# Artificial Groundwater Recharge in Iraq through Rainwater Harvesting (Case Study)

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## ABSTRACT

Groundwater is considered as an important source of water supply in Iraq, so it is need replenishing by any way of recharging. The most important way for recharging the groundwater is by rainwater harvesting. The part of rainfall which losses as surface runoff can be store during the monsoon in collecting reservoirs (such as ponds or tanks) and use it when required. This study deals with the way of harvesting rainwater that falls on the land for the replenishment the groundwater and use it in the dry seasons.

According to availability of recommended potential for successful artificial recharge projects, a site was selected in the Jolak basin north of Karkuk city, north of Iraq. The area is about 400 $km^2$. Since the occurrence of rainfall in the north of Iraq is mostly limited to about five or six months in a year, so the recharge to ground water reservoir is restricted to this period only. The surplus rainwater is assumed to be collected in the several suggested collecting rectangular ponds to catch monsoon rains (storing a fraction of runoff). This water can then be diverted to the aquifer through recharge wells (which already exist in the study area) and replenish falling groundwater table by pumping the stored water. Ponds need to be lined to stop water from seeping out. Plastic lining has proved to be appropriate mainly because of low cost and reliability of the material , so it is suggested to be use in the lining of the ponds. Also the ponds are suggested to be cover during groundwater recharging in order to stop water from being lost into the air by evaporation. A computer software known as Groundwater Molding System (GMS) has been used in the present study to simulate the water conveyance from the collecting ponds to the underground reservoirs by wells. Results indicated that movement of surface water into the groundwater was predominantly an effective process. It can be shown also, that collecting ponds were a key driver of surface water into the subsurface along the study area.

**Keywords:** Rainwater harvesting, groundwater recharging, runoff, collecting ponds,



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plastic lining, recharge wells, GMS software.

## التغذية الاصطناعية للمياه الجوفية في العراق من خلال حصاد مياه الأمطار (دراسة ميدانية)

**الخلاصة**

تعتبر المياه الجوفية مصدرا هاما لتوفير المياه في العراق، لذا فهو بحاجة إلى التجديد بأية وسيلة من رة العواصف المطرية. وهناوسائل التغذية. من الطرق المهمة في تغذية المياه الجوفية هو حصاد مياه الأمطار لتخزين المياه خلال فتلك العديد من الطرق لحصاد مياه الأمطار كتخزينها في خزانات سطحية مثل الاحواض أو خزانات تحت الأرض يجعلها متاحة للاستخدام عند الحاجة.

هذه الدراسة تتعامل مع طريقة حصاد مياه الأمطار لتجديد موارد المياه الجوفية واستخدامها في مواسم الجفاف. وفقا لتوافر الإمكانات اللازمة لنجاح مشاريع التغذية الاصطناعية، تم اختيار موقع حوض جولاك شمال مدينة كركوك، شمال العراق. مساحة المنطقة تقدر ب 400 $km^2$. يقتصر تساقط الأمطار في شمال العراق بنحو خمسة أو ستة أشهر في السنة، لذلك تقتصر تغذية خزانات المياه الجوفية لهذه الفترة فقط. تم اقتراح حفر مجموعة احواض لجمع مياه الامطار (تخزين جزء من الجريان السطحي). و تحويل هذه المياه إلى طبقة المياه الجوفية من خلال آبار التغذية (التي توجد بالفعل في منطقة الدراسة) وتجديد هبوط منسوب المياه الجوفية عن طريق الضخ من المياه المخزنة. كما تم اقتراح تبطين الاحوض بغشاء من البلاستيك نظرا لموثوقية اداء هذه الاغشية وتكاليفها المنخفضة .ولغرض منع تبخر المياه من سطح الاحواض تم اقتراح تغطية الاحواض باغشية بلاستكية اثناء عملية تغذية المياه الجوفية (اثناء الضخ) .وقد تم استخدم برنامج الحاسبة الجاهز والمسمى (GMS) في هذه الدراسة لمحاكاة نقل المياه الخزونة في احواض التجميع الى الخزانات الجوفية عن طريق الابار. وأشارت النتائج المستحصلة أن حركة المياه السطحية إلى المياه الجوفية عملية فعالة. و أن الاحواض هي الدافع الرئيسي للمياه السطحية في باطن الأرض على طول منطقة الدراسة.

