Modelling of Groundwater Quality of Tigris River Reach-in Baghdad-Iraq Using Groundwater Modeling System Software

Thair Sharif Khayyun$^1$ and Mustafa Talib Sharif$^2$

$^1$ Civil Engineering Department, University of Technology, Baghdad-Iraq
$^2$ Dijlah University College, Baghdad-Iraq

Email: 40073@uotechnology.edu.iq, Mustafa.taleb@duc.edu.iq

Abstract. The effect of the industrial effluents which discharge to the Tigris River reach in Baghdad city-Iraq, from the industrial and sewage sources on the quality of groundwater was studied for the right and left sides of the flood plain of the river. There are eight sources of pollution along the Tigris River reach in which the effluent discharges were treated partially. In this study, groundwater modelling system (GMS) software (MODFLOW and MT3DMS models) was used to simulate groundwater flow and solute transport. The study area was divided into 5776 cells with a grid size of 250m × 250m with three soils. Sixteen observation wells for the water level and TDS concentrations of the groundwater were used, obtained from the Ministry of Water Resources –Iraq. The MODFLOW and MT3DMS models were calibrated and validated. The validation model was used for the simulation of the groundwater quality for the next 24 years and for three scenarios: (i) concentration of contaminants remain the same, (ii) use of full treatment for accessing the value of TDS concentration to zero, (iii) increase the effluent discharge to the double. The simulation results show an increase in the TDS concentration for all three scenarios during the next 24 years. There are no significant differences in TDS concentration during the next 24 years for the second scenario (full treatment of effluent flow). The difference in TDS concentration was about 3%. TDS concentration change is from the recharge, advection, and dispersion and diffusion process of the groundwater contaminants. When the TDS concentration of the point sources of pollution will increase to double, there is a significant difference in the TDS concentration during the next 24 years which its value was about 13% (1138-1280 ppm). There is no improvement in groundwater quality, but in all three scenarios, the quality will not meet the Iraqi standard limitation of using the groundwater during the next 24 years. The areas of the Tigris River’s left side were affected by the industrial wastewater more than the right side of the river.

Keywords: Groundwater Quality; MODFLOW; Tigris River; TDS Concentration; Industrial Effluents.

1. Introduction

Groundwater is a significant source of water supply for municipalities, agriculture and industry. So, studying chemical contaminates' behaviour in flowing groundwater is significant for assessing a risk that emerges from the groundwater contaminant problems. Groundwater contaminant is one of the genuine natural issues that nowadays human face to it. The pollution of groundwater is the most of the water resources, which affects the industrialization and urbanization procedure after some time with no respect for the ecological outcomes. Mutaz [1] developed a model using the GMS (Groundwater Modeling System) to investigate the future drawdown in the groundwater of the upper layer unconfined aquifer in the Dukan lake area. For one year of simulation with sinks (wells), the time was divided into 12 stress periods, and each stress period represents a month. The calculated head values for each step illustrated that slight differences in its values occurred. Another simulation was run with sinks for one year in which it divided into 2 stress period (wet season and dry season). After a 1-year simulation with groundwater withdrawal estimated by -1152 m$^3$ / day of 200 wells, the calculated hydraulic head showed a slight difference in hydraulic heads when comparing the dry with the wet readings seasons. After running a predictive simulation with seniors of drilling 50 wells yearly within the next 10 years, with a discharge rate equal to 20 l/sec and pumping rate of 8 hours daily, the output
showed a decrease in the hydraulic head of the unconfined aquifer on both sides of the Lesser Zab River more than the other parts of it. Al-Otaibi [2] used The MODFLOW-MT3D and HST3D software for the numerical modelling of artificial recharge of the Dammam formation in Kuwait to assess the recharge's feasibility project and to optimize the operation.

