

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 km². 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, 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. وهنا وسائل التغذية. من الطرق المهمة في تغذية المياه الجوفية هو حصاد مياه الأمطار لتخزين المياه خلال فتك 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 الإمكانيات 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 الاحواض بغشاء من البلاستيك نظرا لموثوقية اداء هذه الاغشية وتكاليفها المنخفضة. ولغرض منع تبخر المياه من سطح الاحواض تم اقتراح تغطية الاحواض باغشية بلاستيكية اثناء عملية تغذية المياه الجوفية (اثناء الضخ). وقد تم استخدام 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 $44^{\circ} 8'$ and $44^{\circ} 35'$, and latitudes $35^{\circ}30'$ and $35^{\circ} 45'$. 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 & Ingegnaria, (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:

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

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 =

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

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 m³ (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 Modeling 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):

$$\frac{\partial}{\partial x} \left(K_{xx} \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(K_{yy} \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left(K_{zz} \frac{\partial h}{\partial z} \right) - w = S_c \frac{\partial h}{\partial t} \quad \dots(2)$$

X, Y, Z = Cartesian coordinates(L) along the hydraulic conductivity axes K_{xx} , K_{yy} , K_{zz} , (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 m²/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 existing 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.

REFERENCES

- [1]. Bhattacharya, A., K., 2010, "Artificial groundwater recharge with a special reference to India", *IJRRAS* 4(2), India..
- [2]. Bhawan, P.& Nager, A., 2001, "Concepts and Practices for Rainwater Harvesting", Ministry of Environment & Forests, Govt. of India, Delhi-110 032.
- [3]. Dhiman, S.C. & Gupta, S.,2011."Rain water Harvesting and Artificial Recharge" Central Ground Water Board Ministry of Water Resources New Delhi.
- [4]. El Concorde & Med Ingegneria, J.V. 2009, "4 Small Dams in Kirkuk Governorate, Seaa Mansour Dam" Ministry of Water Resources, General Directorate for Engineering Designs ,Preliminary Study Report.
- [5]. General Directorate of Groundwater, (GDGW), 2008, " Hydrogeological study for Alton Kupri area", Unpublished report, Baghdad, Iraq.
- [6]. Hassan, H. A., 2001 "Quantitative and qualitative evaluation of the ground water resources in the Jolak basin" ,M.Sc Thesis, University of Baghdad.
- [7]. Mark A.& Marek, P.E., 2011, "Hydraulic Design Manual" Texas Department of Transportation.
- [8]. McDonald, M.G. & Harbough, A.W., 1984, "A modular three dimensional Finite Difference groundwater flow model", U.S. Geol. Survey, Scientific Publication Co., Washington, D.C., (quoted by Mayer and Miller, 1988).
- [9]. Najmi, K. 2008, "Rainwater Harvesting " *Jornal earth science India*: popular issue. *National Committee on Plasticulture Applications in Horticulture (NCPAH) , 2010,"Farm pond lined with plastic film" Ministry of Agriculture (MOA), Govt. of India.
- [10]. National Committee on Plasticulture Applications in Horticulture (NCPAH) , 2010,"Farm pond and reservoir lining", Ministry of Agriculture (MOA), Govt. of India.
- [11]. Sivanappan, R. K., 2006, "Rain Water Harvesting", Conservation And Management Strategies for Urban and Rural Sectors. National Seminar on Rainwater Harvesting and Water Management 11-12, Nagpur.
- [12]. Tesfay, N. ,H., 2008,"Rain water harvesting in Ethiopia: Technical and socio-economic potential and district" M.Sc Thesis, Wageningen University, Sup Agro.

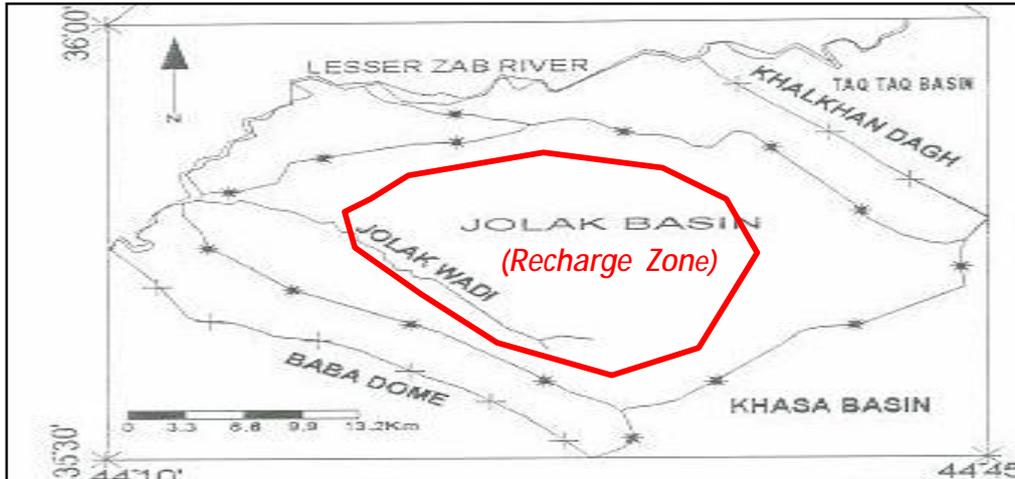


Figure (1) Study area.

