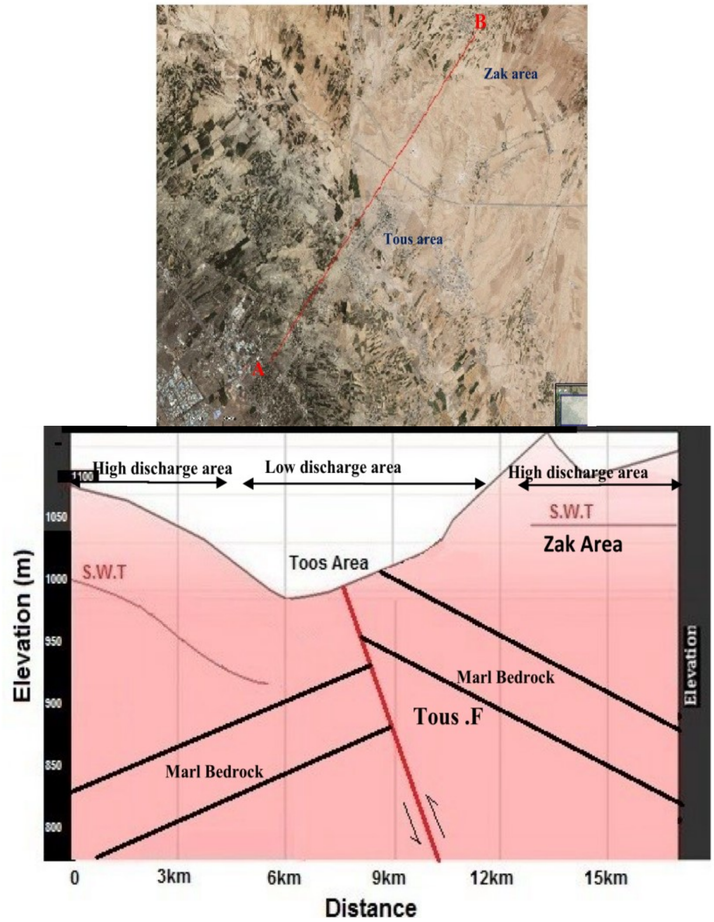

Fig 10. The satellite image of the study area, and a simplified cross in Toos area, showing the position of Tous fault and the division of the areas based on the depth of the bedrock and the water discharge capacity of the wells.