The results of scenario runs suggest that alternate injection of (655 m³/d/well) and recovery (1310 m³/d/well) cycles would give acceptable recovery efficiency with the manageable rise in potentiometric heads. Shifting the recharge site to the southwestern corner of the selected area would allow better injection hydraulics due to the aquifer's higher transmissivity. It would result in improved recovery efficiency due to the lower salinity of the native groundwater. The sensitivity runs indicated that the layer's vertical hydraulic conductivity overlying the Dammam Formation and the horizontal hydraulic conductivity of the Dammam Formation had the most significant influence on the potentiometric head. The recovery efficiency was controlled mainly by the horizontal hydraulic conductivity and the Dammam Formation's dispersivity, and the difference in the salinity between the injection water and the native water. Seyed [3] used Visual MODFLOW to predict subsurface and surface migration of pollution within 10 years in Seri Petalling Landfill. The results of a sample analysis of phosphorus shown that the concentration in place of the landfill was 2.38 mg/l since the National Water Quality Standard for Malaysia defined the maximum value of phosphorus in groundwater for Class IIA/IB and III at 0.1 and 0.2 mg/l, respectively. The prediction showed that the phosphorus was migrated widely to further places such as a river, and it had an adverse effect on the environment, animal and human.

Last few years, Baghdad –Iraq has been subjected to pollution attributed to the industrial and domestic source of pollutant. Many industrial establishments are concentrated near the river basin for obvious reasons, such as getting water for operation and discharge the effluent. These activities put high hydrological stress on existing groundwater by poor quality. This study aims to study the effect of pollution due to discharge of partially treated and untreated effluent of industrial units near the river on groundwater quality and to predict the groundwater quality in this area over the next 24 years by using a numerical model of various scenarios. Several scenarios have been proposed, including (i) concentration of contaminant values remain the same, (ii) in the case of the use of processors and access values of TDS concentrations to zero and (iii) increase the effluent discharge with TDS to a double due to recent resources. This study's established model would finally provide a scientific basis to use the groundwater resources sustainably and use in groundwater resources management.

2. Study area
Baghdad city is the capital of Iraq. It is located on the bank of the Tigris River. Figure 1 shows the study area which is located between the latitude 33°13'52.05" N 33°20'38.09" N, and the longitude 44°11'13.16" E 44°30'32.49" E. The Tigris River divides Baghdad city into two parts for a distance of about 50 km. The direction of river flow is from northwest to south-east, and the Tigris River is the main source of water for domestic, irrigation and industrial uses in Baghdad city. The total area of the study area is 361 Km². In this study area, 16 observation wells are used in the calibration and validation process. SASPlanet [4] program was used to determine the coordinates of the wells. A Russian program can download Google earth photos (ESRI) and other satellite servers with a high degree of accuracy. The study area's boundary and the observation wells' location are shown in Fig. 2.

3. Groundwater Modeling System (GMS V.10)
The Groundwater Modeling System (GMS) is a complete graphical user environment for performing groundwater simulations. The system consists of a program interface to appear the graphical user and consists of several analysis codes such as MODFLOW, MODPATH and MT3DMS. This program was developed by Aquaveo (2016), and it was designed as a comprehensive modelling environment. Many Tools are provided in this program for assisting in the building of the model. They indicate the buildup of mesh and grid, site characterization, and post-processing.
4. Methodology of the study

4.1. Base map

The study area is limited to 361 km$^2$ (12.12 km in x and 29.78 km in y). The map was constructed directly by the grid approach; then, the map is divided into many cells; each cell has the same properties. The model grid consists of (120) columns and (49) rows, and the cell dimension is (250 m by 250 m). This cell dimension was also used by Unoka [5] for modelling the groundwater flow. The total number of grid cells was (5776) in which all cells were active cells, except the boundary cells.

4.2. Geomorphology and soil types:

In this study, the average elevation of 34 m.a.s.l was used in Baghdad city. For modelling purpose, three layers are considered along with the entire depth of the study area. The top layer is silty clay has a depth of 10 m. The medium layer is fine sand with a thickness of 4m. The bottom layer is medium sand with a thickness of 20 m Figure 3. The top layer type is considered an unconfined aquifer. The medium layer and bottom layer in the GMS model were automatically considered as a convertible aquifer.

4.3. Wells

The study area is characterized as a lack of observation wells, which considered one of the difficulties during the calibration and verification processes. Data of the observation wells were obtained from the Ministry of Water Resources-Iraq[6]. Its numbers were 16 wells for the period from 2015 to 2016. The groundwater levels for (416) of these wells were used for calibration for the year 2015, and (9) wells for the year 2016 were used for the validation process, as shown in Figure 2 and Table 1.
4.4. Properties of the layers

The hydraulic conductivity, the specific yield, the effective porosity, and the initial head values are the main properties that may affect building the MODFLOW model, Table (2).

