Conjunctive Use Modeling of Surface Water and Groundwater in The Jolak Basin , North Iraq

نمذجة الاستخدام المشترك للمياه السطحية والمياه الجوفية في العراق

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Abstract

This study contributes to the understanding of the conjunctive use of surface water and groundwater models of the Jolak basin (in the northern part of Kirkuk city, north Iraq) ,with an area of 400 square-kilometers .

The first stage of this work was to collect a dataset to characterize the surface and groundwater .

Soil and Water Assessment Tool (SWAT) and the Groundwater Modeling System(GMS) were adjusted in an interactive manner. In SWAT, a basin to be modeled is divided into multiple sub basins that consist of a homogeneous land use, ground slope, and soil characteristics.

Land use map which was developed by Digital elevation model **(**DEM), that describes the elevation of any point in a given area at a specific spatial resolution, identifies the deferent classifications of land use. Soil Conservation Service (SCS) curve number method was chosen to estimate the surface runoff. The produced runoff volume was suggested to be stored in the several ponds and conveyed to the underground reservoir in order to use it with conjunction of ground water during drought seasons.

SWAT modeling of the groundwater is extremely simplified, so the Groundwater Model System(GMS) was employed to specifically describe the groundwater processes. This model interpreted the available groundwater levels, which is not possible with the used of SWAT. The study suggested using several wells (which already exist in the study area) to be operate at a constant rate in order to divert the stored surface water in to groundwater.

The annual average runoff overall the basin is estimated to be about 1.5×10^8 m^3. This value is suggested to be conveyed to ground water through exiting pumping wells. The results showed that the ground water levels in basin can be raised with about 2m at the middle of the study area from its present level after the steady state condition is reached.

Keywords: Conjunctive use, Surface water, Groundwater, Runoff, SWAT, DEM, GMS.

الخلاصة

تساهم هذه الدراسة في فهم الاستخدام المشترك للمياه السطحية والجوفية في حوض نهر الزاب الاسفل في وادي جولاك (في الجزء الشمالي من مدينة كركوك ، شمال العراق) ، والتي تبلغ مساحتها حوالي 400 كيلومترا مربعا . تبنت المرحلة الأولى من هذا العمل جمع البيانات الكافية لتوصيف المياه السطحية والجوفية .
تم استخدام برنامج (SWAT) ونظام نمذجة المياه الجوفية (GMS) بطريقة تفاعلية . في (SWAT) تم تقسيم الحوض الى مجموعة من الاحواض الفرعية المتجانسة في الاستخدام، الانحدار وخصائص التربة.
خريطة استخدام الأراضي التي تم تنفيذها باستخدام برنامج (DEM) ، التي تصف ارتفاع أي نقطة في منطقة معينة ، تحدد التصنيفات الخاصة استخدام الأحواض الفرعية. وقد تم استخدام طريقة (SCS) لتقدير حجم الجريان السطحي والذي اقترح ان يتم تخزينه في عدة برك من أجل استخدامه بالتزامن المياه الجوفية خلال مواسم الجفاف. فيSWAT يتم نمذجة المياه الجوفية بصيغة مبسطة للغاية ، لذلك تم استخدام النظام النموذجي للمياه الجوفية (GMS) لوصف العمليات الخاصة بحركة المياه الجوفية. يفسر هذا النموذج مستويات المياه الجوفية المتاحة، وهو أمر غير ممكن مع استخدام برنامج SWAT .
وأقترحت الدراسة باستخدام العديد من الآبار (التي توجد بالفعل في منطقة الدراسة) لنقل المياه السطحية المجمعة في الاحواض الافتراضية و بمعدل جريان ثابت إلى المياه الجوفية. متوسط الجريان السطحي السنوي قدر بحوالي 1.5×10^8 م3 . واقترح نقل هذه القيمة إلى المياه الجوفية من خلال آبار ضخ موجودة في منطقة الدراسة . أظهرت النتائج أن مستويات المياه الجوفية في الحوض يمكن أن ترتفع بحوالي 2م في منتصف منطقة الدراسة من مستواه الحالي بعد الوصول إلى الحالة المستقرة .

1- Introduction

Conjunctive use of surface and groundwater is not a new concept but it has been in practice since last three decades. The term ‘conjunctive’ is used to integrate surface and groundwater resources. It includes interaction between surface water and groundwater through groundwater recharge, hydrological cycle, irrigation systems, water balance components etc,[1].

