Hydrogeochemical properties and the exhaustion groundwater reserve from Dammam aquifer at Al-Najaf Governorate, middle Iraq

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Abstract

One of Iraq's most significant groundwater-bearing limestone aquifers is the Dammam Formation. The aquifer groundwater has been studied hydrogeochemically. It is suitable for irrigation, as indicated by sodium adsorption ratio (SAR) and total dissolved solids (TDS), which are 4.15 and 1971 ppm (in average) respectively. Through the vision of the Stiff diagram, the predominant ions are Cl-, SO42- and Na+ while the HCO3- and Mg2+ are relatively poor. There is plenty of flowing wells in the study area in Najaf Governorate producing groundwater from the Dammam aquifer. In recent years, many wells have been drilled in an irregular pattern for forming fish breeding lakes. These lakes' water drains 4.715 m³/s into the Najaf depression by Wadi Al-Khur and artificial channels, where it mixes with brine water, rendering it useless. This lead to the exhaustion huge amount of precious groundwater resource. Many signs that confirm the Piezometric pressure drop and groundwater levels descent in the Dammam aquifer in the region. The groundwater flow has been halted in several flowing wells in the study area especially in Wadi Al-Khur due to the exhaustion of the reserve and a decrease in the level of the hydrostatic pressure of the aquifer. A significant decline in values transmissivity and specific capacity of the Dammam aquifer when compared with previous studies in the years 1996 and...
2009. Through observation of the monitoring well (W/7), a decrease in groundwater levels of flowing wells in the study area.

**Keywords:** groundwater, Dammam, Al-Najaf, fish breeding, exhaustion.

1. **Introduction**

Groundwater is any water, which confined beneath the surface of the earth in aquifers. It spreads over a wide territory in numerous places [1]. It may be near the Earth's surface or as deep as 1000 m, according to the U.S. Geological Survey (USGS). This water is not always accessible or may not be fresh enough for human activities without treatments and it is sometimes difficult to locate, identify and describe it as an aquifer. The dissolution of gypsum, calcite, dolomite, halite as well as silicate weathering control the hydrochemistry of groundwater, which is represented by the ionic exchange between groundwater and clay minerals [2]. The Bahr Al-Najaf province is characterized by its possession of a huge and unique basin of groundwater with good physical, chemical, and biological properties. The Dammam Formation (Middle Eocene), which consisting of limestone, which its character by an especial of secondary porosity with secondary porosity is represented as the major aquifer in the province. It is characterized by the presence of the many caves and connected channels that help to transference groundwater at a good speed in addition to the presence of rooms and very large gaps [3].

The presence of faults and fractures in the water-bearing rocks in the Dammam Formation, especially in the province of Bahr Al-Najaf, has added an exceptional and unique advantage in the transporting process of groundwater and increasing the flowing wells drainage in the region. The scarcity and deficiency of surface water resources, which are limited to a very narrow zone, in Bahr Al-Najaf province, because of a desert nature. The groundwater extraction and investment have been resorted to in several areas such as its use in the field of agriculture and industry, such brick factories, domestic uses, drinking water for human various animals.

The study area is located in the middle of Iraq at Al-Najaf Governorate in the west southwest of Al-Najaf city. It is restricted between coordinates longitude 43°55'51.88" E-
44°23'7.33" E and latitude 31°43'37.12" N- 32°06'4.12" N with a coverage area of about 1720 km² (Fig. 1).

Fig. 1: Location map showing the location and features of the study area

2. **Geological framework of the area**

Geomorphological, the presence of some prominent reliefs, which height of the land in it ranges between 8 and 65 m above sea level approximately, is characterized the study area. The height of the Najaf lands increases in the direction of the western reaches 420 meters above sea level at the Iraqi-Saudi frontier. The land slopes gradually from the west and southwest towards the north and northeast [4]. Some of the marsh depressions are located in the eastern part of the study area, which is adjacent to Tare Al-Najaf. It is located on the eastern side of the study area, which represents the lowest point for collecting water from its various and varied sources. Generally, some valleys that drain rainwater are present in the study area from the west and southwest to the eastern and northeastern directions. Their water drained in the marshes of the Bahr Al-Najaf region, which coincides with the direction of the slope of the topography of the land such as Wadi Al-Khur, Wadi Haussab, Al-Rhimawi, Milih, and Abo Kumssat Valleys [5].
Geologically, the study area is located within the Al-Salman subzone boundaries, which is a part of the Stable Shelf Zone [6]. Two huge deep faults trending NW-SE, which extend in the study area, played an important role in controlling the movement of groundwater [7]. The existence of the springs is considered good evidence of the presence of these deep faults [8].

