Optimum Groundwater use Management Models by Genetic Algorithms in Karbala Desert, Iraq

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Abstract
Shortage in resources of water in semi-arid region as in Iraq have become an increasing extent dangerous problem. This research objective to improve a new management simulation model for resources of groundwater by linked simulation-optimization (S/O) model. The numerical responses of the 3-D numerical model were Integrated with Genetic Algorithm (GA) optimization model in order to obtain the optimal use of groundwater resources in study area of Karbala desert area in Iraq. The three-dimensional numerical simulation program is used to simulate the system of groundwater flow for Al-Dammam confined aquifer under different conditions. The development management simulation model was adopted by operating the model with considered calibrated variables for current and future periods. Results of analysis the management (S/O) models indicate that the maximum value of pumping rate is reach to (450 E05) m³/year). Also, the pumping rates of the wells within study area could be increased to three times the present water required, with a maximum fall reach to 7.21m in the static heads of groundwater of aquifer.

Keywords: MODFLOW; Genetic Algorithm; Simulation-optimization; GMS.

1. Introduction
In Middle East region, groundwater plays an important role in different water resources available within this region, which is utilized in many fields, like the agricultural, industrial and domestic purposes. The management of groundwater simulation models are a high priority in order to provides the increasing water demand. Recently, with climate change threats, life standards change and increasing population there is a rising requirement for the employment one of the important water resources like the groundwater. Nevertheless, since several anthropogenic reasons like industrialization and random urbanization, the quality and amount of groundwater resources goes on to deteriorate. Accordingly, decision makers should be utilized the sustainable management strategies in order to reach the optimum used of groundwater.
The models of the optimization are formulations mathematically describes by the objective function and a group of constraints. Constraints illustrate the feasible solutions area from where the optimal solution is to be find. While, the objective function represents the grade of reach of the objective. So, these models are formulated to obtain best solutions depending to the considered objective, sometime minimum cost or maximum profit, when accepting a grope of declared technological, physical and other limitations. The powerful management models of aquifer, that have the power to find the solutions of the governing equation of groundwater flow in meet with optimization methods. Beside studies of simulation, linear, nonlinear and dynamic programming are the common programming methods. Das and Datta, (2001) presented a comparative research on the computational difficulties and applicability for many from these models.

Genetic algorithms (GAs) are a global inspection method depend on the natural genetics and techniques of matured chosen, which join artificial existence of the fittest with genetics factors excluded from nature. H. Holland, reported his initial study of the genetic algorithm in 1970. The GAs are considered in a very wide set of applications such as water resources due to its hasn’t any limitations in the objective function derivatives respect to decision variables. The evolution and implementation of the connected simulation-optimization process has been an efficient and productive research domain in last year’s such as (Gaur et al.,2011; Singh, 2014; Singh and Datta, 2006; Fattah et al.,2018; Hassan et al.,2018; Safavi et al.,2010; Hassan ,2019 and Hassan et al. ,2020). Chu et al. (2007) presented the study to integrate Constrained Differential Dynamic Programming (CDDP) and genetic algorithms in order to find optimum program of the wells pumping and redaction the ecological effects. Original formulation of hybrid algorithm is Genetic Algorithm, where each chromosome symbolizes the probable wells network design and expansion pumping wells schedule. The constant cost of any chromosome is calculated simply by the GA. Then, solved the optimum pumping program by CDDP, at the end, validation of the optimum working costs accompanied with every chromosome solution. Guan et al. (2008) reported an develop GA called (IGA) in order to find the solutions of optimization issues associated of both inequality and equality limitations. For this improved method, the reform process was included on growth procedure to deal with unsuitable solutions in order to create whole members of population meets requirements whole limitations. The improving method is utilized to evolution the optimum management of groundwater schedule for the region of Savannah, Ga. Moharram et al. (2012) studied the
optimization problem depend on integration of GA corresponding to numerical model. This computation method was applied in El-Farafra oasis, in Egypt in order to found the optimum plan of the pumping through many periods of simulation. Li et al., (2019) presented the analysis of the implementation of the GA in the procedure of the management of water resources, also simulates with certain cases, to verification the acceptability of the algorithms of the model. Also, the results of the research provide an effective decision-making program for the existing management of water resource.