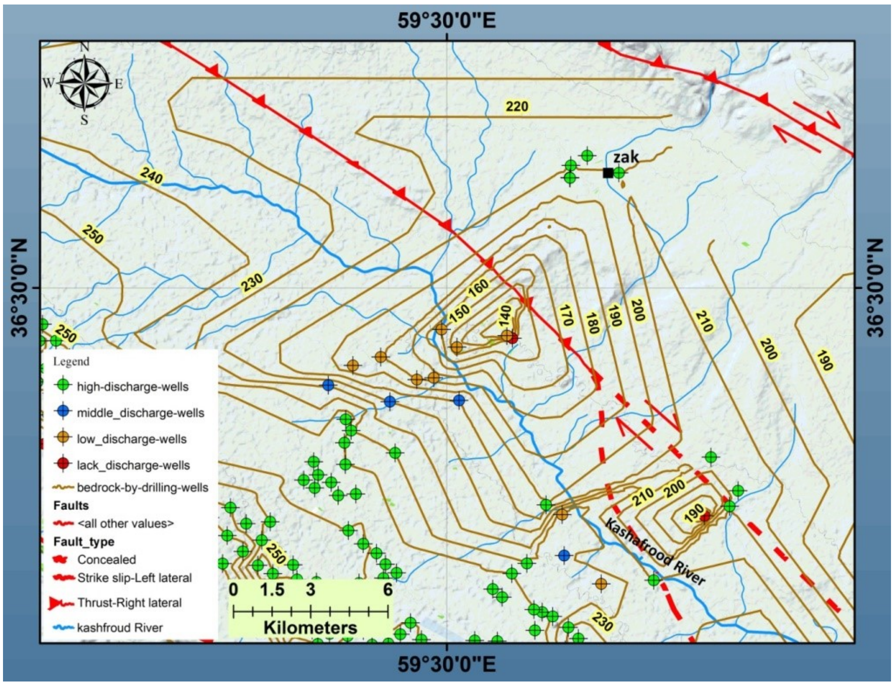

Fig 11- Variability of discharge capacity of withdrawal wells respect to Tous fault (Mighan and Sharifi 2018) & Bedrock depth curves (iso-alluvial thickness) in the study area.

Table 1. Specifications and coordinates of excavated deep wells in the study area (Mashhad Water and Wastewater Co., 1396)

row	Well name	UTM-Y	UTM-X	S.W.T (m)	Bed Rock		Discharge	
					Depth (m)	Lithology	Values(Lit/s)	Description
1	Kalatebarfi	4036237	720861	100	250	Marl	40	High
2	Akbarabad	4035402	720912	85	250	Marl	40	High
3	Shamsabad 2	4037142	720880	83	260	Marl	43	High
4	Tous sofla	4040422	726014	92	150	Marl	2	Low
5	Kalateshafil	4039235	721050	84	190	Marl	9	Low
6	Mordar keshan	4037970	724406	85	210	Marl	12	Middle
7	Ferdosi tomb	4038820	723591	87	185	Marl	9	Low
8	Kalateseyed	4039582	721912	85	190	Marl	9	Low
9	Olia 2	4038737	723065	85	190	Marl	9	Low
10	Sofla2	4040698	723786	90	160	Marl	9	Low
11	Chaharborj	4037865	722245	87	220	Marl	11	Middle
12	Hajiabad	4036718	721061	87	240	Marl	30	High
13	Eslamie	4040515	725843	90	150	Marl	5	Low
14	Katayan	4040028	724286	92	140	Marl	5	Low
15	Eslamie 2	4040515	725843	95	110	Marl	5	Low
16	Mehdiabad	4035886	722459	87	240	Marl	30	High
17	Zak	4046908	729177	50	210	Marl	30	High
18	Rahbar	4046686	727642	50	210	Marl	30	High
19	Mirase 1	4047151	727670	50	210	Marl	30	High
20	Mirase 2	4047549	728171	50	210	Marl	30	High

However, approaching the fault zone, the thickness of the aquifer and the depth of the wells and as well as the discharge capacity of the wells gradually decrease (Fig 10). Fig. 11 show the iso-alluvial thickness of the area that produced by combination of the geoelectric and the log of wells. As can be seen, alluvial thickness around the Tous fault is low and increase by distance from the fault zone in the south and north. Fig. 10 obviously show that due to the rising of the Marly layer in the north of the fault a separate aquifer created. In fact Tous fault act as a barrier against the groundwater flow from the north to the center of Mashhad plain.

5. Conclusion

Integrating of geoelectric sections, deep wells information and geology studies confirm that the right-lateral-reverse mechanism and dip to northeast of Tous fault. Also the fault activities during the Quaternary and Neogene period results to uplifting the Neogene Marly bedrock, which has had significant impacts on the groundwater resources in the north of Mashhad Plain. The area located around the fault zones such as Ferdowsi's Tomb and the villages of Upper and Lower Tous, have a weak groundwater resource with the low aquifer thickness and poor quality. While the withdrawal wells far from the fault to the North such as Zak-Marian areas show a very good discharge capacity. It is seen that the Tous fault have a right lateral-reverse mechanism that acts as a barrier in this area and prevents the flow of groundwater from the northern regions of Tous to the south of Tous fault zone. In the results, Tous fault made a disconnection between south and north alluvial deposits and the creation of an independent aquifer in North of the fault such as Zak-Marian areas.