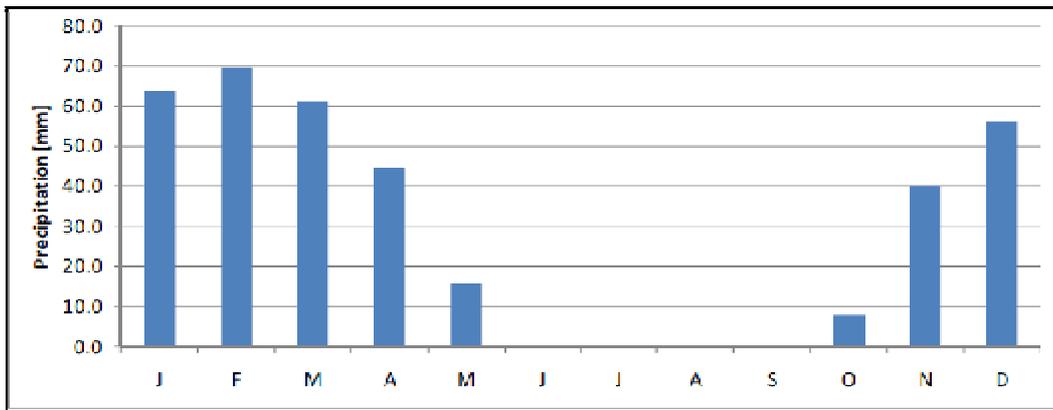


Figure (2) monthly average rainfall at Kirkuk (1934-2008).