Until now, there are no detailed studies available in the study area, only some general hydrogeological studies such as (Khalaf and Hassan,2016; Al-Mussawi,2014). For that, the previous studies shown the knowledge of the hydrogeological for Al-Dammam aquifer in the desert of Karbala is still insufficient based on its importance of groundwater for current and future uses.

2. Study Area

Geographically, study area is lying in the west and southwest of Karbala governorate, Iraq. Coastal of Al-Razzaza lake limits the study area from the south. It is existing between longitudes (43° 46’ 47ʺ - 43° 48’ 39ʺ) E, and latitudes (32° 31’ 48ʺ - 32° 29’ 28ʺ) N, as shown in Figure 1. Its shape represented close to the trapezoidal shape which occupies an area of about (134.6) km². It's consisted from many geological units and exemplify a main section of Karbala-Najaf plateau. Al-Dammam aquifer represented the producing hydrogeological formation of the western desert and the study region. Type of Al-Dammam formation is karst confined aquifer. General, flow direction of groundwater is from the west to the east. Recently, more than 60 new wells for production were established within Karbala desert area. It has an average depth reach to (250-300) m. The main types of soil in the area are sandy soil, sedimentation and sand gravel mixture and some presence of clay lenses. The slope of the region could be characterized as a smooth and the general elevation varying from 50 to 95 m.a.s.l as display in Figure 2.

2.1 Study Area Geology

Generally, the study area projection is within the plain of desert, which is a portion of irresolute plank. It is a part from plain-such as to partially expressed hilly symbol. Also, it is supposed as a piece of Najaf-Karbala plateau, which includes to the Mesopotamia region, existing in the middle area of Iraq. The surface of study area is enveloped by Gypcrete deposits approximately for all. The profile of lithology was
founded by 40 wells drilled by the General Commission of groundwater in Iraq, as well as from additional coring well within study area boundaries. It's content as the next geological formations, in sequence from deepest to highest:

**Figure (1):** Location map of the study area showing the location of 43 wells.

**Figure (2):** Topography of the study area.
2.1.1 Cretaceous (Tayarat formation)

The Tayarat formation is consisted of clayey, limestone and limestone dolomitic and dolostone. Tayarat formation is identified by the being of Karstification and cavities in generality regions (Jassim and Goff, 2006). The formation is spread in the desert of (202288.8) km2 and thus a wider formation found in the desert. The thickness of the formation was varied with an area of this spreading, since the higher thickness of it's in the south-west of the desert, when the Iraqi-Saudi border, specifically at the oil well Sfawi -1, with a thickness of 350 m. This thickness is decreasing towards the north and north-east of up to 50 m at the Sea of Najaf areas (south of the study area) (Al-Jawad et al., 2002). As in the study area, it is at a depth of more than 450 m.

2.1.2 Umm Er Radhuma formation (Upper Paleocene)

The formation called Umm Er Radhuma is generally consists from dolomitic and dolomite limestone with fine bottom of gypsum and anhydrite. Umm Er Radhuma formation is identified by the existence of cracks, gaps and fissure, which creates it a suitable for water reservoir formation within the Southern Desert (Al-Sa'adi, 2010 & Hassan, 2020). Umm Er Radhuma formation is deem one of the most significant aquifers in study area. It appears a complicated hydrogeological formation with Al-Dammam formation, because being of hydraulic link between two formations (Al-Jawad et al., 2002; Al-Jiburi and Al-Basrawi, 2007 and Fattah et al., 2018). The hydraulic connection between the two aquifers has effect evident in salinity of the groundwater in Umm Er Radhuma aquifer. The salinity decreases as a result of the water pressure decrease, due to the vertical movement of water toward the Dammam aquifer. The electrical conductivity ranges more than (2000 µs/cm) (Al-Jiburi and Al-Basrawi, 2007). The piezometric head in Umm Er Radhuma aquifer is about 42m (Consortium, 1977; Basriawy, 1996).

2.1.3 Dammam Formation (Eocene)

The formation of Al-Dammam could be considered one of the more important formation aquifers in south west desert of Iraq. Al-Dammam formation is consisting of different carbonate rocks majorly the dolomite, dolomitic limestone and limestone with marl and evaporates. It is identified by the existence of cavities and karstified canals as well as to fractures, joints and fissures, which produces it have highest permeability and transmissivity, in large area (Jassim and Gaff, 2006). The hydrogeological investigations in the Western and Southern Desert (Jassim et al., 1984) reflected that Dammam
formation contains huge amount of groundwater. In the regional study area, the piezometric head in the Dammam aquifer is about 41.97 m which is very close to piezometric head in Umm Er Radhuma aquifer, this indicating the vertical recharge from the lower aquifer (Umm Er Radhuma) to the upper aquifer (Dammam) (Consortium, 1977; Al-Furat center, 1989).

