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AN APPLIED METHOD FOR ESTIMATING THE AMOUNT OF WATER EXCHANGE BETWEEN THE SEASONAL RIVERS AND AQUIFER, CASE STUDY: ZAYANDEHROUD RIVER IN THE CITY OF ISFAHAN

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Abstract:-
In most cases, the rivers that flow in the alluvial aquifers are hydraulically connected to them. So, in such areas, it is essential to determine the relationship between the river and the aquifer. In this study, hydraulic connection between alluvial aquifer of Isfahan city and Zayandehroud River are evaluated. The main recharge source of this alluvial aquifer is Zayandehroud River. In recent years from March to November, due to the shortage of water and consumption of whole of the river flow rate in the upstream of the Isfahan city, the flow to the Isfahan region is disconnected. Therefore, the November and December are those months which are respectively the end of the dry period and the start of the river flow period. Using the groundwater isopotential maps of the November and December, 2015, the hydraulic connection between the river and aquifer during the dry and wet period was compared. The obtained results show that during the period of water flow in the river, there is an effective connection between river and aquifer. In most places the river recharges the aquifer. In some parts of aquifer in the south of the river, considerable cones of depression caused by heavy pumping have been created which changed the normal pattern of groundwater flow to a forced recharge from the river. Most recharge to the Isfahan aquifer by the river occurs in the western part of the city till the region of Khajo Bridge. The amount of this recharge is about 55028 m^3/day.

Keywords: - *Isfahan - Urban groundwater - Groundwater/surface-water relation – General* hydrogeology – Iran

INTRODUCTION

Effects of surface water such as springs, streams and rivers, in diverse environments are linked with groundwater within a complex process, (Winter *et al*. 1998; Sophocleous 2002)

According to the connection with underground water streams, rivers are divided into three types: 1) Rivers that drain the groundwater through their bed-line (Effluent River). 2) Rivers that recharge the underground water by their bed-line (Influent River) 3) Rivers of both type one and type two (Insulated River) (Winter *et al.* 1998).

Understanding the path of the underground water and the flow rate between the groundwater and surface water in order to assess the potential effects of water resources allocation and evaluation of obtained an increase in the use of water from groundwater that depends on ecosystems, is necessary and imperative (Bank *et al*. 2011; Kalbus *et al*. 2006; Sophocleous 2002). In addition, a comprehensive understanding of the interactions between surface water and groundwater can be helpful in detection of the path of pollution movement and its potential effects on ecological systems.

Determining the amount of the underground water recharge is studied over and over from the year 1980, and due to the need for underground water in arid and semi-arid areas, most of these studies is done in those areas (De Vries and Simmers 2002; Radulovic *et al*. 2012). Due to the complex hydraulic and hydrological conditions and flowing in heterogeneous environment, direct measurements are complicated and usually indirect measurements are used (Jukic and denic-Jukic 2008).

Groundwater interactions on the scale of the catchment area are controlled by three main factors (Yu *et al.* 2013). A) the position of the river channel within the landscape and the morphology of the catchment, B) hydraulic conductivity of the river bed sediments and associated alluvial deposits and, C) the relation of the stream elevation to the water table level of the adjacent aquifer. Winter (1999) and Mencio *et al*. (2014) suggest that the interaction between surface water and groundwater also are influenced by human processes and geological factors. Analysis of physical data, including heat tracer/electrical conductivity (EC), mass balance modeling of stream discharge volumes, stream – aquifer head gradients as input to Darcy's law equation and numerical models are amongst the most reported techniques in the literature for the investigation of GW–SW connectivity. (e.g. Brunner *et al.* 2009; Giambastiani *et al.* 2012; Keery *et al.* 2007; Kalbus *et al.* 2006). Scale of the study area together with the type of connectivity expected (such as gaining versus losing conditions or connected versus disconnected) are the main criteria for the selection of the most suitable techniques (Bank *et al.* 2011). In modern societies, urban development is considered as human requirements. Furthermore, the development needs providing the required water for people, industry and agriculture. In the dry areas of the central provinces of Iran, use of underground water is essential, on the one hand recharge from rainfall for underground water in these areas is negligible and rivers play the main role in recharge, therefore changes in the quality and quantity of surface water, directly effect on underground water resources. Hence it is necessary to specify the relationship between the underground water resources and rivers for the underground water resources management, such as choosing the appropriate points for making drinking water well, controlling the amount of river water and any groundwater monitoring, because the relationship between these two, is among the components of the water cycle, and the study of water cycle is a basic and important task.