## INTRODUCTION

Groundwater is considered as an important source of water supply. The increasing demand for water has increased the request for harnessing this resource for domestic, agricultural and industrial usage. Continuous withdrawal of groundwater leads to lowering of the water table which increases the necessity of its replenishment by any way of recharging to keep groundwater balance in favorable condition for depleting groundwater areas. Natural recharge by rainfall is generally inadequate to replenish the underlying aquifer because most of this water runs off since it`s concentrated during the monsoon which the soil is already saturated. The surplus monsoon water can be used to recharge underground aquifers artificially to augment the aquifer storage potential and minimize water logging as well as use the stored water in dry seasons and avoiding evaporation losses.

Many factors must be considered for artificial recharge such as: quantity and quality of source water available, underground storage space available with its depth,transmission characteristics of the aquifer, applicable methods (injection or infiltration) and costs of the project, Bhattacharya, (2010).

Artificial recharge to groundwater may be done by several methods. The most important method is rainwater harvesting. Structures used for rainwater storing on surface are underground tanks, ponds, check dams, weir..etc., while the structures which used for recharging to groundwater are pits, trenches dug wells, hand pumps, recharge shafts, injection wells…etc. Choice of a particular method is governed by local topographical, geological and soil conditions.

Present research suggests constructing several surface ponds to catch monsoon rains (storing a fraction of runoff) and replenish falling groundwater through injection wells. The ponds are suggested to be dug into the ground in a rectangular shape and lined with a plastic film.

## STUDY AREA AND ITS CLIMATE

Site selection for artificial recharge is critical. Some aquifers hold little or no potential for successful artificial recharge projects, whereas others have great potential. Ideally, an aquifer will hold, store and transmit desired amount of recharge water without significant migration and chemical degradation of the water. In addition, the permeability of shallow earth materials should not limit the infiltration by surface spreading, Najmi , (2008).

According to availability of recommended potential for successful artificial recharge projects, a site was selected in the Jolak basin about 20 Km north of Kirkuk city, north Iraq, between longitudes 44° 8′ and 44° 35′, and latitudes 35°30′ and 35° 45′. It extends over an area of 400 $km^2$, bounded by two parallel chains (Khal Kan and Baba Dome) from the northeast and southwest, respectively and by the Lesser Zab river from north and north-west see Figure (1).

The basin has gentle slopes towards the valley that crosses it from southeast to northwest parallel to the chains.The center of the basin is a flat plain with many wadis coming down from the ridges. These wadis are intermittent, containing water only during the rainy season and discharging into main Jolak basin which is a major drainage outlet into the Lesser Zab river, Hassan, (2001).

The soils of the study site are of alluvial origin gradually transported from the surrounding mountainous area and deposited in the flat portion of the area. It consists of sands and gravels interceded with clay and silt layers.

The climate in the study area may be classified as Mediterranean type, Concorde & Ingegneria, (2009). The available records cover the period (1934-2008) of monthly total rainfall data in the study area was obtained from Kirkuk Meteorological Station , and can be shown in Figure (2).

## RAINWATER HARVESTING

Rainwater harvesting (RWH) refers to collection of rain falling on earth surfaces for beneficial uses before it drains away as run-off. RWH process can be done either by collecting it directly on ground surface for future use or recharging it into the ground to improve the aquifer storage and alleviated the problem of the misbalance between the natural recharge and extraction of water over a period of time.

The estimation of quantity of water that can be harvested is the first step in planning and design of RWH systems. The quantity depends on the area of catchment and the annual average rainfall of the region. Supply of rainwater can be estimated from the monthly average rainfall data available from the local meteorological department, and texture and extend of the catchment area. The surface texture affects the runoff coefficient and hence the quantity, Bhawan & Nager,(2001). If the surface is impervious and smooth, the runoff occurs immediately. If the surface is pervious, the run-off occurs only after the surface is saturated.

The rainwater yield from a catchment is given by, Bhawan & Nager, (2001) as:

Annually Yield($m^3$) = Average annual rainfall (m) x Area of the catchment ($m^2$) x Runoff coefficient for the catchment surface (1) From data published by the Meteorological Department of Karkuk, the annual average rainfall in Jolak basin has been adopted as 360 mm, Runoff coefficients of sandy soil is 0.075, Mark & Marek, (2011).

So, the total quantity of rainwater that can be harvested annually is:

$400 \times 10^6\ m^2 \times 360 \times 10^{-3}\ m \times 0.075 = 10.8 \times 10^6\ m^3$.