2.1.4 Euphrates Formation (Early Miocene)

The Euphrates formation is considered the most extended formations in Iraq and returns to the early Miocene sequence. It is originally described by Bellen and others in 1959. It is containing of limestone with texture ranging from olitic to chalky limestone which locally contain shell coquinas and corals; they are often recrystallized and siliceous (Jassim and Goff, 2006).

2.1.5 Nfayil Formation (Middle Miocene)

Nfayil beds are about (15-30) m thick. Generally, consist of green, partly reddish in places sandy, dolomaitic and gypseous marl with interbedded calcareous, fossiliferous limestone and partly sandy claystone. The red sandy claystone and marl are often present at the bottom and the top part of the sequence. The gypsum occurs as selenite veins and as crystals within the rocks (Al-Jaf and Al-Saady, 2010 and Nile et al., 2019).

2.1.6 Fatha (Lower Fars)

The Fatha Formation is considering the most aerially widespread and economically important formations in Iraq. It is developed in the southern direction of the study area and along the eastern beach of Al-Razzaza Lake. The member has a thickness up to 25 m. The contact with overlying Injana (Upper Fars) formation is apparently conformable and gradational.

2.1.7 Injana (upper fares)

The Injana formation is exposed straight both ridges of Tar Al-Sayid and Tar Al-Najaf and in the eastern beach of Al-Razzaza Lake. Generally, the formation consists of red, partly greenish silty, sandy calcareous claystone and lenticils of grey, brownish, greenish and yellowish sanstone. Thin beds (0.3 m) of marly and chalky limestone are occasionally present in the sequence (Barwary and Slewa, 1995).

2.1.8 Dibdibba Formation (Pliocene – Pleistocene).
Dibdibba formation is composed of sandstone with some claystone and pebbly sandstone, siltstone, and marl associated with secondary gypsum. It is less than 80 thick, (Al-Jawad et al., 2002). Dibdibba formation is uncovered at the southeastern part of the Southern Desert. The formation is well exposed along both ridges of Tar Al-Sayed and Tar Al-Najaf, occupying the top most part of the exposed sequence, hence making up the bed rock of the desert plain between Karbala and Najaf. Another exposed area of the formation located in Al-Basra and Al-Muthana provinces which are located within southern desert, with maximum thickness closed to 350 m(Al-Mussawi,2008).

2.2 Aquifer of Groundwater

Some of the geological formations such as Umm Er-Radhuma, Tayarat, Dammam, Dibdibba and Euphrates formations are considered as water carrier formations in Karbala desert. The geological profiles investigations from many boreholes display the existence of rather complex multi-aquifer regime with impervious layers found in lenses form, which locally dividing the aquifers. Many previous indicated water bearing formations, the main generated aquifers are appeared by the collection of the Al-Dammam and Umm Er Radhuma. Figure (3) illustrate the keyhole positions and all wells which utilizes to obtained an extension and thickness of Al-Dammam. From the Figure (4a) it’s could be showing the Dammam thickness starting in decrease from northeast to southwest. Also, its top level will be increased on this trend. Section (B-B) in Figure (4) illustrate the lithological features fixed without changes. Average thickness of the Al-Dammam close to 195m. Figure 5 shows the equipotential contours map for the regional study area. The main direction of groundwater flow across the east and the northeast.
Figure (3): Trend of the sections between the wells in the study area.

Figure (4): The stratigraphic correlation between the wells in the studied area (a) cross section (A-A) and (b) cross section (B-B) developed from (Consortium, 1977; Sissakian, 1995).
3. Material and Methodology

3.1. Groundwater Model

Groundwater Modeling System (GMS) software v.10.1.4 with MODFLOW application was used to inspect the physical information for qualifier of the flow techniques, as well as the initial and boundary conditions. Three-dimensional anisotropic and heterogeneous governing equation for groundwater flow of uncompressible fluid (Jalal, 2020):

\[
\frac{\partial}{\partial x} \left( K_x \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left( K_y \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left( K_z \frac{\partial h}{\partial z} \right) + W = -S_s \frac{\partial h}{\partial t}
\]

where:

- \( K_x, K_y, K_z \) are the permeability coefficients for x, y, and z directions respectively;
- \( h \) is the total head;
- \( W \) is the flow for one unit volume (sources, sinks), it is positive signs for into flux and negative signs for out flux;
- \( S_s \) is coefficient of specific storage;
- \( t \) is the time.