Stratigraphically, the formations of the region, which belong to the tertiary period. They started from the surface downward Euphrates, Dammam, Rus and Umm Er Radhuma formations that is covered by Quaternary deposits in major places [9] (Fig. 2).

Fig. 2: Formations sequence at the study area (drew by coral 19 program)
The rock component of these formations forms most layers that carrying and affecting on the groundwater chemistry, which has hydraulic characteristics that distinguish them from each other in their ability to store, transport and discharge this groundwater.

1. The Euphrates Formation (E. Miocene): It is the upper formation, which is covered with a few meters of quaternary sediments and overlaid the Dammam Formation. The formation consists of limestone in addition to a low percent of marl and clay layer. The thickness of it in the study area ranges between 20 m and 65 m [4]. The groundwater within the formation contains has a salinity of 4000 ppm and relatively little productivity with a strong H$_2$S odor.

2. Dammam Formation (E- L Eocene): Dammam consists mainly of carbonate rocks (limestone and dolomite) [4]. It is the most important formation in the study area as it represents a semi-confined aquifer and the main source of abundance and the good of quality groundwater. It extends over large areas in the western and southwestern desert of Iraq. The thickness of the formation ranges from 150 to 200 m and divides into three-water storage members, upper, middle and lower.

3. Rus Formation (L. Eocene): It mainly consists of evaporites thick layers of anhydrite (and/or gypsum beds) with interlocking layers of marly limestone and overlies the Umm Er Radhuma Formation. The total thickness is about 20-50 m, and it is a non-storing layer of water [10]. It separated between the aquifers of Dammam and Umm Er Radhuma. It is the main source of dissolved sulfur and salts components that present in Dammam water through the continuous dissolution of gypsum.

4. Umm Er Radhuma Formation (M.- L. Paleocene): It is mainly composed of dolomitic limestone, microcrystalline porous limestone layers and anhydrite nodules. The thickness of this formation ranges between 310 m and 412 m. It is considered a good aquifer for groundwater, and its water may infiltrate into Dammam's aquifer due to the differential pressure difference through the joints and cracks in the Rus Formation. Umm Er Radhuma Formation groundwater is distinguished from Dammam's groundwater, as the first has salty water and a more sulfurous odor.
3. Materials and Method

Twelve wells were selected to investigate the physical and hydrogeochemical properties of groundwater in the study area (Table 1).

| Well. No. | N            | E            |
|----------|--------------|--------------|
| W. 1     | 32º 04' 51"  | 44º 01' 46"  |
| W. 2     | 32º 04' 34"  | 44º 03' 25"  |
| W. 3     | 32º 04' 26"  | 44º 06' 21"  |
| W. 4     | 32º 03' 30"  | 44º 05' 25"  |
| W. 5     | 32º 02' 43"  | 44º 05' 02"  |
| W. 6     | 32º 03' 45"  | 44º 08' 56"  |
| W. 7     | 32º 01' 57"  | 44º 06' 57"  |
| W. 8     | 32º 03' 02"  | 44º 10' 23"  |
| W. 9     | 32º 01' 02"  | 44º 09' 29"  |
| W. 10    | 31º 57' 13"  | 44º 07' 48"  |
| W. 11    | 31º 52' 10"  | 44º 14' 23"  |
| W. 12    | 31º 51' 37"  | 44º 15' 27"  |

The groundwater sampled and then analyzed for conducting to indicate the quality and specifications of this water. The standard method of APHA (2017) used to do the measurements. These measurements comprised hydrogen number (pH), electrical conductivity (EC), Total dissolved solids (TDS) and temperature (T) using TDS-EC-pH and T meter, HANNA, type H19811 that was calibrated by the specific buffer solution. Major cations and major anions which included (K\(^+\), Na\(^+\), Ca\(^{2+}\), and Mg\(^{2+}\), CO\(_3\)\(^{-2}\), HCO\(_3\)\(^{-}\), SO\(_4\)\(^{-2}\), and Cl\(^-\)), as well as anions (NO\(_3\)\(^-\)) were analyzed for all samples. The flame photometer was used for analyzing sodium and potassium. The titrimetric method used for determining calcium, magnesium, chloride, carbonate. Sulfate is determined by spectrophotometer.
4. Results and discussion

The results of the physical and geochemical analyzes of groundwater samples are listed in Table 2. Fig. 3 is represented Pie diagram showed the average percent of ionic constituents (epm %) of groundwater in studied wells.