Conjunctive use of surface and groundwater is more common due to two main reasons: (1) to increase the supply of irrigation water and (2) to improve the groundwater quality through dilution.

Surface and groundwater are related systems. They can be used conjunctively to maximize the efficient use of available resources. Groundwater may be used to supplement surface water to cope with the irrigation demands to meet the deficits in low rainfall periods, [2] .

Surface and ground water resources can be conjunctively used either in space or in time. Surface water and ground water resources are considered to have been utilized conjunctively in space when part of the command is supplied exclusively by surface water and part by ground water. In conjunctive use in time strategy, parts of the command may be supplied by surface water at one time, and by ground water at another time, [3] .

It has become difficult in recent years to construct reservoirs for surface storage of water because of environmental concerns and because of the difficulty in locating suitable sites. An alternative, which can reduce or eliminate the necessity for surface storage, is to use an aquifer system for temporary storage of water. For example, water stored underground during times of high stream flow can be withdrawn during times of low stream flow. The characteristics and extent of the interactions of ground water and surface water affect the success of such conjunctive-use projects. Methods of accounting for water rights of streams invariably account for surface-water diversions and surface-water return flows, [4] .

In the present study two approaches are used for simulating surface and ground water. For surface water analysis Soil and Water Assessment Tool (SWAT) ,and a computer software known as Groundwater Molding System (GMS) has been used to simulate the water conveyance from the surface into the subsurface along the study area.SWAT subdivide the watershed into smaller sub-basins and require data on model inputs such as soil and land use for each of those sub-basins.

The main aim of this study is using the conjunctive process to integrate surface and groundwater resources of the Lesser Zab River basin in the Jolak Valley (in the northern part of Kirkuk city, north Iraq). It includes interaction between surface water and groundwater through groundwater recharge. The output parameters from surface water modeling will be used for modeling the groundwater flow. SWAT was designed to predict the total quantity of runoff water accumulating from the whole watershed area. Also, GMS was used to predict the rising of groundwater levels from its starting levels due to the recharging accumulated runoff water as well as the meager flow of the Lesser Zab .The stored can be put to use where and when it is required, with less risk of seepage or evaporation losses during storage and transmission.

2- Description of the Study Area

The proposed model is applied to the conjunctive use of the surface and groundwater resources in the Jolak basin about 20 Km north of Kirkuk city, north Iraq, between longitudes $44^{o}\ 8'$ and $44^{o}\ 35'$, and latitudes $35^{o}30'$ and $35^{o}\ 45'$. It extends over an area of 400 km^2. The basin has a contrasted topography, with mountains upstream and large plains downstream. It is 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, Fig.(1). The Lesser Zab is partially supply water to the agricultural lands in the northern part of basin.

The study area aquifer is considered as a single layered unconfined aquifer, and therefore only the horizontal hydraulic conductivity is estimated.

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, [5].

