Examining Issues of Groundwater Resources Exploitation in Malayer plain, Iran

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Abstract. In this study, depth of phreatic zone of Malayer plain, which is the third largest plain of the province, has been investigated. The drainage basin of Malayer water, covering an area of 2965 km², is located 80 km south of Hamadan. For this study, performance records of 43 existing wells were monitored over a period of 17 years (1994-2011). Data obtained were subjected to statistical analysis. The aquifer level hydrograph and equipotential maps were drawn in AutoCAD environment. The results of this study are indicative of the estimation of a 20.20 meter total dip and a 415.96 million-cubic-meter reservoir volume shortage in the 17 year period, caused by uncontrolled exploitations. In the water year of 1998-1999 the dip amount has reached 3.72 meters which is equivalent to more than one sixth of the total dip. The largest dip between years 1999-2010 with 39 meters was in Aznaw village and the smallest dip in the same period of time with 1.08 meters was in Farvaz village. From the elements of dropping the phreatic surface, precipitation decrease and waiving the maximum exploitation limits through under-exploitation wells could be mentioned.

Keywords: Ground water, Water Resources, plain, Malayer

1. INTRODUCTION

On the whole, the amount of today's exploitable water per capita is less than the half of that of 50 years ago. Such a decrease in water extraction and supply naturally calls risks for industrial development and supplying required food and water resources for the population. No country has faced a disastrous situation for supplying water in the past 50 years, while today 35 percent of the population of the world is living in such a situation. If no sufficient storage is provided for the disastrous level of water shortage up until 2025, the whole world will be subjected to a really serious shortage (Seifi, 2008).

Kamandani (2005) has observed that according to the country's water reservoirs budget in the water-year of 1379-80 the volume shortage of groundwater storage across the country was 7.009 billion cubic meters, counting for one percent of the whole world’s reservoirs volume shortage. In Hamadan province, the sum total volume of the water used in different sections is 2944.3 million cubic meters, 79.5% of which (i.e. 2340 million cubic meters) is provided from groundwater and 92% of the total exploited water volume is used in the farming section, decreasing to 67.8 percent during development programs and, in turn, increasing the proportion of surface waters. Dips in the phreatic surface of groundwater reservoirs result in several devastatingly qualitative and quantitative damages.

Jafari and Rezvani (2001) have pointed out a number of the significant aftermaths of overexploitations including phreatic surface drop, land subsidence in some regions like Kordabad district in Hamadan, the dryness of legally under-exploitation wells, the spoilage of investments, the economic losses of farmers and in turn increase in unemployment and migration. Investigation the phreatic surface dips in every district, their generative elements get unraveled and therefore proper solutions to them would be considerable.

Meibodi (2003) reported the total drainage volume of the country's groundwater reservoirs by farming, industry and urban usage sections 69.5 billion cubic meters. He concluded that the discharge volume was about 5 billion cubic meters more than the recharge volume of the sustainable groundwater reservoirs. He stated the number of reservoirs as 433 thousand wells, 33 thousand Qanats, and 498 thousand springs in the 6 main drainage basins of the country. He reported the negative complications of the excessive exploitation of groundwater storages and dips in the phreatic surface as increases in water extraction costs, decreases in the permitted watering of neighboring
water resources, advances of salt water fronts and changes in their quality, decreases in the underground reservoirs volume, replacement of farmlands with deserted lands, and the evacuation of rural regions and pervasive migration to big cities. He knew the cause of phreatic surface dips, the negative budget in 202 critical and prohibited plains of the country and the lack of cultural programs concerning optimized uses of water in the agriculture section.

Rahimi and Khaleedi (2000) investigated three different water stress indicators of Falkenmark indicator, United Nations Sustainable Development Commission's indicator, and International Water Management Institute's indicator, decided Iran's annual water per capita equivalent to 1946 cubic meters. Given that and according to Falkenmark index, Iran is presently considered among countries without or with little problems in this regard while with the rise of population in the future is supposed to place among countries suffering from water stresses.

However, according to United Nations Sustainable Development Commission's indicator Iran has been classified among the countries with extremely serious water shortages because, it is already using 68 percent of its annul exploitable water resources whereas the utmost amount of this indicator is supposed to be 40 percent. According to International Water Management Institute's indicator also, like that of United Nations, Iran is placed among the countries suffering from serious water stress.