Table 2: Hydrochemical parameters Results of wells groundwater in the study area

| W. no. | Unit | Ca^{2+} | Mg^{2+} | Na^+ | K^+ | Cl^- | HCO_3^- | SO_4^{2-} | NO_3^- | PH | EC μs/cm | TDS ppm | U | SA R |
|-------|------|---------|---------|------|-----|------|---------|----------|--------|----|---------|--------|---|------|
| 1     | ppm  | 235     | 130     | 390  | 17  | 550  | 241     | 990      | 1.68   | 7.2| 5       | 3970   | 2585| 0.3  |
|       | epm  | 11.7%   | 10.7%   | 16.9% | 0.4%| 15.5%| 3.95    | 20.6%    | 0.03   | 5.0| 6       |         |     |      |
|       | epm% | 29.4%   | 26.8%   | 42.5% | 1.0%| 38.7%| 9.84    | 51.3%    | 0.07   | 5.0| 6       |         |     |      |
| 2     | ppm  | 190     | 98      | 270  | 19  | 504  | 97      | 662      | 1.24   | 7.1| 4       | 2870   | 1880| 0.2  |
|       | epm  | 9.50%   | 8.07%   | 11.7% | 0.4%| 14.2%| 1.59    | 13.7%    | 0.02   | 3.9| 6       |         |     |      |
|       | epm% | 31.8%   | 27.0%   | 39.4% | 1.6%| 48.0%| 5.37    | 46.5%    | 0.07   | 3.9| 6       |         |     |      |
| 3     | ppm  | 180     | 94      | 262  | 16  | 484  | 95      | 647      | 1      | 7.1| 2       | 2800   | 1825| 0.3  |
|       | epm  | 9.00%   | 7.74%   | 11.3% | 0.4%| 13.6%| 1.56    | 13.4%    | 0.02   | 3.9| 4       |         |     |      |
|       | epm% | 31.5%   | 27.1%   | 39.9% | 1.4%| 47.6%| 5.42    | 46.9%    | 0.06   | 3.9| 4       |         |     |      |
| 4     | ppm  | 172     | 90      | 250  | 14  | 460  | 93      | 620      | 1.08   | 7.2| 0       | 2730   | 1763| 0.4  |
|       | epm  | 8.60%   | 7.41%   | 10.8% | 0.3%| 12.9%| 1.52    | 12.9%    | 0.02   | 3.8| 4       |         |     |      |
|       | epm% | 31.5%   | 27.2%   | 39.9% | 1.3%| 47.3%| 5.55    | 47.0%    | 0.06   | 3.8| 4       |         |     |      |
| 5     | ppm  | 210     | 103     | 294  | 22  | 525  | 100     | 706      | 1.13   | 7.1| 1       | 2940   | 1986| 1.7  |
|       | epm  | 10.5%   | 8.48%   | 12.7% | 0.5%| 14.8%| 1.64    | 14.7%    | 0.02   | 4.1| 5       |         |     |      |
|       | epm% | 32.4%   | 26.2%   | 39.5% | 1.7%| 47.5%| 5.25    | 47.1%    | 0.06   | 4.1| 5       |         |     |      |
| 6     | ppm  | 197     | 96      | 281  | 19.2| 515  | 95      | 688      | 1.12   | 7.1| 2       | 2875   | 1916| 0.0  |