3.1.1. Conceptual Model

Suitable description of the parameters of hydrogeological on the modeled region is needed to know the significant of pertinent flow operations. In the case of absence this information, it is difficult to chosen a suitable simulation or improve a surely calibrated simulation. Only some of hydrogeologic information was available in some places for the study area, like the characteristics of aquifer. So, in order to doing the assessment for that information, the Kriging method was utilized to obtained other parameters for the all study region. Positions of the 43 wells are show in Figure (1) will be used to predict the aquifer information.

The conceptual model process includes implementation the geographic information system GIS software tools in the map module to produce a conceptual model of the place being simulated. Position of sinks/sources, simulation boundaries, aquifer properties and whole other information needed for the modeling could be identify at the stage of conceptual model. After this simulation is finished, the grid model is created and the conceptual model is transforming to the grid simulation and whole of the cell-by-cell transfers are doing automatically. The process of the conceptual model is the best efficient process for constricting actuality, complicated approaches is the
conceptual model approach. For this approaching the conceptual model was applied in this study.

### 3.1.2. Design of Grid

The range of the model was covered about 132.7 km$^2$. Selected of grid for the model consists from two layers, 106 columns and 87 rows. This dividing creates 9222 cells in each layer of the model. The dimensions of each cell reach to 150.94m in x-direction and 108.27 m in y-direction as display in Figure (6). Also, significant to obtained that separate grid results have been founded. Used the trial and error to prescribed the size of grid in the surface and was a compromise between computational time and model accuracy.

### 3.1.3. Boundary conditions

The southwestern and northeastern boundary conditions of study area were selected based on the regional groundwater flow (refer to Fig.5). These conditions were represented a constant heads boundary conditions 65 and 50 m for the southwestern and northeastern and respectively. Moreover, the wall boundary or (no-flow) set the southwestern and southeastern edges of the simulated area due to it belong stream lines.

![Figure 6: Flow model boundaries, grid, and pumping wells.](image)

### 3.2. Formulation Optimization Model
GAs are the main expanded sets of models reflecting the implementation of evolutionary algorithms. Genetic algorithm method is improved depend on Darwinian concept of the ‘survival of the fittest’ and the normal procedure of growth during generation. The solutions for any optimization example are introduced in the shape of a string, named “chromosome”, containing from group of elements, named “genes”, that contain a group of parameters for the optimization parameters. Each chromosome (solution) fitness is obtained from examine it versus the mathematical equation represented by the objective function. Each chromosome has a potential as the valid solution for optimization problem. Length of chromosome equal to the number of decision variables. The value of Gene is actual coding (real values). The idea of genetic algorithm is depending on the primary chosen of a small (relatively) population. The person in the population has potential to take a solution in the variable area. Each individual fitness is computed using the amount of the objective function, obtained from a group of parameters. Natural development procedures of crossover, selection, procreation, mutation and selection, are utilized by probability principles to improve the next and best populations. Principles of the probabilistic permit several fewer fit persons to survive. Main idea of this research is to maximize the production function \( Z \) with regard to the rate of pumping, \( Q_j \) as design variable.

\[
Z = \max \left\{ \sum_{j=1}^{N_w} Q_j - \lambda_1 P(h)_j - \lambda_2 P(Q)_j \right\} \quad (2a)
\]

where: \( N_w \) is the total number of wells pumping, \( P(Q) \) and \( P(h) \) are penalty expression related to the total pumping and well piezometric head constraints respectively, its equal to (0) if no one of total pumping constraint and hydraulic head constraint are violated; else gives changes linearly according to the value of constraint violation, depend on:

\[
P(h) = \begin{cases} r_j - d_j & \text{if } r_j > d_j \\ 0 & \text{if } r_j \leq d_j \end{cases} \quad j = 1,2,3,...,N_w \quad (2b)
\]

\[
P(Q) = \begin{cases} Q_D - \sum Q_j & \text{if } \sum Q_j < Q_D \\ 0 & \text{if } \sum Q_j \geq Q_D \end{cases} \quad j = 1,2,3,...,N_w \quad (2c)
\]