Bahramlou (1998) presented a mathematical model for deciding the riparian area of wells by means of point-source pollutions, assumed the well riparian area composed of riparian in terms of negative effects on watering and riparian in terms of pollution and showed that one of the consequences of rises in exorbitant exploitations and drilling illegal wells without attention to the riparian area would be the faster transmission of chemical and microbiologic substances from the location of point-source pollutions like garbage dumps or wastewater wells into exploitation wells.

Bahramlou and Rezvani (2002) indicated the reasons for the striking drop of phreatic surface in Qahavand plain in Hamadan province including overexploitation above the permitted standards, intrusion to the wells riparian zone, the existence of illegal wells and the lack of proper supervision and legal reaction from related authorities to the violators and they recounted the consequences of which as the concentration increase of water salts, legal wells drying up, economic and social losses to farmers and industrial units, migration, and unemployment rise. They recommended a number of solutions to this phenomenon like careful supervision over the observance of limits and resources riparian, prevention of drilling illegal wells and closing them, strict legal reaction to offenders, and artificial feeding of critical plains.

Bahramlou and colleagues (2004) assumed the decline in levels of water table a natural disaster in which human playing a central role by overexploitation and intrusion to the groundwater reservoirs riparian zones. They suggested the only ways of preventing it the observance of scientific riparian zones, careful supervision over permitted exploitations, and the application of punishments defined in the law of just water distribution about violators.

Martinelli and Carminati (2002) studied about land subsidence in the eastern area of central Po plain in the north of Italy, embedding 30% of the Italian population are resides in this plain, due to the decline of groundwater level, an annual subsidence of 0.7 centimeters has been reported.

The aim of the study was to examine issues of groundwater resources exploitation in Malayer plain, Iran.

2. MATERIALS AND METHODS

Malayer Township is located at 48'49' and 34'17' geographical longitude and latitude respectively, 80 km south of Hamadan. Malayer Plain lies on the southern foothills of mountain Alvand and Malayer's drainage basin is considered, in terms of water resources management, one of the areas of study of the domain of Karkhe River with an area of 2965 square kilometers. For this project the statistics of existing monitoring wells (43 wells) were investigated for a period of 17 years (1994-2011) (Hamadan Regional Water Co.). This period of time was used only due to the completeness of its present statistics because; the statistics of the water years earlier to 1994 could not be used in this study due to their incompleteness and therefore their unreliability. Having arranged the statistics, first, in order to expand the measured values to the regional scale the Thiessen equation was used and then the aquifer stage hydrograph and equipotential maps were drawn for the 17-year time base in AutoCAD environment.

The aquifer hydrograph is drawn in order to catch an overall understanding of the groundwater level changes. Given that the existing piezometric wells cannot cover the whole aquifer surface, a specific surface is determined for each well by means of Thiessen equation, according to the location and the congestion of neighboring wells. These surfaces should be so that the sum total of whose areas equals to the whole aquifer surface area.

Equation1: \[ A = \sum a_i \]
In this equation $a_i$ is the area of $ith$ polygon and $A$ is the area of aquifer surface.

For example, the Thiessen area of Azandarian's piezometer is 15.26 square kilometers and that of Kandehlan's piezometer is 8.56 square kilometers. The sum total of which is equivalent to 519.43 square kilometers or the total area of the aquifer surface. Drawing hydrograph on the basis of the Thiessen model is some kinds of weighted averaging therein the dedicated weight to each piezometer is equivalent to the division of the obtained surface through the Thiessen method by the total area of the aquifer.

Equation 2: $W_i = \frac{a_i}{A}$

This measure equals 0.029 for Azandarian's piezometer and 0.016 for Kandehlan's piezometer, etc... and for obtaining the numeric value of the aquifer hydrograph the obtained weight from equation 2 ($W_i$) should be multiplied by each well's groundwater level in different months ($h_{ij}$) and then all the resulting products be added equal $j$s, the result of which will be the aquifer groundwater level in the $j$th month according to equation 3.