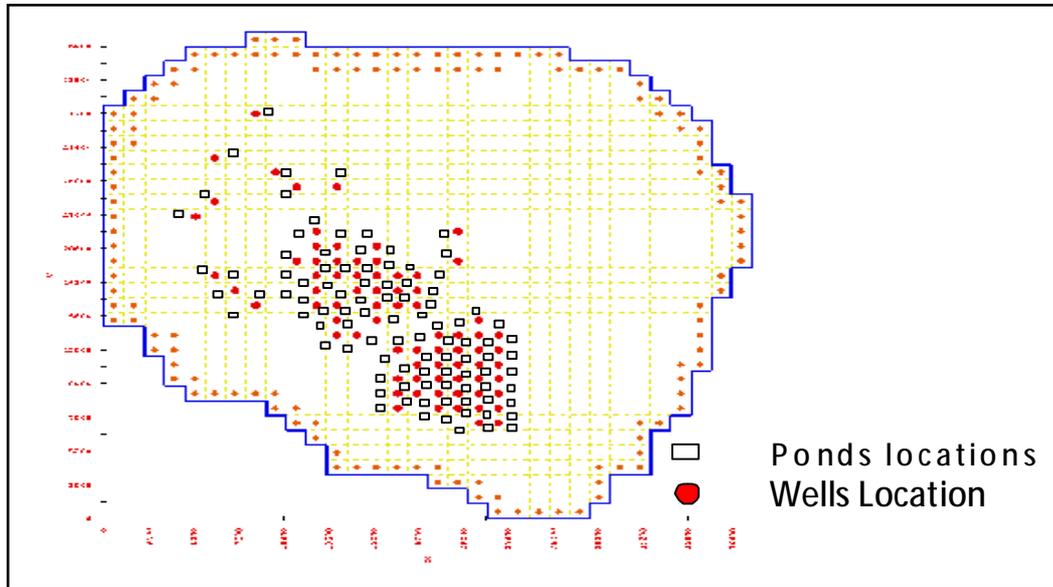


Figure (3) Existing Wells and Suggested Ponds Locations



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

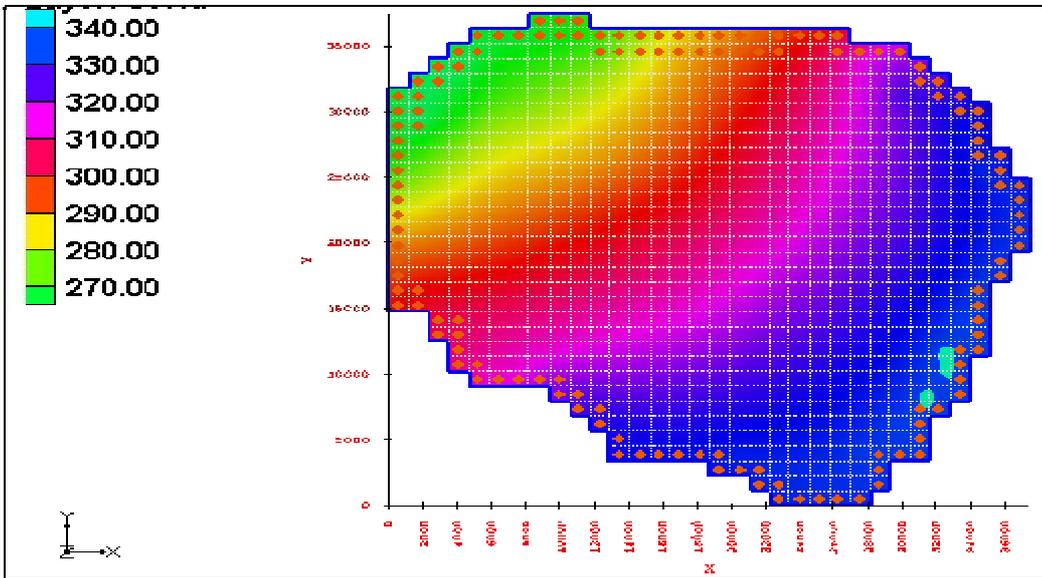


Figure (5) Starting Groundwater contour map in the study area.

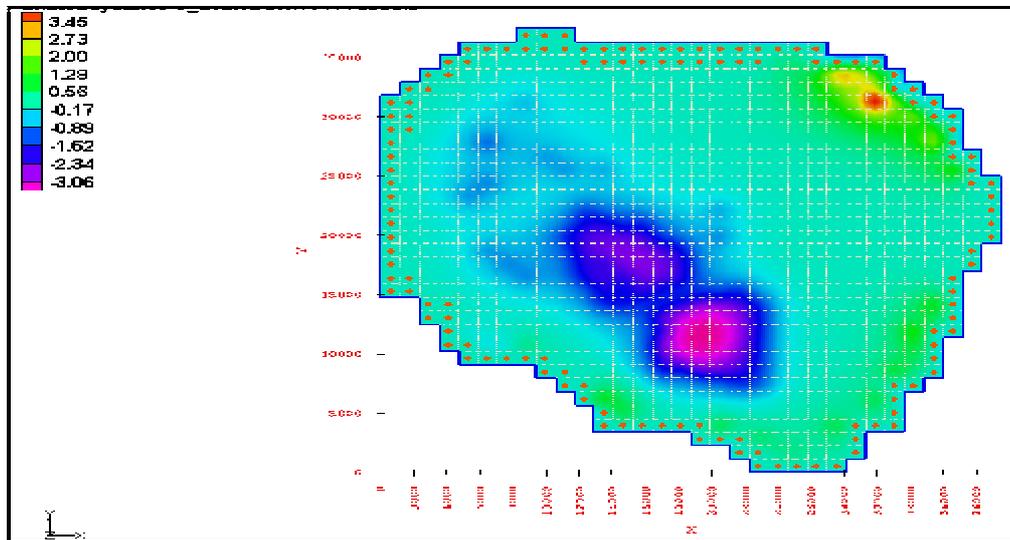


Figure (6) Head contour map after 180 days of Recharging process.