Occurrence of rainfall in the north of Iraq is mostly limited to about six months in a year. The natural recharge to the ground water reservoir is restricted to this period only. The water accumulated after monsoon should percolate to the groundwater at the earliest to avoid the evaporation losses.

For the design of RWH system, critical rainfall value has to be considered. The rainfall data of Karkuk metrological station over the period (1934-2008) indicates that on an average, there are 6 rainy months in a year. with maximum rainfall during the month of February, which accounts for 19.5% of total annual rainfall. The maximum quantity of rainwater that will be harvested and utilized for groundwater recharge during the critical month (February) has been calculated as:

Average rainfall during the month of February = 70 mm, see Figure (2).

Critical rainfall per day=70 / 28 =2.5 mm.

Assuming that only 30 % of runoff volume is evaporated (due to low evaporation rate during this month) during its way to the collection structures.

So, Maximum quantity of rainwater harvested in a rainy day of February =

$$\mathbf{400 \times 10^6\ m^2 \times 1.75 \times 10^{-3}\ m \times 0.075 = 52.5 \times 10^3\ m^3}\ .$$

## COLLECTION PONDS

Collection pond refers to the arrangement made for collecting and storing the rainfall with minimal quantitative loss. It is constructed to harvest and impound the runoff from the catchments for a longer time to recharge groundwater storage.

The shape, size and type of rainwater harvesting ponds vary depending on soil type and climatic conditions. Trapezoidal and rectangular shaped rainwater harvesting ponds are the most common ones. The major advantages of this type of rainwater harvesting are that it is simple, cheap, replicable, efficient, and adaptable, Tesfay, (2008).

Depth of pond should range from 3 m to 5 m. Greater than 2 m of depth is necessary and would prove a less area as well as minimum evaporation loss and maintenance hazard. If space for adequate surface area is not available, this can be offset to some degree by increasing the depth of the pond, NCPAH , (2010).

Based on the area available at the study area the size of the pond has been fixed as 12 m x 12 m x 4 m. The storage capacity of each pond is, therefore 540 $m^3$ (by assuming the depth of water in the pond is 3.75 m). So the request number of the ponds over the area is about 97 ponds, distributed in appropriate locations**,** see Figure (3).

## LINING OF THE COLLECTION PONDS WITH PLASTIC FILM.

A considerable portion of stored water in collecting pond may be loss due to seepage, which leads to drop in depth of water in the pond. To avoid this depletion of stored water , it is necessary to line the pond with an impervious material. One of important lining materials is plastic film, which is becoming available in many parts of the world and can be use alone or in combination with conventional lining to be most effective seepage proof. Plastics film is the flexible membrane, which is a hydraulic barrier consisting of a functionally continuous sheet of synthetic or partially synthetic or flexible material, NCPAH , (2010). Polyethylene film lining has proved to be a seepage proof barrier between the soil and the water, therefore it is recommended to be used in the present study. This film shall be obtained in rolls having a continuous unplaced length, and in various widths without joints as per requirements. The length of rolls may be of about 40 meters for convenience in handling. Film rolls can be obtained in specific lengths and widths as per requirements of the designed section of a canal to avoid wastage and minimize the joints. Available gauge sizes of plastic lining range from 0.4mm to 1.2mm. Thicker gauge will last longer. Figure (4) shows a plastic lined collecting pond, Tesfay, (2008) .The direct evaporation from the water surface in the ponds has also to be taken into consideration and suggested to be controlled by covering the pond surface by covers plastic sheets or rubber membranes during the water diverting to the ground water.

## GROUNDWATER RECHARGE BY WELLS

The purpose of recharge well is augmenting the ground water storage by pumping surface water under pressure. Rainwater can be diverted to the aquifer through recharge wells. By ensuring faster rate of infiltration, the injection wells will also help minimize evaporation losses of the harvested rainwater, Dhiman, & Gupta (2011).

A computer software known as Groundwater Molding System (GMS) has been used in the present study to simulate the groundwater recharging. This software simulates the groundwater three dimensional flow which can be express in the following equation, McDonald, & Harbough, ( 1984):

$$\frac{\partial}{\partial x}\left(Kxx\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial x}\left(Kyy\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial x}\left(Kzz\frac{\partial h}{\partial z}\right)-w=Sc\frac{\partial h}{\partial t} \qquad \dots(2)$$

X, Y, Z = Cartesian coordinates(L) along the hydraulic conductivity axes Kxx, Kyy, Kzz,(L/T).

h = Head or groundwater pressure,(L). W= Flux per unit volume, it represents quantities discharged or recharged to the aquifer.