There are various methods to recognize the relationship between groundwater and surface water, including isotope study (Martinez *et al*., 2015), geochemical study (Musgrove *et al*., 2010), to analyze the relationship of heat riverbed (Conant, 2004) and quantitative study (Hunt *et al*. 2006). In this study, we tried to analyze this relationship through a quantitative method.

Materials and methods

The Isfahan city is located in the central of Iran. A map of the study area with a surface of 100 square kilometres is given in the figure below (Figure 1). This range includes an unconfined aquifer that its slope is from the South to the North and West to East. Detailed study of the direction of recharge and its source is very important because Isfahan city is located on this aquifer which yields the water for different consumptions in this city and its countryside.

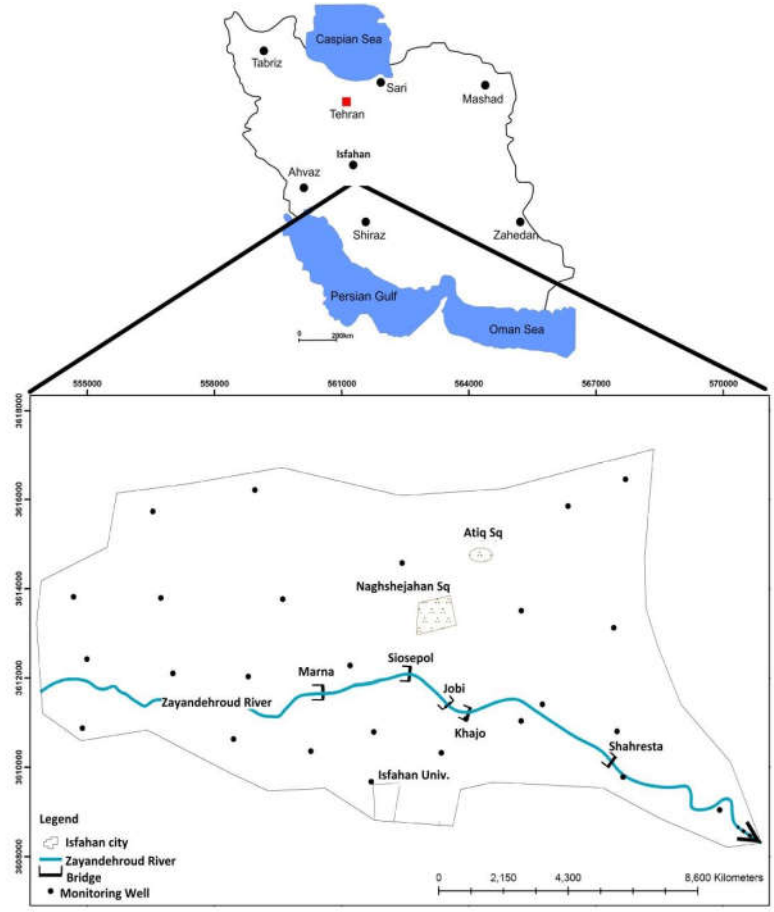

Figure 1. study area and the location of observation holes in Isfahan city

The elevation of Isfahan is about 1570 meters above sea level and its annual rainfall is about 119 mm. Zayandehroud River enters in the west area of the city, with water level of height around 1587 meters and exits in the East of Isfahan with water level of height 1560 meters.

Results

For the initial study, river hydrometric data was analyzed. Thereafter, those data related to the long periods of dry river and those related to the period of to the wet days of river, after dry river, were selected. In the time of gathering the data, (November and December 1394), the water table in the 26 selected observation wells were considered and the is potential map were drawn manually. Using the Arc GIS software, the contours have been corrected and the groundwater flow lines drawn. These is potential maps are as follows. Figure 2, corresponds to the map of water table in November, 2015, that in this period, the river was dry for about 5 months. Figure 3, corresponds to the underground water level in December, 2015, that the water has flowed in the river in this month.