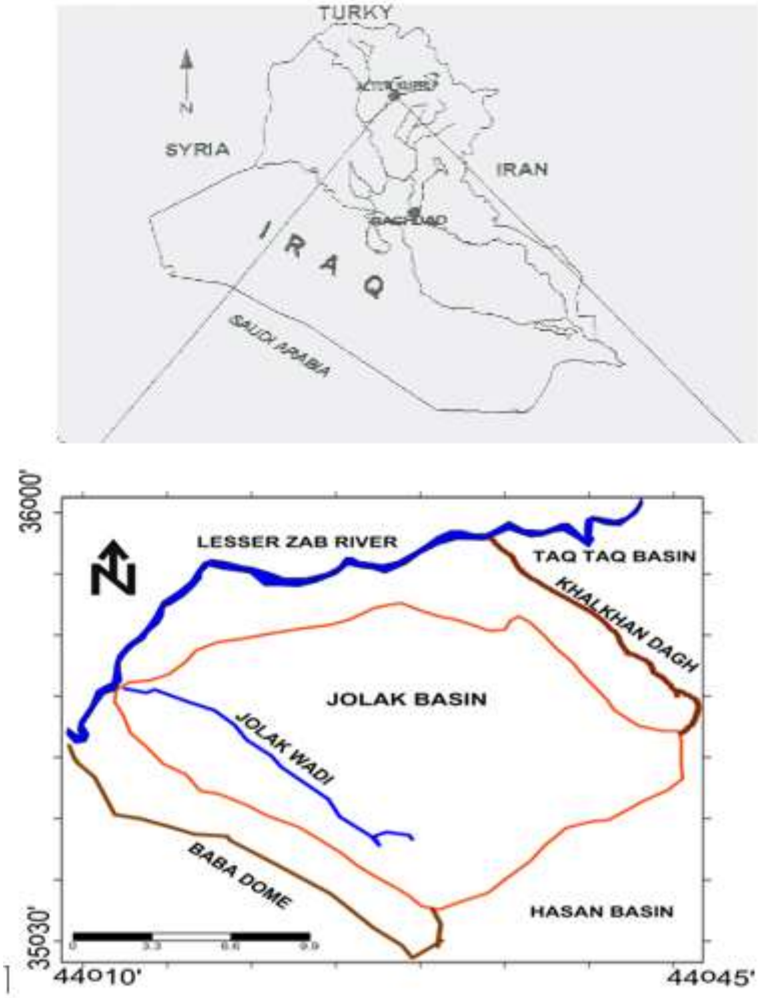

Fig.1: Study area and its boundaries

3- Modelling Soft wares

3.1 Soil Water Assessment Tool (SWAT)

The SWAT model - Soil and Water Assessment Tool is a semi- distributed watershed model with a GIS (Arc View) interface that outlines the sub basins and stream networks from a Digital Elevation

Model (DEM) and calculates water balances from meteorological, soil and land-use data. It developed by the United States Department of Agriculture- Agricultural Research Service [6].

SWAT is a conceptual, physically based hydrological model includes components such as weather, hydrology, sediment transport, crop growth, water quality, and agricultural management, and has been widely applied to assessing water quantity and quality, land use and climate change impacts, and agriculture management in heterogeneous watersheds . This model partitions a watershed into sub basins that allow for consideration of land use and the impact of soil properties on hydrology.

SWAT requires three basic files for delineating the basin into sub-basins: a digital elevation model (DEM), soil map and land use map,[7].

3.1.1 Digital elevation model (DEM) of the study area

The topography is defined by Digital elevation model DEM that describes the elevation of any point in a given area at a specific spatial resolution. DEM was derived from the Shutter Topography Radar Mission (STRM) dataset with a resolution of 90m by DEM map file of USGS, [8], Fig.(2) This DEM was used to delineate the watershed and analyze the drainage pattern of the land surface terrain. A total of 16 sub-basins was delineated in the Jolak catchment. Sub-basin parameters such as slope gradient, slope length of the terrain and the stream network characteristics were derived from DEM.

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,[5]