Sc = Specific storage for the porous media.

t = Time.

Present study suggested using several recharging wells (which already exist in the study area, as shown in Figure (3) , and there information are tabulated in Table(1 )) to convey collecting rainwater in the ponds to the groundwater. The pumping test was conducted by General Directorate of Groundwater, (GDGW), 2008, which provided the value of coefficient of transmissibility and storage coefficient, (as average values of 2000 $m^2$/d and 0.1 respectively). These data are useful to artificial recharge efforts because they provide evidence of the general direction that water will likely travel, from a high water level to low water level. Regional groundwater flow direction at the study site was a uniform decrease in the hydraulic head over the length of the site, following general topography, Figure (5).

The input data (coefficient of transmissibility, elevations of top and bottom of the aquifer, storage coefficient, and net recharge rate) are prepared as contour maps for the areal distribution in the study area grid.

A system of exiting 76 wells is assumed to be operate at a constant rate of (15 l/s).The operation period of the wells is assumed to be 12 hrs a day. The contour map of the resulting head and groundwater levels due to the recharging during 6 months are shown in Figure (6) and Figure (7), respectively.

## CONCLUSIONS

Rainwater harvesting can have an important role in groundwater recharging. It helps bridge the dry times between the rainy season to the benefit of water storing and minimizing the evaporation losses. It is emerging as a viable long-term strategy to tackle the increasing pressure on freshwater resources of our country. It is concluded from the present study that the harvesting the rainwater in collecting lined ponds is very useful in artificial recharge of ground water aquifer. The ground water levels in Jolak basin can be raised by means of 97 collecting ponds and 76 wells distributed over the study area. Water level at the middle of the study area can be raised to about

2 m from its present level after the steady state condition is reached within a period of 180 days.

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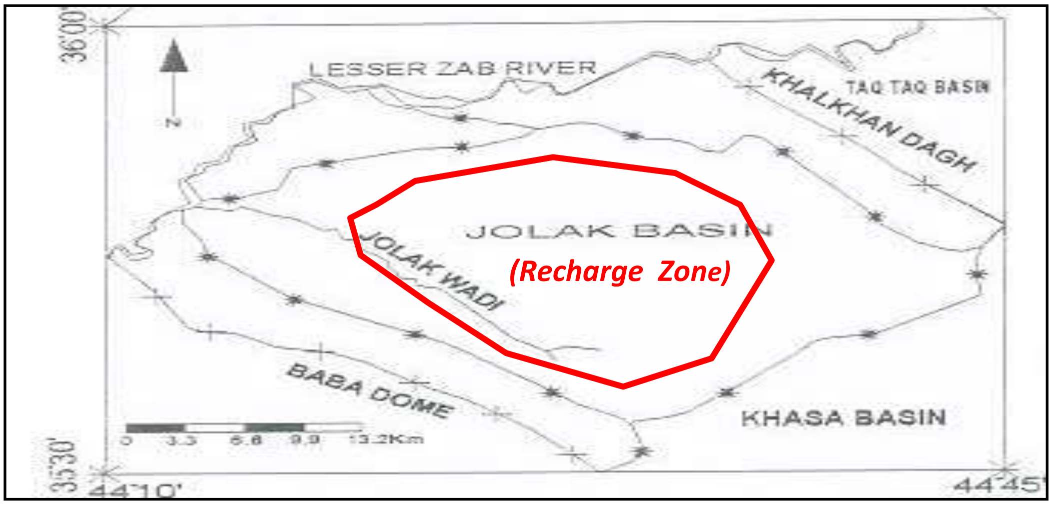