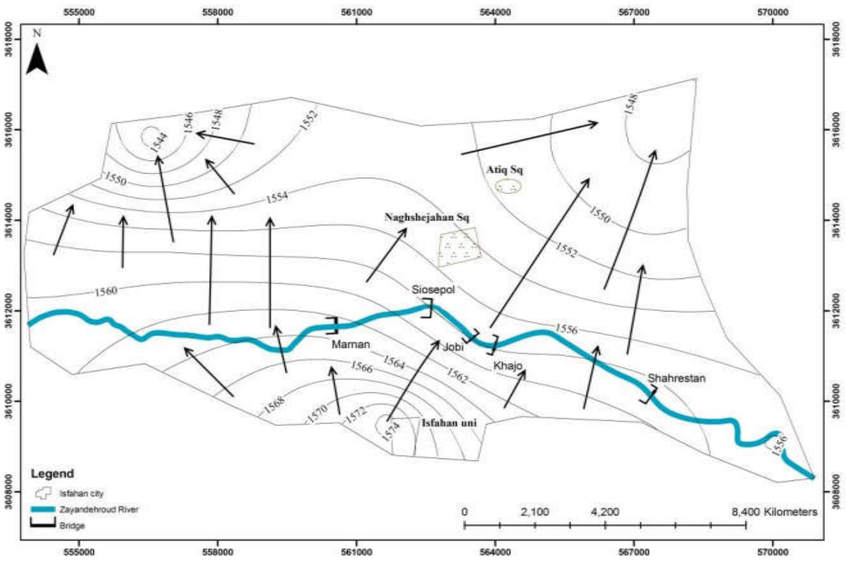

Figure 2. Is potential map of Isfahan aquifer in November 2015

According to Figure 2, the direction of groundwater flow matches with the direction of bedrock topography (South to North). When there is no water in the river, the river plays no role on Isfahan aquifer. It is because the river bed-line level is higher than level of water table and also the river is dry. In this case, the recharge point almost is relevant to southern part of Isfahan and the discharging point is related to the north western and north eastern parts of the city. In the case of recharge from the south of the city towards the north, according to the little thickness of alluvial deposits on Jurassic shale bedrock (i.e. impermeable rock unit) and the lack of effective rainfall in this region, it may be argued that the existence recharge is related to the returned water from irrigated green spaces. As can be seen from the Figure 2, there are two distinctive discharge zones in the north-east and north-west of the city. The main reason for creating the mentioned discharging zones is heavy pumping in both mentioned regions. According to the thickness and the rate of pumping thought the aquifer, low hydraulic gradient in the north-east is related to the low groundwater flowrate in this area. However, high hydraulic gradient in the north-west is concerned to the heavy pumping over there. It is noteworthy to mention that in the eastern region of the city, from the Shahrestan Bridge to the downstream, the river includes perennial flow. Such a flow is originated from the wastewater created in treatment plant of the Isfahan city. Therefore, in this part of the river, the Isfahan aquifer is recharged by the river.