Acknowledgment

We would like to thank all the people who participated in this research, especially Mr. Morteza Salari and the experts in the advising engineering companies of Zamin Physic Pooya and Simaye Ab Khavaran, as well as the valuable support provided by Mashhad Water and Wastewater Company.

References

Aghanabati A (2004) Geology of Iran, *Geological Survey of Iran*, 558 p.

Alavi M (1994) Tectonic of the Zagros orogenic belt of Iran: new data and interpretations, *Tectonophysics* 229: 211–238.

Al-Taj M (2008) Structural Control on Groundwater Distribution and Flow in Irbid Area, North Jordan,

Jordan Journal of Earth and Environmental Sciences 1: 81-88.

Ambaseys NN, Melvile CP (1982) A History of Persian Earthquakes. *Cambridge University press*, London.

Aydin A (2000) Fractures, faults and hydrocarbon entrapment, migration, and flow. *Marine and petroleum geology 17*(7): 797-814.

Azadi A, Javan-Doloei GH, Hafezi-Moghadas N, Hesami Azar KH (2009) Geological, geotechnical and geophysical characteristics of the Tous Fault located North of Mashhad, North-eastern Iran, *Journal of the Earth and Space Physics* 35(4): 17-34 (In persian).

Bense VF, Gleeson T, Loveless SE, Bour O, Scibek J (2013) Fault zone hydrogeology. *Earth Science Reviews* 127:171-192.

Ben-Zion Y, Sammis CG (2003) Characterization of fault zones. *Pure and Applied Geophysics* 160: 677–715.

Berberian M, Ghorashi M, Shoja-Taheri J, Talebian M (1999) Siesmotectonic and earthquake- fault hazard investigations in the Mashhad- Neyshabur region, *Geological Survey of Iran*, report No. 72 (In Persian).

Berberian M, Jackson JA, Qorashi M, Talebian M, Khatib M, Preistley K (2000) The 1994 Sefidabeh earthquakes in eastern Iran: blind thrusting and bedding – plane slip on a growing anticline, and active tectonics of the Sistan suture zone, *Geophysical Journal International* 142: 283-299.

Burbey T (2008) The influence of geologic structures on deformation due to groundwater withdrawal. *Ground Water* 46:202-211.

Caine JS, Forster CB (1999) Fault zone architecture and fluid flow: insight from field data and numerical modeling. *Geophysical Monograph-American Geophysical Union 113*: 101-128.

Caine JS, Evans JP, Forster CB (1996) Faults zone architecture and permeability structure. *Geology* 24(11): 1025-1028.

Cervantes A, Armienta MA (2004) Influence of faulting on groundwater quality in Valle del Mezquital, Mexico. *Geofisica Internacional* 43(3), 477-493.

Chester FM, Logan JM (1986) Implications for mechanical properties of brittle faults from observations of the Punchbowl fault zone California. *Pure Applied Geophysics* 124(1-2): 80-106.

Folch A, Mas-Pla J (2008) Hydrogeological interactions between fault zones and alluvial aquifers in regional flow systems. *Hydrological Processes: An International Journal* 22(17): 3476–3487.

Forster CB, Evans JP (1991) Hydrogeology of thrust faults and crystalline thrust sheets: results of combined field and modeling studies. *Geophysics research letters* 18:979-982.

Geraud Y, Diraison M, Orellana N (2006) Fault zone geometry of mature active normal fault: a Potential high Permeability channel (Pirgaki fault, Corinth rift, Greece). *Tectonophysics* 264: 61-76.

Goldscheider N, Meiman J, Pronk M, Smart C (2008) Tracer tests in karst hydrogeology and speleology. *International Journal of speleology* 37(1), 27-40.

Hafezi-Moghadas N, Azadi A, Rahimi B (2017) Identifying of the route and determining the setback of southern fault of Mashhad, Research project of Ferdowsi university and engineering construction organization of Khorasan Razavi.