where: \( r_j \) is the calculated decline in water level at well \( j \) due to rate of the pumping \( Q_j \) from the well \( j \), \( d_j \) is the allowable decline in water level at pumping well \( j \) and \( Q_D \) is the amount of water required. The application of the penalty process is applied by multiplying the penalty expression with a weighting factor, \( \lambda \), as shown in the above Equation (2a). It is important to say that the bigger \( \lambda \) for any constraint group represent
that the greater emphasis will place on resolving constraint violations. Nevertheless, chosen of the $\lambda$ value is generally dependent on the optimization problem.

The rate of pumping in the objective function (Eq.2a) are intercept to the some constrains as following: **First constraint**: this constraint related to the quantity of the pumping from the each well, the rates of the $Q_j$, this values should be limited between the minimum pumping rate from the well ($Q_j^{min}$) which related to the minimum water required for the area served by this well, and the other limitation is the permissible maximum values of pumping rate from the well ($Q_j^{max}$), this value related to the permissible value of the maximum drawdown in the wells. This constraint could be formulated as the following:

$$Q_j^{min} \leq Q_j \leq Q_j^{max} \quad j = 1,2,3, \ldots, N_w$$

(3)

When application this constraint within genetic algorithm modeling, it is simply fulfilment by limitation the number of populations. So, there is no privet processing necessary for this constraint.

**Second constraint**: this constraint related to the drawdown in each well. This constraint represented the limitations for environment protection and uneconomic withdraws, and its stated as below: 

$$r_j \leq d_j \quad j = 1,2,3, \ldots, N_w$$

(4)

where $r_j$ is the value of drawdown in pumping well $j$ due to a pumping rate from well $j$, $d_j$ is the allowable drawdown at pumping well $j$.

**Third constraint**: this constraint related to the quantity of water required to meet the water demand for each well in the studied area, it was stated as below:

$$\sum_{j=1}^{N_w} Q_j \geq Q_D$$

(5)

where $Q_D$ is the quantity of water required (demand).

### 3.3. Simulation-Optimization (S/O) model

The groundwater management model is suggested the solution performed through connected simulation-optimization (S-O) model. MODFLOW under FORTRAN code is utilized as the solver for the simulation of groundwater model. This simulation model is connected with GA optimization model. Figure (7) displays the flowchart of S-O system model, where FORTRAN code is applied in order to connect between the GA and simulation model. The optimization process continues to be carried out by iterating till reach termination threshold. It is important to mention that different termination
threshold can be used to end the simulation. These may be: Ending the simulation when number of iterations was reached; reaching the specific value of objective function; no development in the value of objective function for a limited number of iterations; or after specified time. The standard error value is utilized in this study in order to review the iterations convergence. Thus, the criterion of convergence is formulated as,

$$\frac{f_1 - f_0}{f_0} \leq \varepsilon$$  \hspace{1cm} (6)

In which $\varepsilon$ is a tolerance for the iteration’s convergence, if $(f_1, f_0)$ satisfy the criterion.

Figure (7): Flowchart for the single simulation-optimization (S-O) model (Moharram et al. (2012)).
4. Results and Discussions

4.1. Model Validation

For steady state calibration, the recharge and hydraulic conductivity for aquifer were expected. Calibration process of steady condition was done by used 43 wells and the two amenable variables. The calibration approach was done used minimizing the error between simulation -estimated head levels of groundwater at steady state and observed head levels pending the simulation time. There are two calibration methods usually used in simulation of groundwater, automated calibration and trial and error process. The second options for the trial and error process could be utilized to repeatedly modify model variables till the simulation obtained values agree with observed data within suitable degree of agreement. Due to the trial and error process depended on the biases and users experience, the process is not effective to obtained the results reliability and the uncertainty of statistical. Best calibration can be carried out by an inverse modeling approach. The inverse approach is a command that automates the parameters estimation operations. It systematically set user-defined group of the input variables tell the error of calculated and measured values is minimized. The software of GMS has a tool for Parameter Estimation Tools (PEST) which represented the inverse simulation, it was used as calibrated approach in this research.

The main results computed by the calibrated simulation for steady condition could be stated as following:

1. Figure (8) shows the scatter diagram with best fit line for observed against computed piezometric heads. The determination coefficient ($R^2$) value for the best fit line reach to (0.9747).