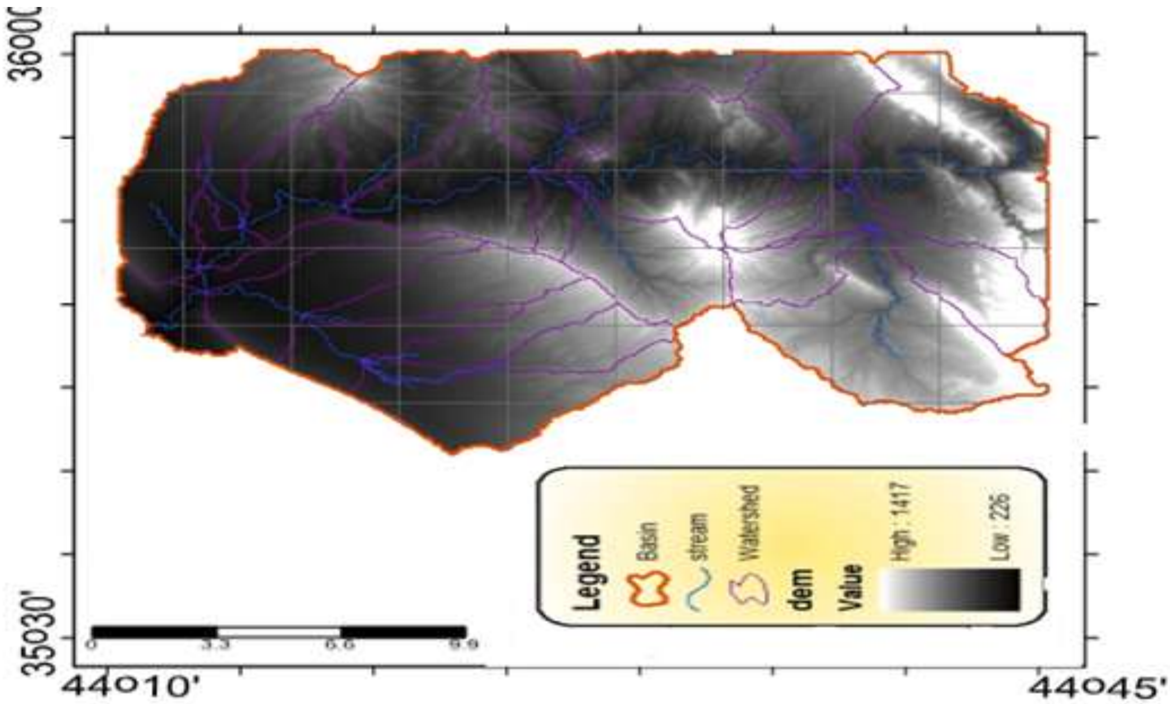

Fig. 2 : DEM of the study area, (USGS, 2002).

3.1.2 Land Use

The physical surface of the earth, including various combinations of vegetation types, soils, exposed rocks, water bodies as well as anthropogenic elements such as agriculture and built environments. The study area was classified by using ERDAS, 2011 program, [9]. Initially, unsupervised classification with a large number of classes was performed. Classification process has created 16 classes of land cover and land use, Fig.(3). Description of each land use code is presented in Table 1, [10]

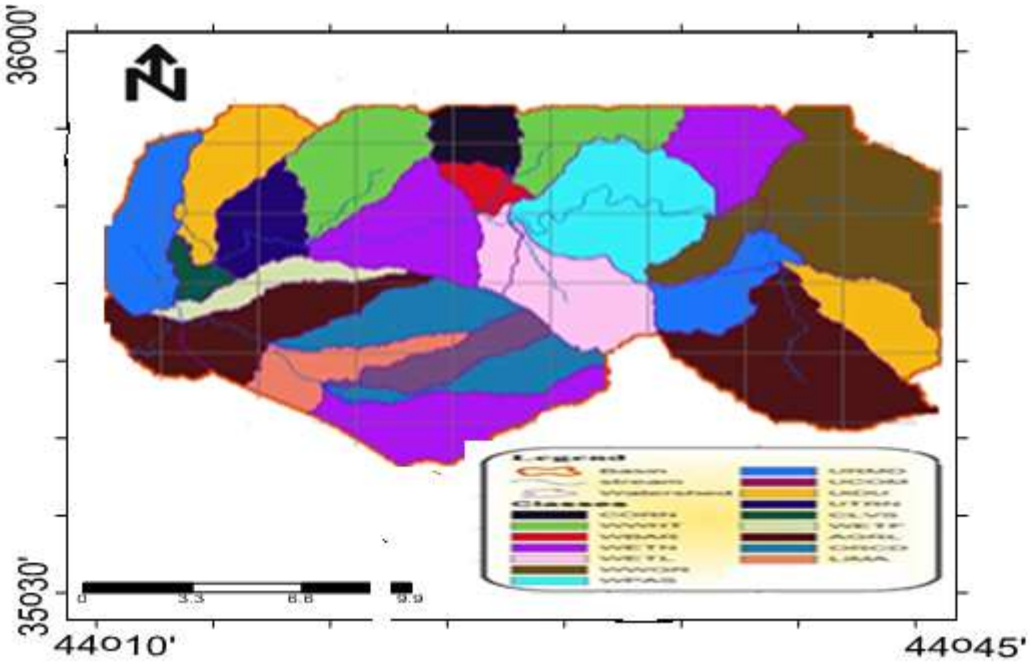

Fig.3 : Land use map, (ERDAS, 2011 program)

Table 1: Land use type and their area coverage in study area, [10]