Table 1: Location and groundwater level for the study area wells (2015-2016).

| well No. | X     | Y     | W.L. (m.a.s.l.) (2015) | W.L. (m.a.s.l.) (2016) |
|---------|-------|-------|------------------------|------------------------|
| 1       | 33°18′02.22″ | 44°24′11″ | 30.84                  | 30                     |
| 2       | 33°16′20″       | 44°26′53.02″ | 36.65                  | 29.2                   |
| 3       | 33°18′23″       | 44°28′3.59″   | 31.3                   | 29.8                   |
| 4       | 33°18′22.39″    | 44°16′12.22″  | 32.25                  | 30.6                   |
| 5       | 33°18′36″       | 44°16′6″      | 32.25                  | 30.1                   |
| 6       | 33°18′30″       | 44°21′50″     | 31.67                  |                        |
| 7       | 33°18′35″       | 44°12′44″     | 32.5                   |                        |
| 8       | 33°19′28″       | 44°13′34″     | 32.43                  |                        |
| 9       | 33°19′30″       | 44°21′54.22″  | 31.4                   |                        |
| 10      | 33°19′30″       | 44°21′50.4″   | 31.63                  |                        |
| 11      | 33°19′28″       | 44°12′42.41″  | 32.6                   |                        |
| 12      | 33°19′35″       | 44°13′34″     | 32.43                  |                        |
| 13      | 33°20′11″       | 44°12′32″     | 32.71                  |                        |
| 14      | 33°14′37″       | 44°30′6.4″    | 30.16                  | 29.2                   |
| 15      | 33°15′17″       | 44°30′6.4″    | 30.15                  | 29.2                   |
| 16      | 33°20′10″       | 44°12′46″     | 32.58                  |                        |

Table 2: Properties of the soil type for each layer

| layer | soil type     | hydraulic conductivity (k) (m/sec) | Effective porosity (n) |
|-------|---------------|------------------------------------|------------------------|
| 1     | silty clay    | $5 \times 10^{-9}$ to $1 \times 10^{-7}$ | 0.42 - 0.68             |
| 2     | fine sand     | $2 \times 10^{-7}$ to $2 \times 10^{-4}$ | 0.01 - 0.39             |
| 3     | medium sand   | $9 \times 10^{-7}$ to $5 \times 10^{-4}$ | 0.16 - 0.46             |

4.5. River

The term river conductance is a numerical parameter representing the resistance to flow between the surface water body and the groundwater. It can be calculated through the following equation, Perez-Paricio[7]:

$$C = \frac{KLW}{H}$$  \hspace{1cm} (1)

Where: C = conductance (m$^2$/day); K = Hydraulic conductivity of the river bed material (m/day), L = Length of the river reach (m); W = Width of the river (m); H = Thickness of river bed (m).

Depending on the information available from previous researches, the following information has been collected for the Tigris river:

- Water Surface elevation: the Tigris River had a low, average and high water stage of 27.6, 29.15 and 30.7 m.a.s.l., respectively, for the period (2000–2015). The Tigris River's maximum water stage was 33 m.a.s.l, so this water stage was used in this study, Ministry of Water Resources-Iraq[8].

- Width: The Tigris River’s average width is 221.1 m, according to Isaac (2016).

- Length: the length of the Tigris River’s reach in this study starts from the Medical City in Baghdad to the point before Diyala River's confluence with Tigris River is about 21 km.
- Bed sediment: The result of the study, as in Ali [9], showed that the sediment in the study reach was Silt. The river bed thickness is considered as 4 m, Perez-Paricio[7].

River Bed elevation: The variations in bed levels for the Tigris river's reach in this study is between (21 to 23 m.a.s.l.) so the average value of bed level was used.