2. Moreover, the analysis of error was carried out as shown in Table 1 for mean error (ME), mean absolute error (MAE) and root mean square error (RMSE). The performance of the model reach to ideally when values of these statistical indexes close to zero. Table 1 shows that the values of (ME), (MAE) and (RMSE) equal to (-0.0003), (0.179) and (0.232) respectively. These values of statistical indexes indicate to the simulation model was very good accuracy and it refer to that the boundary condition, conceptual model and the calibrated parameters of hydrological which applied within the simulation are credible,
so, the final simulation model can be used to estimate the groundwater flow properties within the aquifer.

3. Figure (9B) illustrate the spatial distribution of modeled piezometric heads of aquifer, as shown it was identical with the spatial distribution of observed piezometric heads (Fig. 9A).

According to the calibrated conceptual simulation model, the optimum recharge rate and the values of hydraulic permeability (K) for the aquifer of study area are shown in Figure (10). In order to calibrations the transient model, used the period from 10th of March, 2012 to 10th of January, 2013 to observe data, then dividing this period into 11-time steps. The observed data from 21 observation wells were used in the calibration and validation model. The identical variable is computed from steady state calibrated model. Also, the synchronous discharge rates are assessment by real consumptions in the field.

Figure (11) shows the scatter diagram for observed against computed heads in aquifer for transient, it was used to exam the capability of transient model. The scatter diagram displays $R^2 = 0.7818$. Moreover, it is could be shown from the Table 2 that the statistical indexes of calibration process for the transient state. Based on these assessments, the transition simulation was very good calibrated. This simulation after calibrated for aquifer in study area was utilized to present the effects on Al-Dammam confined aquifer until year 2063 (43 years).

Figure (8): Scatter diagram of relationship between observed piezometric head and computed piezometric head.
Table (1): Statistical indexes values for steady condition calibration.

| Index                              | Value   |
|------------------------------------|---------|
| Mean error (ME)                    | -0.0003 |
| Mean absolute error (MAE)          | 0.179   |
| Root mean square error (RMSE)      | 0.232   |

Table (2): Statistical indexes values for transient calibration.

| Index                              | Value   |
|------------------------------------|---------|
| Mean error (ME)                    | 0.198   |
| Mean absolute error (MAE)          | 0.554   |
| Root mean square error (RMSE)      | 0.694   |

Figure (9): A) Contour map of observed piezometric heads and B) final calibration contour map of simulated aquifer piezometric heads (m.a.s.l) during 2012.

Figure (10): Calibrated hydraulic conductivity for the aquifer (m/day) (left map) and calibrated recharge rate for the aquifer (m/year) (right map).
4.2. (S-O) Modeling

In this study, the evaluation of optimum objective function represented by the quantity of pumping rate from the existing 43 pumping wells which founded on Al-Dammam formation confined groundwater aquifer with total flux reach to 42609 m$^3$/day and its drawdown. The S-O simulation model evolved was operated for five years’ time stage 2018, 2023, and 2028, then, simulation for ten future years 2043, 2053 and 2063. The optimum pumping discharge through modeling time stages and regarding decline of water level on the aquifer was shown in Table 3. The water required of present pumping discharge is 42609 m$^3$/day, with corresponding declination of water level values ranging (19.05 -24.61) m. The optimum pumping rate was found from the produced optimization model in this study ranging (123148 m$^3$/day to 94405 m$^3$/day) and the corresponding maximum drawdown range from 26.26 m to 30.77 m. For the initial five years simulation time step, it was obtained the optimum (maximum pumping rate) which represent the value of the objective function is (123148 m$^3$/year), in other words, the pumping rates value could be increased to three times the pumping rates demand at present, corresponding to the maximum fall in the water level of groundwater, versus with current water level closed to 7.21m. However, at the end of the modeled time (future 50 year), quantity of pumping recharges can be increased to double the present value of pumping water demand, corresponding to the maximum fall in the wells water levels relative to current water levels closed to 6.15m. Figure (12)
illustrates the maps of contour lines of the predicted head distribution for Al- Dammam confined aquifer located in studied region for optimum water pumping simulations for the periods 2018, 2023, 2043, and 2063. It is showed by this figure, that only one etcher of reduction will show near a well No. 8 in the north edge of wells collection with diameter of about 2.0 km at the end of the modulation time. This behavior could be because the influence of the small values of coefficients of permeability and associated vertical recharge in the region and the geologic structure effect. The other sections of the simulated region have lower impacts with this pumping rate stresses. So, this behavior mirrors the low ability of the northern region for intensive pumping activity.

