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Two Dimensional Mathematical Model of Contamination Distribution in the Lower Reach of Diyala River

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Abstracts

One of rivers that suffer from the effect of pollutants is Diyala River, due to the untreated effluents from Rustimiyah wastewater treatment plant (WWTP) and from other contaminants sources such as Army Canal Outfall. These outfalls are discharged continuously to the river and located at different positions along the lower reach of the river. In this context, a two-dimensional mathematical model is provided to simulate the distribution of pollutants transport in the river. Strong coupling between K-ε turbulent model and advection-dispersion equation. The mathematical model has been implemented with COMSOL Multiphysics 3.5a, which is a versatile computational fluid dynamics (CFD) software package that solves coupled PDEs based on the Finite Element Method. Total Dissolved Solids (TDS), Chloride (Cl-), and Heavy Metals (Fe, Cr), are selected as principal indicators of pollutants transport in the case study. Sensitivity analysis was performed to study the effect of different parameters on the results predicted by application the two-dimensional model. The calibration of the model indicates that the best roughness height is 0.024m and the best water slope is 9cm/km. The verification indicates that a good agreement between the observed and the predicted data with a percentage error less than 10%.

Keywords: Pollutants distribution, mathematical model, K-ε turbulent model, advection-dispersion, Diyala River.

Introduction

Fresh water are facing an increase load of the disposal of polluted water due to rapid growth of industrial and municipal activities as well as the increase of land drainage due to agricultural activities. Outfalls effluents with high pollutant concentrations when discharged to fresh water without treatment causing near field and far field pollution conditions [22]. The concentration of pollutant in the river is affected by water discharges and its velocities, which is continuously changes with time. The estimation of the velocity, which is the major factor affecting the pollutant movement, is often based on physical models or actual measurements. Both are time-consuming and relatively expensive [2]. It is well known that the major pollution problems caused by treatment plants are those of water pollution. However, the effluents from these plants present a high pollution load if not treated efficiently before disposal. The treated wastewater quality is a function of the treatment provided, the rating strategy employed and the characteristics of raw wastewater. Therefore, treated wastewater exhibits wide variation in quality [8]. During the last years, the increase of pollution in rivers, lagoons and coastal regions has attracted much interest in numerical methods for the prediction of its transport and dispersion. In many situations, this pollution problem has an impact on the ecology and environment and may cause potential risk on the human health and local economy. Efficient and reliable estimates of damages on the water quality due to pollution could play essential role in establishing control strategy for environmental protection. Introduction and utilization of such measures are impossible without knowledge of various processes such as formation of water flows and transport of pollutants. The mathematical models could be very helpful to understand the dynamics of both, water flow and pollutant transport. In this respect mathematical modeling of water flows and the processes of transport-diffusion of pollutants could play a major role in establishing scientifically justified and practically reasonable programs for long-term measures for a rational use of water resources, reduction of pollutants discharge from particular sources, estimation of the impact on the environment of possible technological improvements, development of methods and monitoring facilities, prediction and quality management of the environment, etc. The success of the mathematical model in solving practical problems depends on the convenience of the models and the quality of the software used for the simulation

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of real processes [12]. Prediction of the pollutant transport is providing valuable information for the management of the river quality. Modeling of the river system is not a trivial task due to the complex physical, chemical and biological processes involved [26]. Two-dimensional mathematical model will provide in this study. K-ε turbulent model will be used to simulate the flow field and estimate the viscosity variation along the river. Advection-dispersion equation consists the effects of advection, dispersion, dilution, and any identified sources or sinks within the river reach. These effects are used to simulate the variation of the selected conservative substances along the river. The model has been implemented with COMSOL Multiphysics, which is a versatile CFD software package that solves coupled PDEs based on the Finite Element Method.

The objective of the present work is develop of a two dimensional mathematical model to simulate the water velocity and pollutant transport along the lower reach of Diyala River. In additional, investigate the effect of hydrodynamic parameters on the pollutant transport in the lower reach of Diyala River as water velocity, variation of flow rates and dispersion coefficient.