The data above the value of river conductance is about 1005 m2/day, estimated using equation (1).
4.6. Recharge
The recharge package is designed to simulate distributed recharge to the groundwater system. Most recharge occurs as a result of precipitation that percolates into the groundwater system. This result can also be used to simulate recharge from sources other than precipitation like artificial recharge. Ali [9] was studied the groundwater recharge of the Baghdad basin. The defined recharge rate was (2.19*10^-5 m/day). Mahmood [10] used a balance of chloride ion mass technique to calculate the groundwater recharge for the Samarra region's unsaturated zone. The results were indicated that the value of groundwater recharge was 9.49 *10^-5 m/day. According to this value, a constant recharge rate of (2.19 *10^-5 m/day) was applied to the study area's top layer.
4.7. Evapotranspiration
According to the Iraqi Agro-meteorological Network[11], the average evapotranspiration in Baghdad city was 0.0052 m/day for 2016. In the MODFLOW model, an important parameter (extinction depth) must be known. The extinction depth represents the point below a ground surface elevation in which the evapotranspiration from the water table stops at it. It depends on the soil type and the land cover types. In this study for silty clay soil, the extinction depth of 335 cm was used (Nirjhar[12]).
4.8. Initial Hydraulic Head
The selection of the appropriate initial values of groundwater level makes access to the current levels faster. In many previous research types, the initial head values were selected close to the observation wells' levels. In this research, the GMS software option is activated by making the initial values equal to the above layer's top elevation.
4.9. Boundary Conditions
In this study, all model boundaries are considered as constant head for the steady-state condition. Depend on the available data of groundwater level for the wells close to the boundary of the study area, the constant head was chosen for each cell in the boundary. The range of these values is between (30-33 m.a.s.l.).
4.10. MT3D - Mass Transport Modeling
4.10.1. Coefficient of diffusion.
The longitudinal dispersivity ($\alpha_L$) and transverse dispersivity ($\alpha_T$) are required to estimate dispersive transport of the solute. The value of the ratio of the horizontal transverse dispersivity to the longitudinal dispersivity (TRPT) and the ratio of the vertical transverse dispersivity to the longitudinal dispersivity (TRPV) was 0.1 and 0.01, respectively. The molecular diffusion coefficient is, in general, minimal and negligible compared to the mechanical dispersion. So it was 0.1, Aamir et al. [13]. The average flow path lengths are 353 m, so the longitudinal dispersivity according to equation (3) is about 3 m. Peter et al. [14] reported that the longitudinal dispersivity range's value was between 1 to 10 m.

4.10.2. Initial concentration. To reach the correct distribution of TDS concentration at present for the study area, any information can be used as an initial concentration from the previous studies. The suitable value of the initial concentration was 1100 ppm because this value is nearest to the concentration of TDS of all observation wells in the study area.
4.10.3. Point source. From the source/sink menu in GMS, the point source can be added. It represents the drain, river and well cells. The sources that discharge the industrial effluent to the Tigris River were considered the point's sources for the model's appointed cells. There are eight-point sources locations identified by Ali et al. [15]. Figure (4) shows the locations of the industrial effluent. The TDS concentration of treated and untreated effluents are given in Table (3). The treated and untreated water volume that discharges daily into the Tigris River is about 2.0 to 1.5 million m$^3$ respectively, with a range of (704 – 1376 ppm).
4.10.4. TDS Concentration of the observation wells. For model calibration, TDS Concentration values of the Observation wells for 9 wells located in the study area were obtained from the Ministry of Water Resources-Iraq[6]. The locations of the wells and the concentrations of total dissolved solids (TDS) for the observation wells are shown in Table 4.

![Figure 4: Point sources located along the Tigris River reach.](image)

4.11. Model run

The model was run and calibrated for the year (2015) for the 16 wells data of the hydraulic head of groundwater obtained from Table 1. Then, the model was validated for the year 2016 for 9 wells which were shown in Table (1). MODPATH model and MT3DMS were run for steady-state to show the particle flow path and TDS concentration.