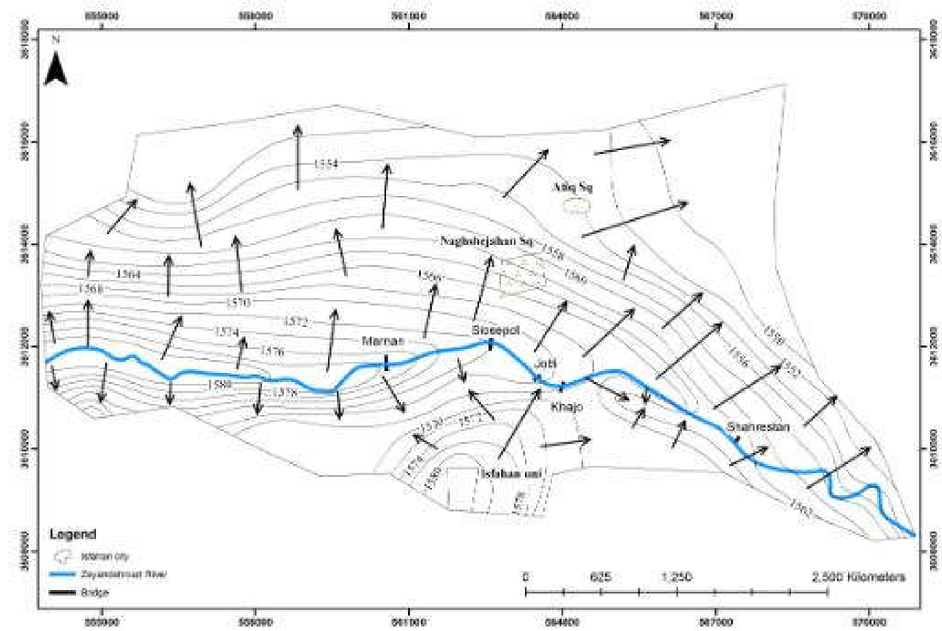

Figure 3. Isopotential map of Isfahan aquifer in December 2015

Figure 3 shows that the isopotential map of Isfahan aquifer in December 2015 which water flows in the river after five Months waterless period. Having comparison between figures 2 and 3, it may be concluded that the pattern of groundwater contour lines and flow direction show considerable discrepancies in two deferent water regimes of the river. As can be seen from the Figure 3, in the river wet period, the river recharges Isfahan aquifer in both sides, from upstream to Shahrestan Bridge area. After Shahrestan Bridge the recharging behavior of the river is the same as dry period. In some locations in the southern portion of the Isfahan aquifer, the cones of depressions have been formed due to heavy pumping for municipality consumptions. Such that these regions are recharged from south and north directions by normal groundwater flow of the aquifer and Zayandehroud River, respectively. From the Shahrestan Bridge to the downstream, the river recharges the Isfahan aquifer from north side of the river only. This is because there is no aquifer in the south of the river. In fact, there is an outcrop of the Jurassic Shale rocks in the south of the river in this part of the city.

Discussion

In order to assess the values of aquifer recharge in Isfahan city, first of all, the values of aquifer transmissivity have to be determined. For this purpose, the values of hydraulic conductivities around the river have been assessed using the data from pumping tests and boreholes drilling logs. Thereafter, having the aquifer thickness for two periods (i.e. river waterless and river wet periods) and multiplying by values of hydraulic conductivities, the values of aquifer transmissivities around the Zayandehroud River have been calculated. Figures 4 show the different selected zone of aquifer transmissivities for river waterless and river wet periods.

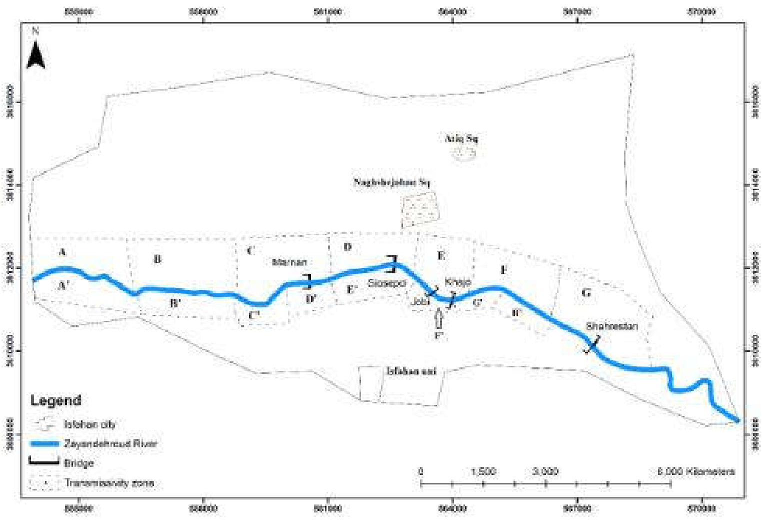

Figure 4. Zonation of aquifer transmissivity around the Zayandehroud River

The values of hydraulic gradients of groundwater flow in Isfahan aquifer can be computed using equipotential maps of Isfahan aquifer (Figures 2 and 3). Since the values of hydraulic gradients and also aquifer transmissivities are not the same around the river, computations of aquifer flowrates have been carried out for different segment of aquifer around the river. For this purpose, below equation have been used (Lohman, 1972)