St. No.	Land use Code	Land use Description	Percentage of each sub-basin area(%)
1	CORN	Corn	4.685
2	WWHT	Winter Wheat	7.717
3	WBAR	Winter Barley	4.417
4	WETN	Wetlands-Non-Forested	9.718
5	WETL	Wetlands-Mixed	5.525
6	WWGR	Western Wheatgrass	9.330
7	WPAS	Winter Pasture	7.804
8	URMD	Residential-Medium Density	4.916
9	UCOM	Urban Commercial	4.940
10	UIDU	Industrial	5.404
11	UTRN	Transportation	5.541
12	CLVS	Sweet Clover	4.248
13	WETF	Wetlands forested	4.443
14	AGRL	Agricultural Land-Generic	8.750
15	ORCD	Orchard	7.137
16	LIMA	Lima Beans	5.424

3.1.3 Soil Characteristics

The soil information had to be processed before entering it in SWAT. In particular, the qualitative description had to be transformed into equivalent quantitative values for the soil database of SWAT, [11]. With SCS-CN method, the soil was classified into four hydrological soil groups A, B, C and D. The hydrologic soil group refers to the infiltration potential of the soil after prolonged wetting,[12] as:.

-Group A Soils*:* High infiltration (low runoff). Sand, loamy sand, or sandy loam. Infiltration rate > 0.3 inch/hr when wet .

- Group B Soils: Moderate infiltration (moderate runoff). Silt loam or loam. Infiltration rate 0.15 to 0.3 inch/hr when wet .
- Group C Soils: Low infiltration (moderate to high runoff). Sandy clay loam. Infiltration rate 0.05 to 0.15 inch/hr when wet .
- Group D Soils: Very low infiltration (high runoff). Clay loam, silty clay loam, sandy clay, silty clay, or clay. Infiltration rate 0 to 0.05 inch/hr when wet.

The soils of the study area 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, GDGW, 2008. So, with regarding to the descriptions of the Chow's soil croups classifications, the soil of the study area can be considered as croup A.

3.1.4 SWAT simulation of the surface runoff

SWAT provides two methods for estimating surface runoff: the Soil Conservation Service (SCS) curve number procedure and the Green and Ampt's infiltration method. The latter required intensive data compared to the SCS curve number method, which is simpler [6]. The SCS curve number method was chosen to estimate the surface runoff because of the restriction in available data.
The SCS curve number equation is, [13] **.**

$Q = (P-0.2\,S)^2/(P+0.8\,S)$ if $P > 0.2\,S$ …………….(1)

$Q = 0$ $P \leq 0.2\,S$ …………………………………..(2)

In which,
Q is the accumulated surface runoff (L),
P is the rainfall depth for the day (L),
S is the potential maximum watershed water retention after runoff begins (L).

The retention parameter (S) is defined by equation,[14]:

$S = 25.4\left(\frac{1000}{CN} - 10\right)$ ……… …………………..(3)

Where CN is the curve number (dimensionless). It has a range from 30 to 100; lower numbers indicate low runoff potential while larger numbers are for increasing runoff potential. The lower the curve number, the more permeable the soil is. As can be seen in the curve number equation, runoff cannot begin until the initial abstraction has been met.

The SCS curve number is a function of the soil's characteristics , land use and the antecedent moisture condition . Typical curve numbers, as calculated by the Soil Conservation Service, 1972 method, (tabulated curve number) is for normal (average) conditions, and termed CNII, or average soil moisture . The other moisture conditions are dry, or CNI, and moist, CNIII.

As explained by Chow et al.,1988 CNII, for normal (average) conditions, is modified for dry (CNI) and wet(CNIII) conditions, through the following equations, [12]:

$CNI = \frac{4.2 \times CNII}{10-0.058\times CNII}$ ………..………………..(4)

$CNIII = \frac{23\times CNII}{10+0.13\times CNII}$………..……………… .(5)

Williams, [15] developed an equation to adjust the Curve number to a different slope as:

$$[CNII]slp = \frac{CNIII - CNII}{3} \times [1 - 2 \times \exp(-13.86 \times slp)] + CNII \qquad (6)$$

Where:

$[CNII]slp$ is the Curve number for average condition adjusted for the slope, slp is the average fraction slope of the basin

To find the runoff in different basins by using the Digital Elevation Model (DEM) of the study area, the curve numbers (CN) values for normal, dry and wet conditions must be found based on the information obtained from land use map, soil type and the selected basins.