epm: parts per million; ppm: parts per million; percent; EC: electrical conductivity; TDS: total dissolved solids; U: uranium; SA R: salinity ratio.
| W. no. | Unit | Ca\(^{2+}\) | Mg\(^{2+}\) | Na\(^+\) | K\(^+\) | Cl\(^-\) | HCO\(_3\) \(^-\) | SO\(_4\) \(^{2-}\) | NO\(_3\) \(^-\) | PH | EC \(\mu\)s/cm | TDS ppm | U | SA R |
|-------|------|-----------|-----------|---------|-------|-------|-------------|-------------|-------------|----|---------------|--------|---|-----|
| 7     | epm  | 9.85      | 7.90      | 12.2/2  | 0.4/9 | 14.5/5 | 1.56        | 14.3/3      | 0.02        |    | 4.10         |        |   |     |
|       | epm% | 32.3/4    | 25.9/4    | 40.1/1  | 1.6/2 | 47.7/7 | 5.11        | 47.0/6      | 0.06        |    |              |        |   |     |
|       | ppm  | 187/93    | 268/17.5  | 489/97  | 97/65 | 655/1.10 | 7.1/3       | 2765/1830  | 0.0/7       | 4.00 | 4.40/5       |        |   |     |
|       | epm  | 9.35      | 7.65      | 11.6/5  | 0.4/5 | 13.8/1  | 1.59        | 13.6/5      | 0.02        |    |              |        |   |     |
|       | epm% | 32.1/2    | 26.3/0    | 40.0/3  | 1.5/4 | 47.5/2  | 5.47        | 46.9/5      | 0.06        |    |              |        |   |     |
| 8     | ppm  | 179/91    | 258/15    | 460/93  | 620/1.08 | 7.1/0   | 2593/1739 | 1.0/6       | 3.91 | 4.00 |              |        |   |     |
|       | epm  | 8.95      | 7.49      | 11.2/2  | 0.3/8 | 12.9/9  | 1.52        | 12.9/2      | 0.02        |    |              |        |   |     |
|       | epm% | 31.9/2    | 26.7/1    | 40.0/0  | 1.3/7 | 47.3/3  | 5.55        | 47.0/5      | 0.06        |    |              |        |   |     |
| 9     | ppm  | 186/98    | 270/19    | 504/96  | 659/1.21 | 7.3/0   | 2823/1857 | 0.0/5       | 3.98 | 4.00 |              |        |   |     |
|       | epm  | 9.30      | 8.07      | 11.7/4  | 0.4/9 | 14.2/4  | 1.57        | 13.7/3      | 0.02        |    |              |        |   |     |
|       | epm% | 31.4/3    | 27.2/6    | 39.6/7  | 1.6/5 | 48.1/6  | 5.32        | 46.4/5      | 0.07        |    |              |        |   |     |
| 10    | ppm  | 176/93    | 255/15.1  | 472/94  | 633/1.16 | 7.1/6   | 2780/1800 | 0.2/7       | 3.87 | 4.00 |              |        |   |     |
|       | epm  | 8.80      | 7.65      | 11.0/9  | 0.3/9 | 13.3/3  | 1.54        | 13.1/9      | 0.02        |    |              |        |   |     |
|       | epm% | 31.5/1    | 27.4/1    | 39.7/0  | 1.3/9 | 47.4/8  | 5.49        | 46.9/6      | 0.07        |    |              |        |   |     |
| 11    | ppm  | 220/119   | 360/17    | 542/241 | 978/1.61 | 7.1/2   | 3762/2508 | 3.6/3       | 4.85 | 4.00 |              |        |   |     |
|       | epm  | 11.0/0    | 9.79      | 15.6/5  | 0.4/4 | 15.3/1  | 3.95        | 20.3/8      | 0.03        |    |              |        |   |     |
|       | epm% | 29.8/2    | 26.5/6    | 42.4/8  | 3.86/1 | 9.96/0  | 51.3/7      | 47.3/3      | 0.06        |    |              |        |   |     |
| 12    | ppm  | 200/100   | 289/21    | 521/98  | 705/1.12 | 7.2/3   | 2940/1960 | 0.4/9       | 4.16 | 4.00 |              |        |   |     |
|       | epm  | 10.0/0    | 8.23      | 12.5/7  | 0.5/4 | 14.7/2  | 1.61        | 14.6/9      | 0.02        |    |              |        |   |     |
|       | epm% | 31.9/1    | 26.2/7    | 40.1/0  | 1.7/2 | 47.4/3  | 5.18        | 47.3/3      | 0.06        |    |              |        |   |     |
| Av    | epm% | 28.8/2    | 24.5/36.9 | 1.3/42.1| 5.70/43.7| 0.06   |              |             |             |    |              |        |   |     |
The analytical accuracy (U %) for all water samples computed statistically according to the equation below depending on [11] for avoiding mistakes.

\[
U\% = \left( \frac{r \Sigma cation - r \Sigma anions}{r \Sigma cations + r \Sigma anions} \right) \times 100
\]

Where U is the uncertainty, r is a value in equivalent per mil (epm). When U (as absolute value) \( \leq 5 \), the result could be accepted, but if \( 5 < U \leq 10 \) the result will be accepted with risk [12]. The average value of U is 0.11 that means the analysis results are accepted.