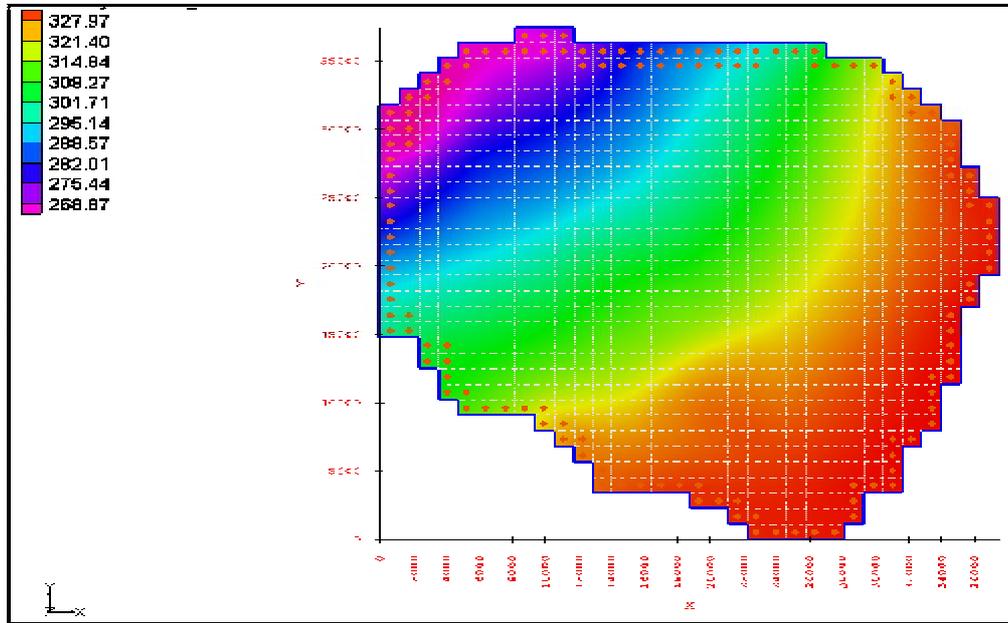


Figure (7) Ground water contour map after 180 days of Recharging process.

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	Low Zone	342.28	21.9	320.38	100
2	Boyd	333.89	28.5	305.39	74.4
3	Boyd House	386.44	49.2	337.24	107
4	Golden	283.24	47.1	236.14	115
5	K.Ram	319.14	10.2	308.94	98
6	Yarqo	330.34	26.0	304.34	126
7	Sakti	213.34	52.1	161.24	79
8	Direna	361.24	32.1	329.14	109
9	Sajid	383.34	47.1	336.24	149
10	Shan Sha	179.44	30.9	148.54	160
11	Obay	179.44	30.9	148.54	160
12	Kadh Bani	310.41	27	283.41	105
13	Kida	235.84	68.9	166.94	146
14	Kart	275.62	20	255.62	96
15	Q.Rajber	233.51	25.4	208.01	132
16	Nabi Awad	206.4	18	188.4	111
17	Qubay	291.24	33.6	257.64	47
18	Qubay	313.54	25.4	288.14	179
19	47	330.5	27.5	303	122
20	44	363.0	27.0	336.0	128
21	45	388.0	42.0	346.0	126
22	48	348.0	19	329	128
23	45	336	34.5	301.5	130
24	26	338	20.35	317.65	122
25	55	366.5	34	332.5	128
26	18	366.0	27	339	128
27	41	377	46.5	330.5	124
28	24	349	27	322	124
29	31	383	52	331	120
30	17	385	24	361	128
31	21	383	30	353	124

No.	Name	Elevation (m.a.s.l)	Water Depth (m)	Head (m.a.s.l)	Well Depth (m)
32	03	379	29	350	130
33	51	385	43	342	104
34	12	382	27	355	128
35	34	368	30	338	130
36	25	374	27	347	130
37	14	367	21	346	122
38	16	360	13	347	124
39	07	363	15	348	124
40	17	361	17	344	128
41	05	373	21	352	120
42	03	361	17	344	122
43	23	375	41	334	126
44	23	364	23	341	120
45	22	377	48	329	130
46	23	363	19	344	124
47	57	380	38	342	124
48	54	371	33.5	337.5	122
49	27	354	20	334	124
50	28	351	17	334	130
51	40	382	32	350	130
52	52	375	29	346	128
53	13	377	26	351	128
54	42	372	45	327	128
55	36	356	25.7	330.3	126
56	16	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	341.39	14	327.39	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

No.	Name	Elevation (m.a.s.l)	Water Depth (m)	Head (m.a.s.l)	Well Depth (m)
66	F2	343.7	19	324.7	120
67	A3	328.24	8.5	319.74	94
68	F3	328.64	9.8	318.84	109
69	D3	332.89	13.5	319.39	109
70	F4	333.07	13	320.07	109
71	F5	332.2	13	319.2	105
72	F6	328.08	7.8	320.28	106
73	F7	330.17	6	324.17	109
74	D4	328.35	11	317.35	101
75	F8	340.63	14	326.63	110
76	F9	328.89	16	312.89	110
77	F10	312.34	6	306.34	106
78	D5	329.08	11	318.08	120
79	F11	327.54	12	315.54	110
80	F12	314.78	7	307.78	85
81	D6	319.67	10	309.67	120
82	D7	321.62	12.5	309.12	120
83	D8	318.71	11.25	307.46	108
84	D9	313.43	5.8	307.63	108
85	D10	316.17	10	306.17	120
86	D11	315.68	12	303.68	200
87	D12	317.86	14	303.86	120
88	D13	309.34	10	299.34	120
89	D14	311.81	9	302.81	110
90	D15	312.42	12	300.42	110
91	D16	310.23	8	302.23	100
92	D17	306	7	299	110
93	D18	302.02	6.5	295.52	110
94	D19	301.76	5	296.76	112
95	D20	303.82	8.5	295.32	124
96	D21	291	16	275	120
97	D22	296	16	280	120
98	D23	296	16	280	120