The calculation are done by divided a watershed into sixteen sub-regions represented by different curve numbers. Then, the overall curve number is computed. Overall curve number(CN) is computed from, [16]:

$$CN=(1/A)[A_1([CNII]slp)_1+A_2([CNII]slp)_2+A_3([CNII]slp)_3+\ldots+A_n([CNII]slp)_n] \qquad (7)$$

Where,

A_T is the total area overall the basin, as:

$$A_T = A_1+ A_2+ A_3+\ldots+ A_n \qquad (8)$$

And, A_1,A_2 and A_3 are the areas of sub-basin 1, 2 and 3, respectively. n is the number of sub-basins,

The weighted average CN values for sixteen selected basins were estimated depending on area of specific land use land cover as a percent of total basin area, Table 2.

Basin	Basin area (km^2)	Basin slope (m/m)	CNII	CNI	CNIII	(CNII)slp
1	18.942	0.021	67	46.025	82.362	61.005
2	30.868	0.040	65	43.820	81.029	63.154
3	17.469	0.021	60	38.650	77.528	53.586
4	38.875	0.025	49	28.751	68.845	43.463
5	22.102	0.024	36	19.110	56.403	30.604
6	37.323	0.033	63	41.695	79.659	59.635
7	31.218	0.040	68	47.159	83.014	66.221
8	19.666	0.042	55	33.920	72.244	53.500
9	19.757	0.026	89	77.263	94.900	86.678
10	21.613	0.020	81	64.164	90.745	76.429
11	22.164	0.021	76	57.081	87.927	70.911
12	16.992	0.033	64	42.748	80.349	60.667
13	17.773	0.012	45	25.575	65.299	35.816
14	34.997	0.014	59	37.671	76.796	50.559
15	28.546	0.011	57	35.763	75.301	47.548
16	21.695	0.010	71	50.697	84.919	62.545

Table 2: Curve number for average condition adjusted for the slope

Note: Slope of the multi sub-basins which are of the same class is taken by average value of them.

Overall curve number(CN) computed from eq.(7) is found to be 57.098. Equation(3) was used to compute the value of the potential water retention ,(S) which is found to be 190.919 mm for the study area.

Annual average rainfall for the period (2002- 2012), as obtained from Kirkuk meteorological station was applied for the whole basin to find out the volume of water produced by the runoff, Table 3. The result shows that the average total runoff volume from the total catchment area of the sixteen sub-basins was (1.5×10^{8}) m^3 during this period. This produced runoff volume was captured from catchment area and suggested to be stored in the several ponds in order to use it with conjunction of ground water during drought seasons .

Table 3: Total annual runoff

Year	Rainfall (mm)	Runoff (mm)
2002	738.22	550.029
2003	863.50	670.266
2004	681.80	496.375
2005	484.40	312.507
2006	425.10	259.078
2007	388.10	226.394
2008	365.19	206.465
2009	337.89	183.081
2010	610.57	429.221
2011	580.00	400.643
2012	571.26	392.504

3.2 Groundwater model

3.2.1 Groundwater Model System

Since SWAT modeling of the groundwater is extremely simplified, the Groundwater Model System(GMS) developed by the department of defense,(1998) was also employed to specifically describe the groundwater processes. This model interpreted the available groundwater levels, which is not possible with the used of SWAT.

Groundwater Molding System (GMS) software simulates the groundwater three dimensional flow which can be express in the following equation, [17]

$$\frac{\partial}{\partial x}\left(Kxx\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial x}\left(Kyy\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial x}\left(Kzz\frac{\partial h}{\partial z}\right)-w=Sc\frac{\partial h}{\partial t} \text{ ------------------- } (9)$$

Where

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.

3.2.2 Input data

Present study suggested using several wells (which already exist in the study area) as shown in Fig.(4). The figure shows, also suggested locations of runoff collecting ponds near the existing wells. The pumping test was conducted by General Directorate of Groundwater, [18] 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 groundwater movement 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, Fig. (5)

The input data (coefficient of transmissibility, elevations of top and bottom of the aquifer and storage coefficient) are prepared as contour maps for the areal distribution in the study area grid. Lesser Zab river is considered as a constant head boundary or recharge boundary which supplies water continuously to the aquifer.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 groundwater levels due to the recharging during one year is shown in Fig, (6). Figures 4, 5 and 6 show the boundaries of the study area that affected by the recharging process as it considered in GMS.