Hashemi N (2010) Surveying the relationship between faults and large-scale fractures and the quality and abundance status of groundwater resources in Semnan province*, The First Iranian National Conference on Applied research in Water Resources,* Kermanshah , Kermanshah University of Technology , (In Persian).

Hung LQO, Batelaan DN, De Smedt F (2004) Lineament analysis for the groundwater in karst fractured rocks in the suoimuoi karst catchment, In Proceedings of the International Transdisciplinary Conference on Development and Conservation of Karst Regions, Hanoi, *Vietnam* 13-18.

Jourde H, Flodin EA, Aydin A, Durlofsky LJ, Wen XH (2002) Computing permeability of fault zones in eolian sandstone from outcrop measurements. *AAPG Bulletin* 86 (7): 1187- 1200.

Khorsandi-Aghai A, Miyata T, Ghoreishi H (2008) The interaction between water resources and faults: a Case study of Lar valley in northeast Tehran, *International Journal of Geology* 2(3): 38-42.

Kim YS, Peacock DCP, Sanderson DJ (2004) Fault damage zones. *Journal of Structural Geology* 26: 503–517.

Koch M, Mather PM (1997) Lineament mapping for groundwater resource assessment: a comparison of digital Synthetic Aperture Radar (SAR) imagery and stereoscopic Large Format Camera (LFC) photographs in the Red Sea Hills, Sudan. *International Journal of Remote Sensing* 18 (7): 1465-1482.

Lippmann MJ, Truesdell AH, Pruess K (2000) The control of fault on the hydrology of the Cerro Prieto III area, Twenty-Fifth Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, *SGP-TR* 165: 24-26.

Mayer A, May W, lukharila C, ziehl J (2007) Estimation of fault-zone conductance by calibration of a regional groundwater flow model: Desert Hot Springs, California. *Hydrogeology Journal* 15: 1093- 1106.

Meijerink AMJ (2007) Remote Sensing Applications to Groundwater. IHP-VI, Series on Groundwater.

Mighan N, Sharifi H (2018) Active Fault map of Mashhad City, *Geological Survey of Iran North-East Territory,* (in Persian).

Nabavi, MH (1976) An Introduction to geology of Iran. *Geological Survey of Iran*, Tehran. (In Persian)

Naderi-Mighan N, Sharifi H (2018) *Active Fault map of Mashhad City*, *Geological Survey of Iran North-East Territory*.

Natal'in BA, Sengör AMC (2005) Late Palaeozoic to Triassic evolution of the Turan and Scythian platforms; the pre-history of the Palaeo-Tethyan closure. *Tectonophysics* 404: 175-202.

Rana SS (1998) Application of Directional Filtering in Lineament Mapping for Groundwater Prospecting Around Bhinmal- A Semi-Arid Part of Thar Desert. *Journal of the Indian Society of Remote Sensing* 26(1-2): 35-44.

Saba N, Skooi B (2012) Two-dimensional modeling of very low frequency (VLF) data along a profile region, Iran, *Journal of The Earth and space physics* 38(2): 149-156, (In Persian).

Sander P (2007) Lineaments in groundwater exploration: a review of applications and limitations, *Hydrogeology Journal* 15: 71-74.

Seaton WJ, Burbey TJ (2005) Influence of Ancient Thrust Faults on the Hydrogeology of the Blue Ridge Province.

Travaglia (1988) Ground water exploration by satellite remote sensing on the Syrian Arab Republic. RSC services 76, *FAO International*43 (3): 477-493.

Williams NH, Lee M (2008) Ireland at risk - Possible implications for groundwater resources of climate change. *Geological Survey of Ireland 13*: 1-28.

Zaigham NA, Aburizaiza OS, Nayyer ZA, Mehar GA, Siddiq A, Noor S (2003) Satellite Tech-Identification of Groundwater Offshore Springs in the Red Sea along Jeddah-Rabigh Costal Belt: A Case of Fault-Zone-Aquifers in Crystalline Rocks of Arabian Shield.