**Figure (1) Study area.**

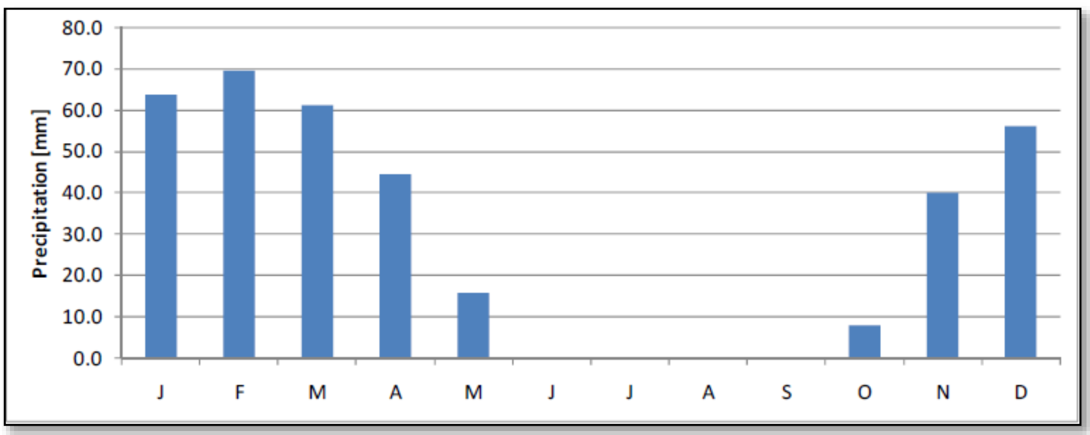


**Figure (2) monthly average rainfall at Kirkuk (1934-2008).**

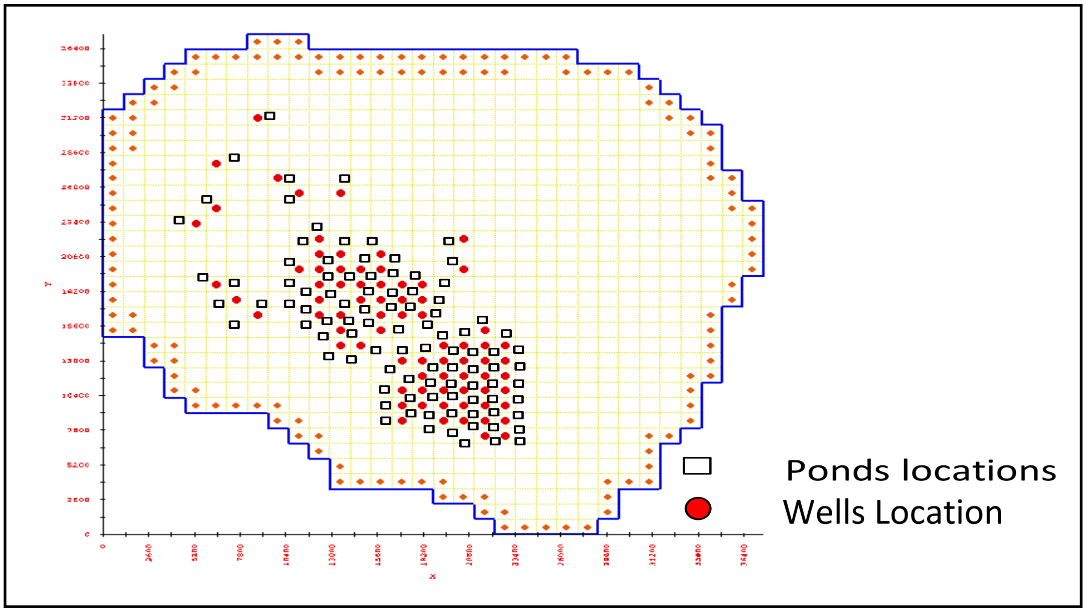


**Figure (3) Existing Wells and Suggested Ponds Locations**

**Figure (4) A Plastic lined collecting pond, by Tesfay, (2008).**

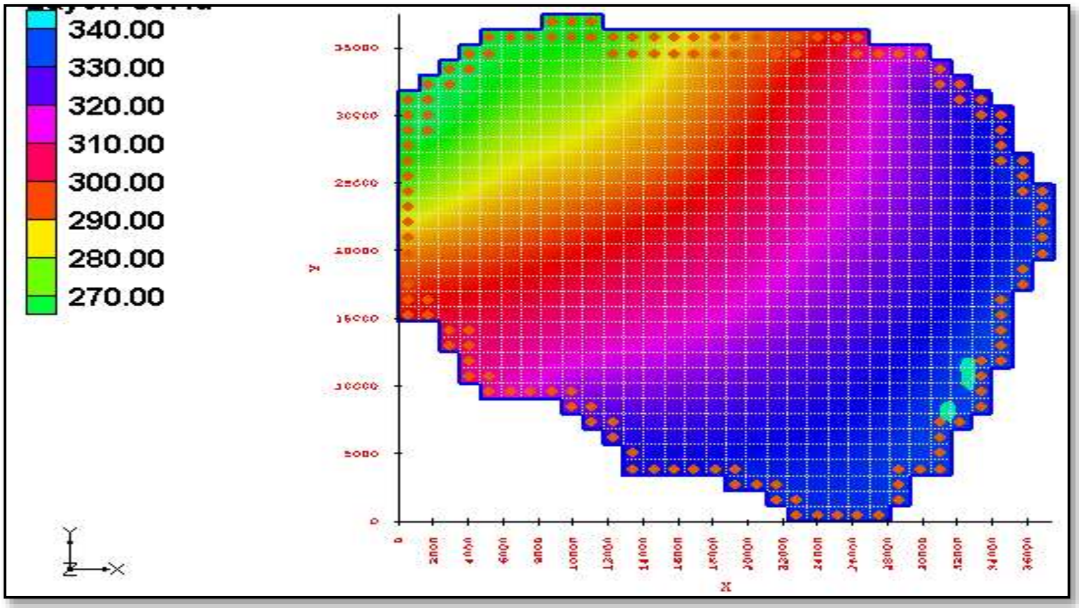


**Figure (5) Starting Groundwater contour map in the study area.**

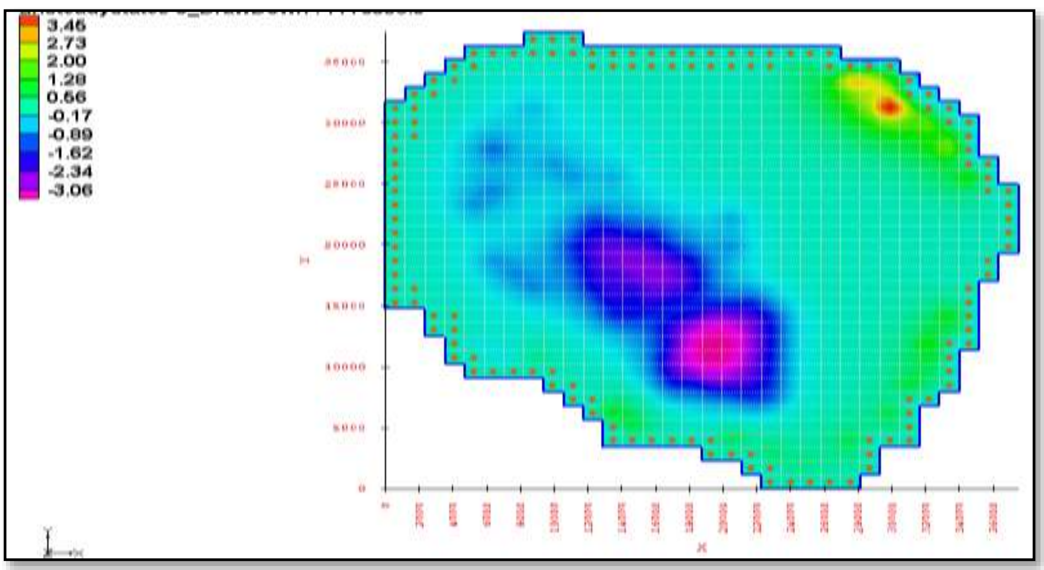


**Figure (6) Head contour map after 180 days of Recharging process.**

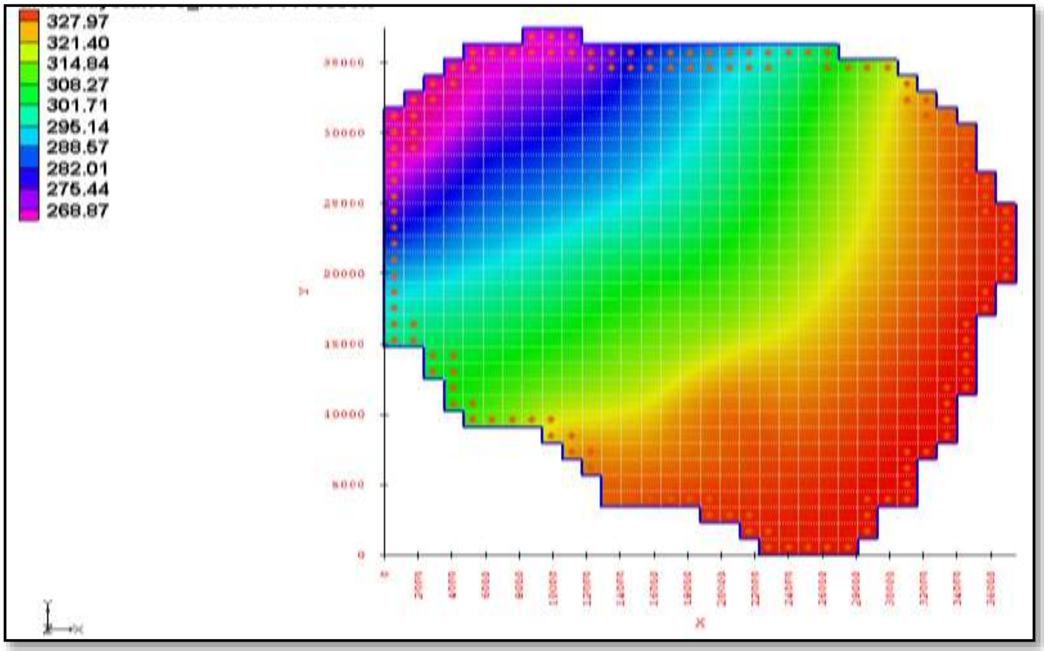


**Figure (7) Ground water contour map after 180 days of Recharging process.**

**Table (1) Summary of Information of the wells in the study area (after GDGW ,2008),**

| No. | Name | Elevation (m.a.s.l) | Water Depth (m) | Head (m.a.s.l) | Well Depth (m) |
|---|---|---|---|---|---|
| 1 | Tepe Zardic | 342.28 | 21.9 | 320.38 | 100 |
| 2 | Buyuk Brisibian | 333.89 | 28.5 | 305.39 | 74.4 |
| 3 | Buyuk Hissar | 386.44 | 49.2 | 337.24 | 107 |
| 4 | Guldarah | 383.34 | 47.1 | 336.24 | 115 |
| 5 | K.Biani | 319.14 | 10.2 | 308.94 | 98 |
| 6 | Yarimja | 330.34 | 28.0 | 302.34 | 126 |
| 7 | Sarbi | 313.34 | 52.1 | 261.24 | 79 |