Equation 3: Head of Pizometric $= \sum (h_{ij} \cdot W_i)$

The result of this equation for Azandarian's piezometer in October 1389 gets 50.37 and for Kandehlan's piezometer well in October 1389 gets 29.18, etc. The sum total of which will represent the piezometric elevation of Malayer plain's aquifer.

Head of Pizometric $= \sum (h_{ij} \cdot W_i) = 1669.243$

By drawing a diagram with x and y axes representing year months and groundwater stage respectively, the aquifer hydrograph will be drawn.

3. RESULTS AND DISCUSSION

3.1. Investigation of the map of the ground's natural level lines in Malayer Plain

The highest land in terms of natural level elevation from free waters with an altitude of 1804.75 meters belongs to Kandehlan village and the lowest natural level with an altitude of almost 1645 meters goes to Babakamal, Meykharan, and Jaria villages. The difference between the highest and the lowest natural levels of land is 159.75 meters that is indicative of a high hydraulic gradient in Malayer plain.

![Fig. 1: Land's natural level lines](image)

3.2. Investigation of the minimum isopiestic map

According to the drawn minimum isopiestic (Fig. 2), the groundwater level has reached it’s the lowest amount during the October of 2010 water year and it is obvious that the groundwater flow generally follows the region's topography. There are three general groundwater fronts in the region: first is flowing from the southeast of the plain to the west, the second from the north to the south, and the third from the west to the south, all three of which finally getting together and leaving the plain in the southwest. However, in the above map, due to the recent droughts and overexploitations of groundwater resources by deep wells around villages such as Hosein Abad Shamloo, Pir-Gheib, Ghale Aghabeig and also Jaria, Meykharan, Kahriz, Mehdi Abad, and Jade Dehno, the groundwater flow has got fuzzy and
lost its natural direction so that it shifts towards high exploited areas in these regions and, it is seen that, may even flow against the natural direction. The first front starts from the level line of 1770 and goes on steeply to the level line of 1640 in the direction of the land slope, the second front beginning from the level line of 1760 goes on with a relatively steep slope to the level of 1640 in the direction of the land slope, and also the third front starts from the level line of 1690 and with a milder slope continues to the level line of 1640 in the direction of the land slope, but at the point of the second and the third fronts intersection, around the villages of Hossein Abad, Pir-Gheib, and Ghale Agha Beigh, the flow direction has strayed into high-exploitation points instead of flowing south. Exactly the same condition is also seen at the exit of the front around villages Jaria and Meykharan with a level line of 1630. In Kahriz, Mehdi Abad, and Jade Dehno villages, the redirection of flow is caused by unconscionable dips in and overexploitation of groundwater reservoirs that result in the inversion of the flow direction and the closure of the 1640 curve. In villages Kahriz and Pir-Mishan and some parts of Nakil Abad and Jade Dehno the redirection of flow is caused by intense drops in groundwater reservoirs and their exorbitant exploitation resulting in the inversion of flow direction and the closure of curves.

3.3. Investigation of the maximum isopiestic map

According to the drawn maximum isopiestic (Fig. 3) in the aquifer territory in the April of 2010 water years, the groundwater flow is seen to generally follow the topography of the region. There are three general fronts of groundwater flow in the region: the first front flowing from the southeast of the plain to the west, the second flowing from the north to the south, and the third one flowing from the west to the south, all of which ultimately joining together and leaving the plain from the southwest. In this map too, similar to minimum isopiestic map, because of drought and the overexploitation of groundwater resources by means of deep wells around the villages of Hossein Abad Shamloo, Pir-Gheib, Kahriz, Pir-Mishan, Nakil Abad, and Jade Dehno, the direction of groundwater flow gets fuzzy and unnaturally strays to overexploited regions and is also seen to flow in the opposite direction. The first front begins from the level line of 1780 and ranges to the level line of 1660 with a relatively steep slope in the direction of the land slope, the second front also begins with the 1760 level line and continues to the 1660 level line with a relatively steep slope in the direction of the land slope, and the third one beginning from the level line of 1690 continues with a milder slope to the 1640 level line in the direction of the land slope. In Hossein Abad and Pir-Gheib villages the direction of the flow, instead of south, strays to overexploited points.
Investigation of the groundwater isopleth map ($\Delta H$)