Table 3: TDS concentrations for the industrial effluent discharge.

| Factory | TDS ppm | Effluent discharge (m³/hr) | state |
|---------|---------|-----------------------------|-------|
| Southern Baghdad Thermal Power Plant | 750 | 15000 | treated |
| Southern Baghdad Gas Plant Power | 900 | 600 | treated |
| Al-Dora power station | 704 | 82000 | treated |
| Al-Dora Refinery | 1062 | 780 | treated |
| Tawilis factory / S'raeda | 1376 | 266.4 | treated |
| (M12) sewage pumping station. | 950 | 0 | untreated |
| (M10) sewage pumping station. | 600 | 0 | untreated |
| Al-Saidiya pumping station (PN) | 1005 | 64800 | untreated |

Table 4: TDS concentrations for the observation wells.

| well NO. | X | Y | DATE | Observed TDS |
|----------|---|---|------|-------------|
| 3 | 44° 23’ 3.59” | 33° 16’ 23” | 2016 | 780 |
| 6 | 44° 21’ 50” | 33° 18’ 30” | 2016 | 1250 |
| 9 | 44° 23’ 15.22” | 33° 19’ 30” | 2016 | 996 |
| 10 | 44° 21’ 50.4” | 33° 19’ 30” | 2016 | 780 |
| 11 | 44° 12’ 42.41” | 33° 19’ 56” | 2016 | 1149 |
| 12 | 44° 26’ 25” | 33° 19’ 56” | 2016 | 1150 |
| 13 | 44° 12’ 32” | 33° 20’ 11.7” | 2016 | 1108 |
| 17 | 44° 30’ 6” | 33° 15’ 17” | 2016 | 1122 |
| 18 | 44° 13’ 40” | 33° 20’ 19” | 2016 | 1300 |

5. Results and discussions

5.1. MODFLOW output

5.1.1. Calibration of the model

Hydraulic conductivity, effective porosity and recharge are the most sensitive parameters in the numerical model. The simulation runs were repeated with the increments in these parameters. These parameters values of layers were changed by trial and error to minimize the difference between the simulated and the observed groundwater level for each observation wells in the study area and the three river water surface elevations of Tigris River (27.6, 29.15 and 33 m.a.s.l.). Calibration is achieved when the error is within the estimated error interval (±0.05) of the observed value. The best
fit result was shown in Figure 5. The statistical analysis was carried out, and the values of the $R^2$, mean error (ME), mean absolute error (MAE), and root mean squared error (RMSE) were 0.888, 0.54, 0.56 and 0.746, respectively. Table 5 shows the value of the three parameters which give the best match between the observed and computed groundwater levels after running the MODFLOW for the calibration process. The groundwater level contours maps of this study when the Tigris river stage is maximum (33 m.a.s.l) are shown in Figure 6. Groundwater level contours maps for the minimum and average river stages are shown in Figure 7 and 8, respectively. These figures are for selected layers.

**Figure 5: Simulated Vs. Observed groundwater surface elevation at Steady State.**

**Table 5: Optimal parameters' values fitted from the Calibration Process.**

| NO. | Calibrated parameters          | Layer 1 | Layer 2 | Layer 3 |
|-----|--------------------------------|---------|---------|---------|
| 1   | Hydraulic conductivity m/day   | 0.0008  | 17      | 40      |
| 2   | Effective porosity             | 0.6     | 0.1     | 0.4     |
| 3   | Recharge m/day                 | 2.19x10^-5 | -      | -      |

From the last Figures 6, 7 and 8, groundwater direction was from the northwest to the south-east because the groundwater flow was from the high head to the low head. The areas that lie adjacent to the river showed an increase in the value of the groundwater hydraulic gradient $\frac{\Delta h}{\Delta l}$ for the case of the minimum surface elevation of Tigris river, the other cases (average and maximum water surface elevation of Tigris river) respectively. The velocities of groundwater flow were very slow in all cases of the Tigris water surface elevation. The velocities were (1.72 x 10^-7 m/day, 1.224x10^-7 m/day and 7.5 x10^-8 m/day) for the three cases, respectively and the first soil layer. The groundwater level drawdown was between 1 m to 4 m for the maximum water surface elevation of Tigris River (33.0 m.a.s.l).

**Figure 6: Equipotential contour lines for layer 2 at 33 m.a.s.l. river stage.**

**Figure 7: Equipotential contour lines for layer 3 at 27.6 m.a.s.l. river stage.**

5.1.2. Validation of the model
Validation aims to achieve the most significant possible trust in the MODFLOW model. The maximum water level of the Tigris River was used in the calibration process. For this purpose, 9 wells were selected in the study area, Ministry Of Water Resources[6]. The observed and computed groundwater surface elevations are shown in Table 6.