| 8 | Daraman | 361.64 | 32.1 | 329.54 | 100 |
| 9 | Sagisloe | 383.34 | 47.1 | 336.24 | 140 |
| 10 | Shan Shin | 329.84 | 30.9 | 298.94 | 190 |
| 11 | Qalwar | 329.84 | 30.9 | 298.94 | 81 |
| 12 | Rosh Biani | 310.51 | 27 | 283.51 | 105 |
| 13 | Kitka | 325.84 | 69.9 | 255.94 | 146 |
| 14 | Kurzi | 275.62 | 20 | 255.62 | 96 |
| 15 | Q.Bagher | 313.51 | 23.5 | 290.01 | 132 |
| 16 | Nabi Awah | 306.4 | 18 | 288.4 | 111 |
| 17 | Qalwazi | 291.34 | 33.6 | 257.74 | 47 |
| 18 | Qazanfer | 332.84 | 25.4 | 307.44 | 170 |
| 19 | 4/7 | 350.5 | 27.5 | 323 | 122 |
| 20 | 4/4 | 363.0 | 37.0 | 326.0 | 128 |
| 21 | 4/3 | 368.0 | 43.0 | 325.0 | 126 |
| 22 | 4/8 | 348.0 | 19 | 329 | 128 |
| 23 | 4/5 | 356 | 34.5 | 321.5 | 130 |
| 24 | 2/6 | 358 | 20.25 | 337.75 | 132 |
| 25 | 5/5 | 366.5 | 34 | 332.5 | 128 |
| 26 | 1/8 | 366.0 | 27 | 339 | 128 |
| 27 | 4/1 | 377 | 46.5 | 330.5 | 124 |
| 28 | 2/4 | 369 | 27 | 342 | 124 |
| 29 | 3/1 | 383 | 52 | 331 | 120 |
| 30 | 1/1 | 385 | 34 | 351 | 128 |
| 31 | 2/1 | 363 | 10 | 353 | 124 |
| 32 | 0/3 | 379 | 29 | 350 | 130 |
| 33 | 5/1 | 385 | 45 | 340 | 104 |
| 34 | 1/2 | 382 | 27 | 355 | 128 |
| 35 | 3/4 | 368 | 30 | 388 | 130 |
| 36 | 2/3 | 374 | 27 | 347 | 130 |