Materials and methods

Study area

Diyala River is one of the main water resources of Iraq and one of the most important tributaries of Tigris River in Iraq. It originates on the eastern border of Iraq and flows for 386 km to confluence with the Tigris River just south of Baghdad. The climatic conditions vary so much in the river catchments at which rainy season starting from November to April, with an annual amount of precipitation varies from 800 mm near the northern parts to 250 mm near southern limits of the basin [4]. On the other hand, the annual evaporation rate may reach as high as 2000 mm/year [6].

Field surveying indicate that Diyala River was not looked upon as natural resources, but as a commercial resource, something to be used, but not necessarily respected. It was seen as a place to discard the unwanted wastes of growing society, it received untreated wastes from a large number of different sources. Primary sources of wastes are municipal and agriculture. Rustamiyah wastewater treatment plants were considered one of the major sources of pollution. The project discharges about 470,000 m^3/d into Diyala River [18].

Sixteen kilometers (16 km) length of the lower reach of Diyala River is studied in this present work. The study reach started from 2km upstream Rustimiyah third Expansion plant (R3) at coordinates (33°18'34.2"N, 44°32'13.8"E) and extends to the confluence of the Tigris-Diyala Rivers at coordinates (33°12'59.0"N, 44°30'09.3"E). The layout of the river system is shown in figure (1).

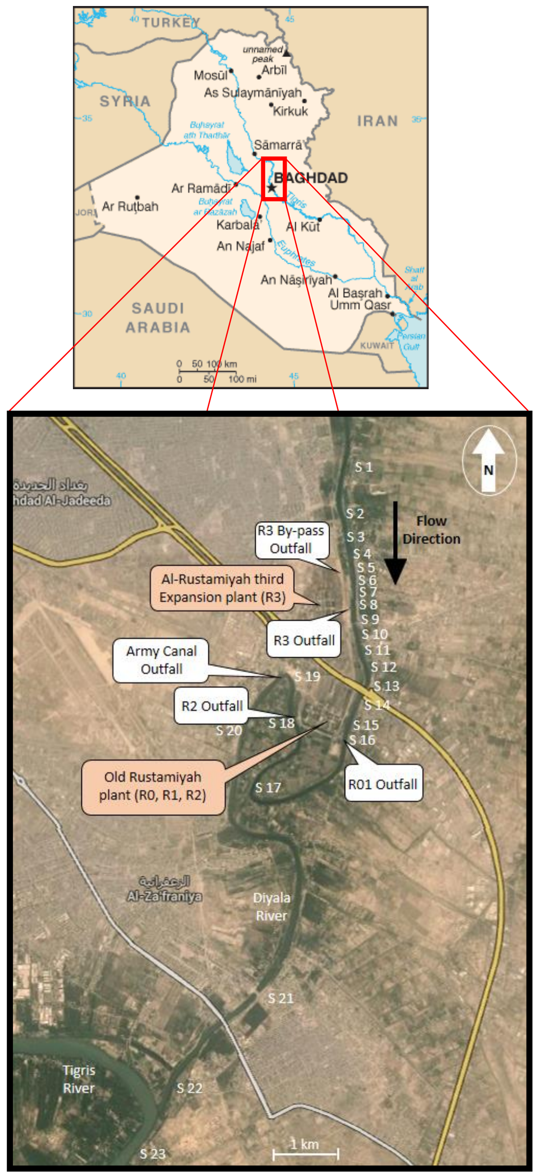

Figure (1) General layouts of the study reach

Five outfalls are recorded and taken as point sources of pollutants, which are discharged continuously to Diyala River. These outfalls are wastewater treatment plants at Rustimiyah, and the discharge of Army Canal. These outfalls are located at

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different positions along the lower reach of Diyala River, as shown in Figure (1). Diyala River is prone to considerable level of physical, chemical and biological pollution emanating from such outfalls. These outfalls have considerably changed the color, smell, test and other characteristic of the river's water.