In order to investigate the long term dips of groundwater level in Malayer plain, the isoleths map ($\Delta H$) of the water level of the April of 2000 in relation to the corresponding month in 2011 was provided that can be viewed in fig. 4. According to the provided groundwater isopleths fig, in year 2011 the depth of encounter with groundwater has risen from 23.9 meters to 62 meters (a 39 meter drop) in the rural regions of Aznav and also from 42.7 meters to 79.5 meters (a 36.8 meter drop) in Azandarian-Jokar region, which is the biggest drop after that of Aznav. The smallest drop with 1.08 meters belongs to Farvaz village. Villages Jourab, Baba Kamal, and Seyed-Shahab have also had a drop of nearly 2 meters. The average dip in other regions of the plain is also between 10 and 20 meters. The amounts of occurred drops are indicative of the destructive effects of the congestion of wells and the overexploitation of groundwater reservoirs beside the losses of recent droughts.

Investigation of the groundwater level fluctuations and the unit hydrograph of the plain

The defining hydrograph of the plain from 1994 to 2011 has been drawn according to the results of the monthly measurements of the 43 monitoring wells (Fig 5). This diagram shows that the groundwater dips of Malayer plain begin from the October of 1997 and continue with a relatively steep slope. In the 17-year period of time, the groundwater reservoir has undergone a 20.02 meter drop, which means an average dip of 1.18 meters per year. In the recent years, steeper increases have been seen in the drop amount, specifically in the water year of 1998-1999 that has reached 3.72 meters, accountings for almost one sixth of the total drop. The causes of such a sudden drop have been drought and the overexploitation of the groundwater resources of the plain that are indicative of the high frailty of the plain's groundwater aquifers during dry years. Given the extension of the underground aquifer (519.43 square kilometers), the 20.02 meter drop, and an average storage coefficient of 4 percent, the volume decrease of the groundwater reservoir of Malayer plain is estimated 415.96 million cubic meters in the last 17 years and given the average annual dip of 1.18 meters, the average annual decrease of the reservoir volume is estimated around 24.46 million cubic meters. In the 2010-2011 water year, the water dip amount and the corresponding reservoirs volume shortage have been estimated 1.16 meters and 24.1 million cubic meters, respectively.
3.6. Precipitations Direct Permeation ($Q_p$)

Direct permeation stands for the amount of rain that falls directly over the plain. The rain gauge stations of Pihan, Namileh, and Khei Abad are placed in the balance territory. According to the reported data from the 17-year rain statistics of Pihan and Namileh stations and the 25-year statistics of Khei Abad station, the annual average precipitation of the whole plain is 315 millimeters per year that taking account of the 20 percent permeation, the annual fed water volume works out 23.76 million cubic meters in the balance territory. For the water year 2010-2011, the average precipitation of the three stations has been 317 millimeters that taking the 20 percent permeation into account, the feeding volume is estimated about 32.93 million cubic meters.
3.7. Surface Flows Permeation

According to the hydrometric stations of Vasaj, Peyhan, Doroudgaran, and Marvil, the volume of the stream entering the plain territory is 555.3 million cubic meters that taking account of the 10 percent permeation, the volume of the feeding stream of this factor is estimated 55.53 million cubic meters.

3.8. Framing Returning Water (Qₚ)

The total volume of the water provided for agriculture by deep wells, semi-deep wells, springs, Qanats, etc... In the balance territory is estimated equivalent to 222 million cubic meters. The volume of the returning water to the aquifer, given the region's soil pattern, the type of vegetation, and the type of watering that is mostly ancient, is calculated 20 percent of the used water, the corresponding number of which is estimated equivalent to 44.4 million cubic meters per year.

3.9. Permeation through Artificial Feeding (Qₐm)

There is no artificial feeding carried out in the plain currently.

3.10. Drinking and Industrial Returning Water (Qsw)

In the under-study territory, the volume of the water provided for drinking and industrial purposes through surface and underground streams is 24.6 million cubic meters and, given the capacity of the sanitation system, the returning water to the groundwater aquifer is set at 65 percent therefore, the volume of the water that is fed by this factor is estimated equivalent to 16 million cubic meters on aggregate.