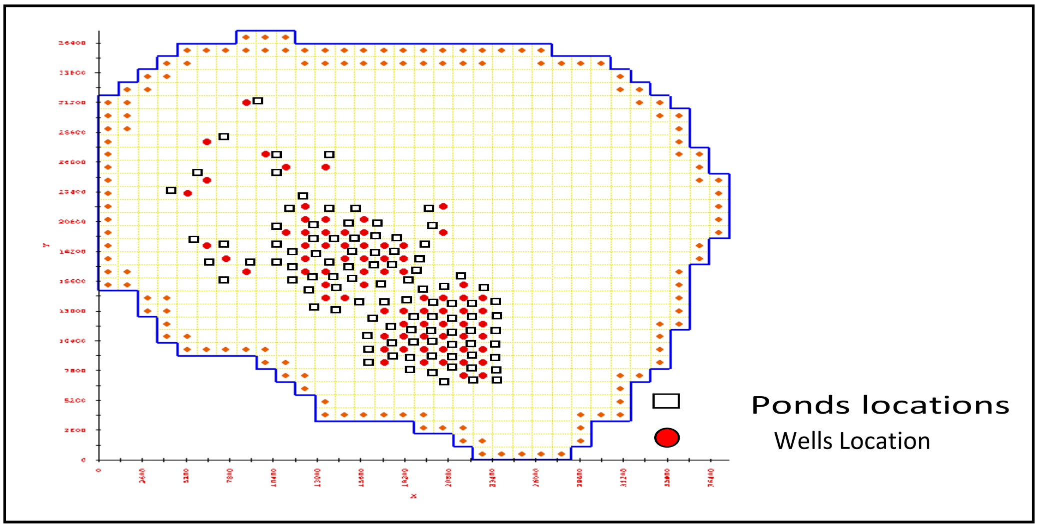

Fig. 4: Existing wells and suggested ponds location

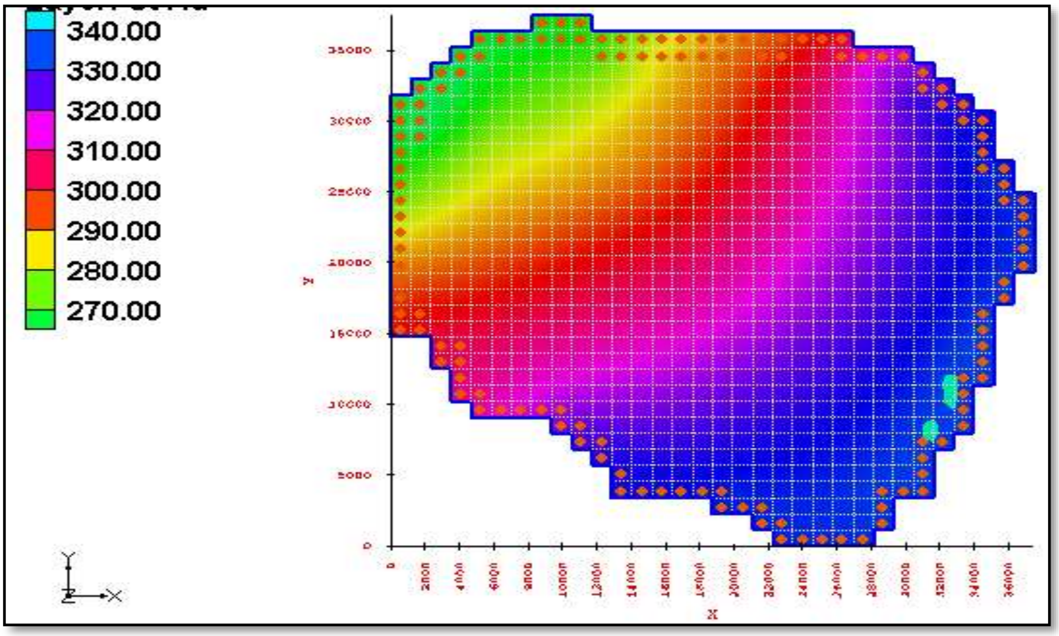

Fig. 5: Starting Groundwater contour map in the study area.