$$T = \frac{2Q}{(L_1 + L_2)\Delta h / \Delta r}$$

Where L_1 and L_2 are the lengths of any two concentric closed contours, Δh is the contour interval, and Δr is the average distance between the two closed contours. Table 1 illustrates the values of various parameter required for computing the flowrates in the aquifer.

Table 1. the values of various parameters required for computing the flowrates in the aquifer

		River wet period				River waterless period			
	Segment	T (m^2/d)	L (m)	Δr	Q (m^3/d)	T (m^2/d)	L (m)	Δr	Q (m^3/d)
North side of river	A	420	2458.5	609.5	10342.5	280	2305	1006	1186.5
	B	380	2652.5	817	10698.9	250	2572	751.5	1844.3
	C	360	2296	588.5	5066.4	240	2302.5	634.5	1693.7
	D	300	2191.5	320	4217.8	200	2506.5	653.5	1646.6
	E	150	1451.5	452.5	1032.6	120	1587.5	897.5	418.1
	F	80	2476	221	1805.1	70	2102.5	822.5	337.2
	G	50	3166.5	539.5	520.5	50	2411	935	229.9
South side of river	A'	250	2446	184.5	7170.9			Sum =7356m^3/day	
	B'	210	2538.5	135.5	8548.2				
	C'	240	1211.5	214	5603.1				
	D'	250	1184	151	3722.2				
	E'	160	1986.5	262.5	2557.1				
	F'	120	1437.5	385.5	779.8				
	G'	50	756	344	227.3				
	H'	10	1149.5	253	92.1				
				Sum = 42384 m^3/day					

As can be seen from the Table 1, the total aquifer flow rate during the River waterless and River wet periods is 7356 and 62384 m^3/d, respectively. The difference between flowrate for mentioned periods (i.e. River water less and River wet periods) is the role of Zayandehroud River in recharging the Isfahan aquifer which equals 55028 m^3/d.

Conclusions

In this Study, using the hydrometric data of water table, connection and mutual effect between Zayandehroud River and the underground water were studied. Hydrometric measurements from the whole Isfahan city and measurement of the level of underground water over a range of 90 km^2 around the River were address. The basic findings include the following results.

If the River is dry for 5 continuous months, the relationship between the River and the underground water table will be disconnected completely in such a way that the River is not play the role of recharging of the underground water and not draining of it. However, with flowing water in the River, sensible underground water recharging occurs by the River, in Isfahan city, from the entrance of the River into city to nearly Shahrestan Bridge. After Shahrestan Bridge the recharging behavior of the River is the same as dry period.

The difference between the level of underground water when the River has been dry and when the water flows in the River, in the western part is about 18 to 20 meters and less than 1 m in the East. The low difference between the water levels in the east is because of sewage current in the east, during the dry period.

In an area around Si-O-Se Pole Bridge and Khajo Bridge in the south of the River some cones drop was formed which is recharged from two sides (North and South). This drastic high drop is because of water discharge for urban uses by municipal wells. According to the study, total aquifer flow rate during the River water less and River wet periods is 7356 and 62384 m^3/d, respectively. Then, 55028 m3/d of this flow rate is about the amount of River recharging rate. This amount of recharge water from river to the aquifer, is the main water demand that necessary supply for Zayandehroud river to stay wet and this situation is important because the river is must importance source of recharge aquifer and connection between this two source is in wet river situation.

These results represent a strong and effective relationship between groundwater and the Zayandehroud River, which more emphasis on the role of recharging by the River to the groundwater, and wet period of the River play a significant role on the aquifer of Isfahan city.

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