3.11. Groundwater Inflows (Qin)

One of the most important parameters of feeding plains aquifers in different balance territories are groundwater inflows that enter the water into aquifers through flow sections with specific gradients and transmissibility. The volume of the inflows in every section is as below by using groundwater level map, transmissibility map, and measuring their front length and hydraulic gradient using the Darcy equation:

\[ q_{in} = T.L.\left(\frac{dh}{dx}\right) \]

The balance territory has been specified through flow and isopiestic lines on the groundwater level map. There exist 39 inflow sections on the map and according to our calculations the total underground inflow aggregates 39.55 million cubic meters per year.

Drainage Factors

3.12 Aquifer exploitation (wells) (Qex)

In the balance territory, given the water resources map, the drainage volume from groundwater reservoirs through deep and semi-deep wells is equivalent to 207.59 million cubic meters.

3.13. Groundwater outflows (Qout)

According to the drawn map, there is only one underground exit pathway for the plain's aquifer which is placed in the Babakamal village zone. With a section length of 16980 meters, a hydraulic gradient of 4.59, and a transmissibility coefficient of 200 square meters per day, consequently, the amount of the plain's groundwater outflow is equivalent to 5.69 million cubic meters per year.

Other parameters like evaporation (Qₑ) and drainage from groundwater aquifer (Qd) do not practically exist due to the groundwater level drops in the recent years. Table 1 and Table 2 show the specifications of Malayer plain's outflow front and Malayer plain's groundwater balance using recharge and discharge elements, respectively.

Table 1: The specifications of Malayer plain's outflow front

<table>
<thead>
<tr>
<th>Segment</th>
<th>Length (m)</th>
<th>T (m²/day)</th>
<th>Hydraulic Gradient</th>
<th>Volume of Output stream (M.C.M)</th>
<th>Volume of Output stream (M³ in year)</th>
<th>Period of balance (day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16980</td>
<td>200</td>
<td>4.59</td>
<td>5.69</td>
<td>5691164</td>
<td>365</td>
</tr>
</tbody>
</table>

3.14. Storage volume changes (±ΔV)

Comparing the aquifer's total annual recharge and discharge factors in the balance territory as well as investigating the results of the groundwater unit hydrograph, it is revealed that the aquifer of the under-study territory is subject to groundwater level drops.

According to the plain's unit hydrograph, the dip concerning the water year of 2010-2011 has been estimated 1.16 meters (Δh) and according to the extension amount of the groundwater aquifer (519.43
square kilometers) and the aquifer's average storage coefficient of 4 percent, the corresponding volume shortage of the reservoirs has been estimated equivalent to 24.1 million cubic meters. According to the calculations made through the balance equation, the volume shortage of the calculated storage is equivalent to 24.87 million cubic meters, which is in accord with the number produced by hydrograph.

### Table 2: Malayer plain's groundwater balance using recharge and discharge elements

<table>
<thead>
<tr>
<th>Precipitations</th>
<th>Surface flows</th>
<th>Farming returning water</th>
<th>Permeation through artificial feeding</th>
<th>Drinkable and industrial returning water</th>
<th>Groundwater Inflow</th>
<th>Aquifer exploitation (wells)</th>
<th>Groundwater outflow</th>
<th>Total discharge in million cubic meters</th>
<th>Storage volume changes</th>
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<tr>
<td>Precipitations direct permeation</td>
<td>Surface flows permeation</td>
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<td>Permeation through artificial feeding</td>
<td>Drinkable and industrial returning water</td>
<td>Groundwater Inflow</td>
<td>Aquifer exploitation (wells)</td>
<td>Groundwater outflow</td>
<td>Total discharge in million cubic meters</td>
<td>Storage volume changes</td>
</tr>
<tr>
<td>32.93</td>
<td>55.53</td>
<td>44.4</td>
<td>0.00</td>
<td>16</td>
<td>39.55</td>
<td>188.41</td>
<td>207.59</td>
<td>5.69</td>
<td>213.28</td>
</tr>
</tbody>
</table>

4. CONCLUSION AND SUMMARY

Investigating the factors and causes playing role in the phreatic surface dips of Malayer plain, the following conclusions could be derived.

1. Malayer plain is the third biggest plain of the province and one of the plains that has suffered considerable dips in the recent years.