The ionic constituents that predominated in the groundwater are \( \text{SO}_4^{2-} \) and \( \text{Cl}^- \) as anions and \( \text{Na}^+ \), \( \text{Ca}^{2+} \) and \( \text{Mg}^{2+} \) as cations.

Through the vision for the Stiff diagram, which suggested by [13], the anion \( \text{Cl}^- \) and \( \text{SO}_4^{2-} \) and cation \( \text{Na}^+ \) and \( \text{K}^+ \) are the predominant ions in the well groundwater while the \( \text{HCO}_3^- \) and
Mg$^{2+}$ are relatively poor (all ions in epm) (Fig. 4). Through the vision of the Stiff diagram, the predominant ions are Cl$^-$, SO$_4^{2-}$ and Na$^+$ while the HCO$_3^-$ and Mg are relatively poor.

![Stiff diagram](image)

**Fig. 4: Stiff diagram (for average) of studied groundwater**

The electrical conductivity values refer to groundwater mineralization. EC is the ability of an electric current to connect through 1 cm$^3$ of water at 25˚C [14]. The average of Ec in studied wells is 3015 μs/cm on average (Table 2). Depending on [15] classification (Table 3), the groundwater of the Dammam aquifer is slightly mineralized water (limestone terrains) due to interactions between limestone rocks and groundwater in the Dammam Formations depending on its lithology.

The TDS values of the groundwater in the study area are (1971.04 ppm) in average (Table 2). It refers that the groundwater in the study area is classified as brackish water as [16] classification (Table 4). It is not appropriate for drinking water depending on [17]. The studied groundwater has a pH (7.16) which is mean neutral.

| EC (μs/cm) | Mineralization                          |
|------------|----------------------------------------|
| <1000      | very weakly mineralized water (granite terrains) |
| 1000-2000  | weakly mineralized water               |
| 2000-4000  | slightly mineralized water (limestone terrains) |
| 4000-6000  | moderately mineralized water           |
| 6000-10000 | highly mineralized water               |
| >10000     | excessively mineralized               |
Table 4: Classification of water salinity according to the TDS [16].

| Water type | TDS (ppm) |
|------------|-----------|
| Fresh water | < 1000    |
| Brackish   | 1000-10,000 |
| Saline     | 10,000-100,000 |
| Brine      | > 100,000 |

The groundwater of studied wells is appropriate for irrigation by using the sodium adsorption ratio (SAR) [18]. The SAR result (in average) 4.15 (Table 2) indicates that the water class is excellent for irrigation [14] (Table 5).

Table 5: Todd classification of irrigation water depending on SAR

| Parameter | Equations | Limits | Water class |
|-----------|-----------|--------|-------------|
| SAR       | \[
\frac{rNa^+}{\sqrt{\left(\frac{rCa^{2+} + rMg^{2+}}{2}\right)}}
\] | <10 10–18 18–26 >26 | Excellent Good Doubtful Unsuitable |

5. Using groundwater for breeding fish

The groundwater of the Dammam aquifer has been invested in establishing multiple lakes for fish breeding. These lakes are fully supplied from groundwater by drilling unofficial and irregular flowing wells. Most of the lakes are concentrated in several locations of the study area and on both sides of Wadi Al-Khur. This area is an intersection between the Abu Jir fault, towards the northeast of the southwest, with the Al-Rhimawi - Hilla fault, towards the northwest of the southeast, in addition to many rock cracks, which facilitate the movement and transportation of groundwater to flowing wells in the areas. The Fish breeding lakes are either regular lakes with dimensions (40 m * 100 m) with a depth ranging between 1 and 1.5 m or irregular shapes and large areas. These lakes consume large amounts of groundwater, and the fate of this water is either to evaporate or to drain into the marshes of the Najaf marshes through the Wadi Al-Khur or some channels that have been constructed by the excavators (Fig. 4). The amount of drained water from the fish breeding lakes towards the Najaf marshes reaches 4.715 m³/ s [19].
6. Piezometric pressure drop sign in Dammam aquifer

The piezometric pressure is the amount of water pressure inside the confined groundwater layer resulting from the difference in the height of the water level between two points, which is equal to the atmospheric pressure [20]. The piezometric pressure may be higher than the ground level in some areas, which results in the emergence of flowing wells like the Dammam aquifer. There are many signs confirm the Piezometric pressure drop and drop of groundwater levels in the Dammam aquifer in the region.

a. The groundwater flow has been halted in several flowing wells.