Table (3): Optimal pumping rate for first scenario.

| Year | 2018 | 2023 | 2028 | 2043 | 2053 | 2063 |
|------|------|------|------|------|------|------|
| $N_w$ | 43   | 43   | 43   | 43   | 43   | 43   |
| $r$ (m) | 26.26 | 28.66 | 29.90 | 30.62 | 30.73 | 30.77 |
| $Q_{min}$/well | 792.62 | 631.33 | 592.42 | 567.99 | 566.15 | 565.31 |
| $Q_{max}$/well | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 |
| $Q_{opt}$ (m$^3$/day) | 123148 | 101668 | 97403 | 94894 | 94517 | 94405 |
implementation of the submitted simulation - optimization (S-O) model for groundwater resources management was evaluated depend on selected GA criteria such as crossover type, mutation ratio and the ratio of cross-overing. Moreover, the sensitivity tests were carried out for each GA variables to compute the impact of each variable on the final solutions found by the simulation as shown in Figure 13. It was obtained that the population size and probability of the crossover had low impacts on the solution, also the selected values (No. of generation =200 and crossover ratio= 0.6) produce more fixed results, also when using other values more than these values (0.6 and 200) , obtained the same results. Four variables magnitudes of the ration of mutation (0.005, 0.009, 0.01 and 0.05) were applied as display in Fig. (12), it was obtained that the mutation ratio equal to 0.005 produce the optimum quantity of pumping discharge belong stable solution.

It is also importance to note that the genetic algorithm model solution is robust, in other words, for each program operation, the optimal solutions display several variations through the final solutions for same the input data. That attribute to the results begins with the randomize selection and generation of the rate of pumping for each well, as well as the selected of the mutation ratio and cross-over values are also randomly, also for each program operation, variables random matrices of those parameters were calculated.

**Figure (12):** Predicted contour maps of groundwater level of the Al-Dammam confined aquifer for optimum pumping rate a) at 2018, b) at 2023, c) at 2043, and d) at 2063.

**Figure 13:** Sensitivity analysis of the optimization Genetic algorithm models.
5. Conclusions

Groundwater management model was produced depend on the integrated between the MODFLOW simulation model and genetic algorithms optimization model as (S-O) system model in this study. In the (S-O) integrated system proposed model, FORTRAN codes of MODFLOW program was applied as a simulation groundwater flow model in the desert of Karbala governorate, Iraq. Calibration and verification model were done for the groundwater simulation models with steady and transition conditions. Evaluation of calibration for both conditions’ models were highly constrained by observing the field data of piezometric head and its calculated by simulation for the confined aquifer. In this study, used the tools of parameter estimation model (PEST) which working within GMS software in order to calibrated the simulation groundwater model. The final results of the calibration model show that the computed piezometric head by simulation groundwater model matches the observed values with coefficient of determination $R^2 = 0.9747$ for steady condition and $R^2 = 0.7818$ for transient model. The transient simulation includes ten months data from March 2012 to January 2013 for Al-Dammam confined aquifer, divided into 11 stress periods. Single maximum objective function was used in formulation of optimization problem based on maximization of total pumping rate from an aquifer. It is solving by GA method. The performance of the proposed (S-O) model was tested on groundwater management problem. The results show that the GA method product optimum solutions and this model has potential to solve different groundwater management problems. This developed model can create the feasible solution in order to solve problems of the 3-D flow of groundwater problems with complex aquifer, steady and transient state and complicated boundary conditions.

The results display for the present conditions in study area, the value of optimum solution for pumping rate is equal to 94894 m$^3$/day. Moreover, after five years period study, it was obtained that the value of optimum solution which represented the maximum pumping discharge equal to 123148 m$^3$/day, i.e., the rates of pumping can be increased to 3 times the present rates of the pumping water required, corresponding with
a maximum drawdown in the groundwater heads level compared with primary groundwater heads level closed to 7.21m. At the end of simulation model time period (50 year) the rates of pumping can be increasing only about twice the present rates demand, with maximum drawdown in the groundwater heads level compared with primary groundwater heads level closed to 6.15m.

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