| 37 | 1/4 | 367 | 21 | 346 | 122 |
| 38 | 1/6 | 360 | 13 | 347 | 124 |
| 39 | 0/7 | 363 | 15 | 348 | 124 |
| 40 | 1/7 | 361 | 17 | 344 | 128 |
| 41 | 0/5 | 373 | 21 | 352 | 120 |
| 42 | 0/8 | 361 | 17 | 344 | 122 |
| 43 | 3/3 | 373 | 41 | 332 | 126 |
| 44 | 2/5 | 364 | 23 | 341 | 120 |
| 45 | 3/2 | 377 | 48 | 329 | 130 |
| 46 | 3/5 | 363 | 19 | 344 | 124 |
| 47 | 5/2 | 380 | 38 | 342 | 124 |
| 48 | 5/4 | 371 | 33.5 | 338.5 | 122 |
| 49 | 2/7 | 354 | 20 | 334 | 124 |
| 50 | 2/8 | 351 | 17 | 334 | 120 |
| 51 | 4/6 | 382 | 32 | 350 | 120 |
| 52 | 5/3 | 375 | 39 | 336 | 128 |
| 53 | 1/3 | 377 | 26 | 351 | 128 |
| 54 | 4/2 | 372 | 45 | 327 | 128 |
| 55 | 3/6 | 356 | 25.7 | 330.3 | 126 |
| 56 | 1/5 | 364 | 19 | 345 | 128 |
| 57 | A1 | 335.38 | 10 | 325.38 | 106 |
| 58 | B1 | 336.37 | 7.5 | 328.87 | 90 |
| 59 | C1 | 339.51 | 12 | 327.51 | 90 |
| 60 | D1 | 341.59 | 14 | 327.59 | 112 |
| 61 | E1 | 345.91 | 18 | 327.91 | 110 |
| 62 | A2 | 332.72 | 8.5 | 324.22 | 106 |
| 63 | C2 | 335.1 | 11 | 324.1 | 110 |
| 64 | D2 | 337.45 | 15 | 322.45 | 110 |
| 65 | E2 | 340.02 | 16 | 324.02 | 110 |
| 66 | F2 | 343.7 | 19 | 324.7 | 110 |
| 67 | A3 | 330.24 | 8.5 | 321.74 | 94 |
| 68 | C3 | 325.04 | 9.8 | 315.24 | 110 |