In the last years, the demand for drilling flowing wells to create fish breeding lakes has increased. All the flowing wells have been flowing large amounts of groundwater to fish breeding lake projects in the region. The ground level is descending towards the Wadi Al-Khur with a level difference of up to 30 m, this caused halted many wells flow of groundwater due to exhaustion of the reserve and a decrease in the level of the hydrostatic pressure of the aquifer (Fig. 5).
b. Hydraulic specifications decrease of the Dammam aquifer

The hydraulic specifications of the groundwater-bearing aquifer layer are very important to identify the characteristics of the aquifer and its permanence. They obtained it by conducting a pumping test for wells that penetrate the water-bearing layer. Pumping test is operating a pump for particular hours, monitoring the decrease in the water level inside the well against time, and then analyzing these readings to obtain the hydraulic specification for the aquifer such as Hydraulic conductivity (K), Transmissivity (b) and storage capacity (Sc) [21]. The pumping test process was carried out for twelve wells penetrating the Dammam aquifer in different locations in Bahr Najaf Province (Fig. 1). The hydraulic specification values were compared with the values of previous studies in the region. A difference in these values appeared with the time progressed [9], [1], [4]. As in Tables (6 and 7).

Table 6: Comparison of Transmissivity (b) values with the conductivity values of previous studies in the region.

| Transmissivity m²/day | [22]  | [23]  | This study, 2020. |
|-----------------------|-------|-------|-------------------|
| Minimum value         | 123.9 | 112.9 | 22.21             |
| Maximum value         | 1654.7| 1129.4| 222.85            |
| Average               | 889.3 | 621.15| 122.53            |
Table 7: Comparison of the Specific capacity (Sc) values with the values of the previous study in the region.

| Specific capacity m²/day | [23]     | This study, 2020 |
|-------------------------|---------|-----------------|
| Minimum value           | 69.2    | 22.23           |
| Maximum value           | 771.4   | 142.8           |
| Average                 | 420.3   | 82.515          |

c. Groundwater levels reducing in the monitoring wells

Monitoring wells, which are wells that are drilled and locked up to the groundwater-bearing aquifer layer, are useful to monitor the groundwater levels periodically. The monitoring, either daily or monthly, is an important factor to knowledge the groundwater state in process of dragging and discharging the aquifer to sustain and permanence the groundwater [24]. The decrease in groundwater levels in the monitoring well (W/7) shows Fig. 7. Which lies in the Al-Ruhba region (General Commission of Groundwater).

![W. 7](image)

Fig. 6: Groundwater levels measurements of Al-Ruhba monitoring well per month. Where, W. L mean Pumping Water Level in meters

d. Groundwater levels decrease in wells scattered in the area

Recently, many farmers suffer from a decrease in groundwater levels in their wells that were drilled by them for agriculture, which forced farmers to drill new wells or increase the depth of these wells. There is two kinds of the decrease in groundwater levels in the area.
A- Seasonal reduction in groundwater that occurs during the wheat cultivation season, which necessitates an increase in the demand for groundwater extract for irrigation of crops.

B- General decrease in the levels of the aquifer water due to the increase in drilling wells and the expansion in the land areas of agriculture and the creation of fish breeding lakes.

7. Conclusions and Recommendations

7.1 Conclusions

The Dammam water specifications conform to the specifications of water suitable for irrigation. The reservoir suffers from an over-exhaustion of groundwater resources because of use in lakes fish breeding.

A significant decline in values hydraulic specification transmissivity and specific capacity of the Dammam aquifer. Through the observation of the monitoring well (W/7), a clear reduction and decrease in groundwater levels of flowing wells in the study area.

7.2 Recommendations

The researcher recommends closure of the flowing wells that drilled without observing the groundwater investment controls. Backfilling of the random fish breeding lakes because causes the exhaustion of groundwater resources.

Recycle and reuse water used in fish breeding lakes and irrigation. Establishing regulations and laws to preserve the groundwater reserves and holding accountable those who do not abide by them.

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