2. Surveying the statistics of water resources and groundwater drainage volume reveals that from 1986 to 1995 the number of semi-deep wells, Qanats, and springs and the drainage amounts by these factors have been increased and from 1995 to 2004 the number of these factors and their depletion have decreased and several springs and Qanats have dried up, but during these years deep wells have always experienced increase in number that is suggestive of the groundwater surface dip of the under-study plain, which is in accord with Jafari & Rezvani's 2001 study.

3. The difference between the highest and the lowest ground natural levels is 159.75 meters that is indicative of high hydraulic gradient in Malayer plain.

4. According to the minimum isopiestic map, around villages Hossein Abad, Pir-Gheib, and Ghale Agha Beig the direction of flow has strayed to overexploited regions instead of flowing south. Exactly the same condition is seen at the exit of the front in the vicinity of villages Jaria and Meyjaran with a level line of 1630. In the villages of Kahriz, Mehdı Abad, and Jade Dehno, flow deviation is caused by severe dips and the overexploitations of groundwater reservoirs that have resulted in the inversion of the flow direction and the closure of 1640 curve.

5. Like minimum isopiestic map, maximum isopiestic map is also indicative of the fact that due to drought and the overexploitation of groundwater reservoirs by deep wells in the area of villages Hossein Abad Shamloo, Pir-Gheib, Kahriz, Pir-Mishan, Nakil Abad, and Jade Dehno, the direction of groundwater flow has got disordered, losing its natural condition in these areas, and has strayed into overexploited regions flowing in the opposite direction, while in this map nothing is seen at the exit of the front.

6. The largest drop between years 1999 and 2011 with 39 meters belongs to Aznав village while the smallest one in the same period of time with only 1.08 meters goes to Farvaz village. Jurab, Baba Kamal, and Seyed Shahab villages have had dips of about 2 meters. The average dip of the other areas of the plain is also between 10 and 20 meters. These amounts of drops are suggestive of the destructive consequences of wells congestion and the overexploitation of groundwater reservoirs beside the effects of recent droughts.

7. Investigating the map of minimum and maximum contact with groundwater surface (isopleth), in the water year of 2010-2011, the maximum depth of contact with groundwater in the northern margin of the plain, in Azandarian-Jokar region, has been about 80 meters and the minimum contact with groundwater in the center and the southeast of the plain, around villages Eskanan and Farvaz, has been monitored about 8 meters, while this amount had been 5 meters for Eskanan village in the 1997-1998 water year.

8. The defining hydrograph of the plain in indicative of a total 20.02 meter dip in the plain in the period of 17 years, meaning an average dip of 1.18 meters for each year.

9. In the water year 1998-1999, the dip has reached 3.72 meters that accounts for over one sixth of the total dip. The reasons for this abrupt dip have been drought and the overexploitation of the groundwater reservoirs that is suggestive of the fact that the plain's underground aquifer is very fragile during dry years.

10. The volume decrease of Malayer plain's groundwater storage in the recent 17-year period (1994-2011) is estimated equivalent to 415.96 million cubic meters and the annual average decrease, taking account of the annual average dip of 1.18 meters, equivalent to 24.46 million cubic meters.
11. According to the plain's unit hydrograph, the dip concerning the water year of 2010-2011 has been estimated 1.16 meters ($\Delta h$) and according to the extension amount of the groundwater aquifer (519.43 square kilometers) and the aquifer's average storage coefficient of 4 percent, the corresponding volume shortage of the reservoirs has been estimated equivalent to 24.1 million cubic meters. According to the calculations made through the balance equation, the volume shortage of the calculated storage is equivalent to 24.87 million cubic meters, which is in accord with the number produced by hydrograph.

12. According to investigations, the main reason for phreatic surface dip is demonstrated to be the overexploitation of groundwater reservoirs.

Comparing the results of this study with those of other studies done by Rahimi and Khaledi in 2000, Jafari and Rezvani in 2001, Meibodi in 2003, Bahramlou et al. in 2004, Kamandi in 2005, Matrini and Karminati in 2002, the suggested hypotheses are demonstrated and it can be said that of course one of the important factors in phreatic surface dips is the overexploitation of groundwater that has to be accorded more, as the coincidence of the results says.

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