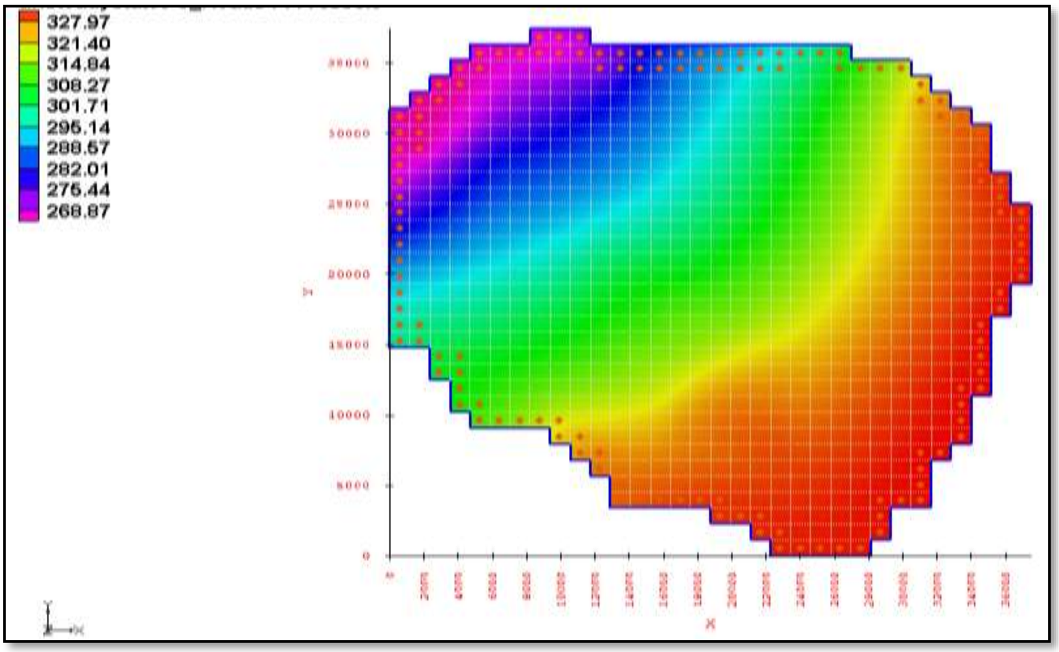

Fig.6: Ground water contour map after water pumping process.

4- Results Discussion

Conjunctive use process was implied in this study to maximize the efficient use of total water resources through the interrelationship between surface and subsurface water by storing the surplus of surface water in subsurface reservoirs to meet the water deficits in years of low rainfall.

The surface water model(SWAT) was prepared by specifying the model entrances consist of basin characteristics(areas ,slope, land use), rainfall depth and soil type. The modeling results during the period 2002-2012, Table 3, demonstrate that the maximum runoff depth was 670.266mm in the year 2003, while the minimum depth was observed in the year 2009 with the value of 183.081 mm. This can be explained the high variety of quantity of runoff that captured during the runny years and less rainfall years. So, the importance of storing the surplus of surface water during the runny years, was the goal of this study.

In order to estimate the total average annual runoff volume in the catchment area of sixteen sub- basins with total area of 400 Km^2, the period of 2002-2012 was selected with average annual rain fall depths listed in Table 3. Rainfall depths during this period were ranging from 337.89 to 863.50 mm that produced total average runoff volume of $(1.5 * 10^8) m^3$. This value was used as a recharge rate in the groundwater modeling. Figure 6 shows the rising of ground water levels from its starting levels,(Fig.5) due to the recharging the annual runoff volume . As it can be seen in this Figure, most of the allocated water was concentrated in the middle of the Jolak valley.

5- Conclusions

According to the results, the following conclusions may be drawn from the present study:

1- Conjunction use of groundwater with surface water helps bridge the dry times between the rainy season to the benefit of water storing and minimizing the evaporation losses.

2- This study was revealed that the rain depth was not the only influential factor. There are other factors that influence the quantity of the runoff water such as: the size of the catchment area, its slope, antecedent moisture conditions (AMC), and the curve number value (CN).

3- The total annual runoff in the whole catchment reached about 1.5×10^8 m^3. This quantity will contribute in solving the problem of water shortage within the region.

4- The ground water levels in basin may be raised by means of several collecting ponds and pumping wells distributed over the study area.

5- Also, the present study showed that the 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 after 12 months.

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