5.1.3. MODPATH Run
The running of MODPATH illustrated that the particle flow path for the particles which lies near the left side of the Tigris river in the lower part of the study area was from northwest to the south-east direction. The groundwater movement on the right side of the river is not clear because of the low hydraulic gradient ($\frac{\Delta h}{\Delta l}$) so the velocity of groundwater was slow. The value of groundwater velocity on the Tigris river's right side was ($8.72 \times 10^{-10}$ m/day) while on the left side was ($1.1 \times 10^{-7}$ m/day). It was found that the fluctuation of the water surface elevation of the river affects the groundwater level on both sides of the river for a distance of about (1380) m from the river on the Al-Kharkh side (right side) and about (2450) m on the Al-Rusafa side (left side).

Table 6: Computed and observed groundwater surface elevation for the Validation process (2016).

| well No. | observed head (m.a.s.l.) | computed head (m.a.s.l.) |
|----------|--------------------------|--------------------------|
| 1        | 30                       | 30 73272                 |
| 2        | 29.6                     | 30 69029                 |
| 3        | 29                       | 30 90146                 |
| 4        | 30.6                     | 31 37669                 |
| 5        | 30.1                     | 31 40699                 |
| 6        | 30                       | 31 03689                 |
| 12       | 29.2                     | 30 02845                 |
| 16       | 29.2                     | 30 13806                 |
| 17       | 31.6                     | 32 58409                 |

5.2. MT3DMS model output: Solute transport
MT3DMS model was run depending on the validated parameters of the MODFLOW for the year (2016). The model was run for two stress period, the first period (1990 to 2016) was (9490.0) days for validation, and the second period (2016 to 2040) was (8760.0) days for prediction. The simulated results of TDS concentration and those observed in the groundwater observation wells were plotted for the year (2016) and Tigris River's maximum water stage level with the best match, Figure 9. The Statistical analysis for the absolute error and root mean square was (87 and 103) ppm.

The simulated results for three scenarios are plotted for the TDS concentration level versus year for the Tigris River's observation wells. These wells are influenced by the discharge of the treated and untreated effluent of the eight-point sources. The TDS concentration is predicted for the following scenarios, considering that the industrial effluent discharge started its effluent in 2016, and a similar recharge pattern continues. The TDS concentration started to change according to the three scenarios.
from 2016 to 2040. Four-point sources were selected from the primary observation wells and the other four wells from data, as in Ali[9]. The symbol (X) is added for these wells appointed to distinguish it from the primary observation wells. The location of the observation wells is shown in Figure 10.

Figure 9: Comparison of measured and simulation results.

Figure 10: The Observation wells used for TDS concentration Predictions.

5.2.1. TDS level in the well (w9). The scenarios show no clear changes in the TDS level at this well because the well (w9) is upstream of the Tigris river, and the groundwater flow direction is from northwest to the south-east towards the water flow of the river. Figures 11 illustrate the increase in TDS during the next twenty-four year until the year (2040) for each scenario. TDS level reaches the highest value of 863 mg/l in the next 24 years. The TDS level change from 814 mg/l to 863 mg/l during 24 years was not from the TDS effluent concentration of the treated and untreated sources along the Tigris River. The change in TDS level is from the recharge, advection, dispersion and diffusion processes of the groundwater contaminants, the soil layers and groundwater flow.

5.2.2 TDS level in the well (27x). The river's TDS levels increase toward the flow direction due to existing treatments and untreated point sources. These levels vary between 560 to 1650 mg/l and the Tigris River Abdul- Hameed[15]. The results show an increase in the concentration value of TDS when compared with the well (9). TDS level reach (1126 ) ppm in the year 2040. This value does not change with the change of point sources concentration values, according to the scenarios. This result indicates that the increase is due to the flow phenomenon of groundwater contaminant. The comparison between the three scenarios is shown in Figure 12 for the well 27x.