| 69 | D3 | 332.49 | 13.5 | 318.99 | 110 |
| 70 | E3 | 333.97 | 13 | 320.97 | 110 |
| 71 | F3 | 335.2 | 15 | 320.2 | 145 |
| 72 | A4 | 325.18 | 7.8 | 317.38 | 106 |
| 73 | B4 | 320.12 | 6 | 314.12 | 100 |
| 74 | D4 | 326.25 | 11 | 315.25 | 101 |
| 75 | E4 | 340.63 | 14 | 326.63 | 110 |
| 76 | F4 | 330.69 | 16 | 314.69 | 110 |
| 77 | B5 | 317.34 | 6 | 311.34 | 106 |
| 78 | D5 | 322.38 | 11 | 311.38 | 120 |
| 79 | E5 | 324.63 | 12 | 312.63 | 124 |
| 80 | F5 | 327.54 | 15 | 312.54 | 110 |
| 81 | B6 | 314.78 | 7 | 307.78 | 85 |
| 82 | D6 | 319.57 | 10 | 309.57 | 126 |
| 83 | E6 | 321.33 | 12.5 | 308.83 | 120 |
| 84 | F6 | 318.71 | 11.25 | 307.71 | 108 |
| 85 | B7 | 313.43 | 5.9 | 307.71 | 108 |
| 86 | D7 | 316.17 | 10 | 306.17 | 120 |
| 87 | E7 | 315.01 | 12 | 303.01 | 206 |
| 88 | F7 | 317.68 | 14 | 303.68 | 150 |
| 89 | D8 | 309.24 | 10 | 299.24 | 120 |
| 90 | E8 | 311.81 | 9 | 302.81 | 110 |
| 91 | F8 | 312.42 | 12 | 300.42 | 110 |
| 92 | C9 | 310.23 | 8 | 302.23 | 102 |
| 93 | E9 | 306 | 7 | 299 | 110 |
| 94 | F9 | 302.02 | 6.5 | 295.52 | 110 |
| 95 | D10 | 301.76 | 5 | 296.76 | 112 |
| 96 | E10 | 303.83 | 8.5 | 295.33 | 124 |
| 97 | 0/6 | 370 | 16 | 354 | 120 |
| 98 | 8 | 386 | 36 | 350 | 130 |