5.2.3. TDS level in the wells (w9x, w2, w35x and w1). Table 7 shows the simulated TDS level results for the four wells close to the Aldora refinery for the three scenarios. TDS levels were increased in all the wells for all the scenarios from 2016 – 2040. In all of the scenarios, and for each well, there is an adverse effluent of the Tigris river water quality (the effluent of the treated and untreated point source)
on the right side's groundwater quality Tigris and small regions at the right side of Tigris River. The movement of groundwater occurs as slow seepage through the pores between particles. A velocity of 0.3 m/day is considered a high rate of movement for groundwater. In contrast, velocities at streamflow are about 0.4 to 0.6 m/sec. So the movement of the contamination is so slow in the direction of groundwater flow. However, TDS levels were towards increasing groundwater flow due to the groundwater pollution processes within the soil layers at the study area Figures 13, 14, 15 and 16. These figures also illustrate that the TDS levels were in a rising trend in which all of the wells did not meet the desirable limit of (1000) mg/l TDS level of drinking water as in (Iraqi Standard[16]). The worst aquifers were near the wells (w9x and w2) due to high concentration levels during the next 24 year.

![Figure 11: TDS profile of well 9 for the three scenarios.](image1)

![Figure 12: TDS profile of well 27x for the three scenarios.](image2)

| Well No. | Scenario | TDS \_mg/l | year/2016 | year/2040 |
|----------|----------|------------|-----------|-----------|
| w9x      | 1        | 1111.5     | 1173.3    |           |
|          | 2        | 1111.6     | 1126.7    |           |
|          | 3        | 1111.6     | 1120.9    |           |
| w2       | 1        | 1116.0     | 1236.0    |           |
|          | 2        | 1116.0     | 1210.0    |           |
|          | 3        | 1116.0     | 1237.0    |           |
| w35x     | 1        | 1100.3     | 1104.3    |           |
|          | 2        | 1100.3     | 1103.7    |           |
|          | 3        | 1100.3     | 1103.7    |           |
| w1       | 1        | 1102.0     | 1105.6    |           |
|          | 2        | 1102.0     | 1105.6    |           |
|          | 3        | 1102.0     | 1105.6    |           |

**Table 7:** TDS level for the four wells near AlDora- Refinery for the three scenarios.
5.2.4. TDS level in the wells (w12 and w11x). The simulated results for three scenarios are plotted for TDS level in mg/l versus year (2016-2040) and monitoring wells (w12 and w11x) located at the Tigris River's left side. These wells are influenced by the discharge of the point source effluent, Figure 17 for w12 and Figure 18 for well 11x. The TDS level of the groundwater shows a high value of more than 1270 mg/l in the year 2040 for the third scenario. This level was observed for the well 11x located downstream of the Tigris River and adjacent to the industrial wastewater. The TDS level in all the wells (w12 and w11x) raised the trend for all three scenarios. TDS levels trend in the two wells was from upstream to downstream of the river's left side due to the river's groundwater flow moves toward the south-east direction. The areas of the Tigris River's left side are affected by the industrial wastewater effluent more than the right side of the river.

6. Conclusions
The run of the MODFLOW model for the three water level cases of Tigris River (high, average and low) showed that groundwater flow was from the northwest to the south-east in Baghdad city. In general, groundwater flow velocity in all three cases is low for the soil's first layer. The river fluctuation affected the groundwater level on both sides of the river for a distance of about (1380 and 2450) m from the river on the right and left sides. According to the three scenarios for the TDS concentration, industrial effluent discharge was noticed downstream of the Tigris river reach,
especially at the Tigris River's left side. For all wells in all of the scenarios, TDS concentration's value is more than the Iraqi limitation standard for drinking water (1000 mg/l). When the point sources' effluent discharge was doubled, the results demonstrated that this scenario was the worst scenario for the groundwater quality than the other scenarios. The high TDS level in the study area for the next 24 year will reach a value of 1280 mg/l. There are significant differences in TDS concentration during the next 24 years which its value was about 13%. There are no significant differences in TDS concentration during the next 24 years (the difference in TDS concentration is about 3%) for the second scenario (Full treatment of effluent flow). A comprehensive management strategy and treatment of the pollution must be done for the Tigris River and groundwater and considering possible solutions to reduce pollution levels and the deterioration of the groundwater quality.

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