Rustimiyah wastewater treatment plant (WWTP) is located on the right bank of Diyala River 14 km prior to confluent of Tigris River south of Baghdad city. Rustimiyah WWTP serves the east side of Baghdad city (Rusafa) and is considered one of the largest projects that treat wastewater in Iraq. The effluent is discharged into Diyala River and thus into the Tigris River [21], as shown in figure (1). Rustamiyah WWTP is the oldest project in Iraq; it consists of two projects [1]**,** the first one is the old Rustimiyah project (Rustimiyah South plant) which is working since 1963 and consists of three integrated projects, which are zero expansion (R0), first expansion (R1), and second expansion (R2) with a designed capacity of (175,000 m^3/day) where the actual flow reaches (300,000 m^3/day). This plant serves 1.5 million inhabitants on the eastern side of Baghdad city. The second one is the new Rustimiyah project (Rustimiyah North plant) third Expansion (R3) working since 1984 with a design capacity of (300,000 m^3/day) and the actual influent (450,000 m^3/day) from 1.5 million people served in the eastern side of Baghdad city. The final disposal of the plant is into the Diyala River and thus into the Tigris River.

The Army Canal Outfall is one of the main pollution sources that discharged directly into Diyala River and consequently to the Tigris River, as shown in Figures (1), the Army Canal Outfall is located between latitudes 33°16'48.5"N and longitudes 44°31'36.1"E. Its water supplied from seven lifting pumps, each of which has a capacity of (2 m^3/sec). Thus, a total discharge of (14 m^3/sec) could be supplied to this canal. However, this canal dose not operates at present continuously with its maximum capacity; it only supplies water to some farms, gardens and nurseries along its bank. Thus, a value that is less than the maximum operational capacity, (1 m^3/sec) may be adopted. [7].

Table 1. Locations and distances of the sampling stations on Diyala River

St. No.	Dis. (km)	Location
1	0.0	2 km upstream R3 By-pass Outfall
2	1	1 km upstream R3 By-pass Outfall
3	1.5	0.5 km R3 By-pass Outfall
4	1.75	0.25 km upstream R3 By-pass Outfall
5	2	at R3 By-pass Outfall
6	2.1	0.1 km downstream R3 By-pass Outfall
7	2.2	0.2 km downstream R3 By-pass Outfall
8	2.3	at R3 Outfall
9	2.5	0.2 km downstream R3 Outfall
10	2.7	0.4 km downstream R3 Outfall
11	2.9	0.6 km downstream R3 Outfall
12	3.1	0.8 km downstream R3 Outfall
13	3.3	1 km downstream R3 Outfall
14	3.7	0.6 km upstream R01 Outfall
15	4.1	0.2 km upstream R01 Outfall
16	4.3	at R01 Outfall
17	6	1.7 km downstream R01 Outfall
18	7.5	at R2 Outfall
19	8.2	at the Army Canal
20	8.8	0.6 km downstream the Army Canal
21	13.5	2 km upstream the confluence of Tigris-Diyala rivers
22	15.3	Diyala River 0.2 km upstream the confluence of Tigris-Diyala rivers
23	16	Tigris river 0.5 km downstream the confluence of Tigris-Diyala rivers

Sampling and analysis

The objective of river sampling is to obtain a representative and reliable measure of water quality constituents along the river reach. Four parameters are involved in the present work; which are Total Dissolved Solids (TDS), Chloride (Cl^-), and Heavy Metals (Iron (Fe) and Chromium (Cr)) concentrations. Seasonally sampling of water is conducted on Oct. 30, 2013, Jan. 2, 2014, and Apr. 8, 2014 at stations No. (1) to No. (23) at the same day. Figures (2) to (4) show the variation of TDS, Cl^-, Fe, and Cr concentration with distance along the study reach on Oct. 30, 2013, Jan. 2, 2014, and Apr. 8, 2014.

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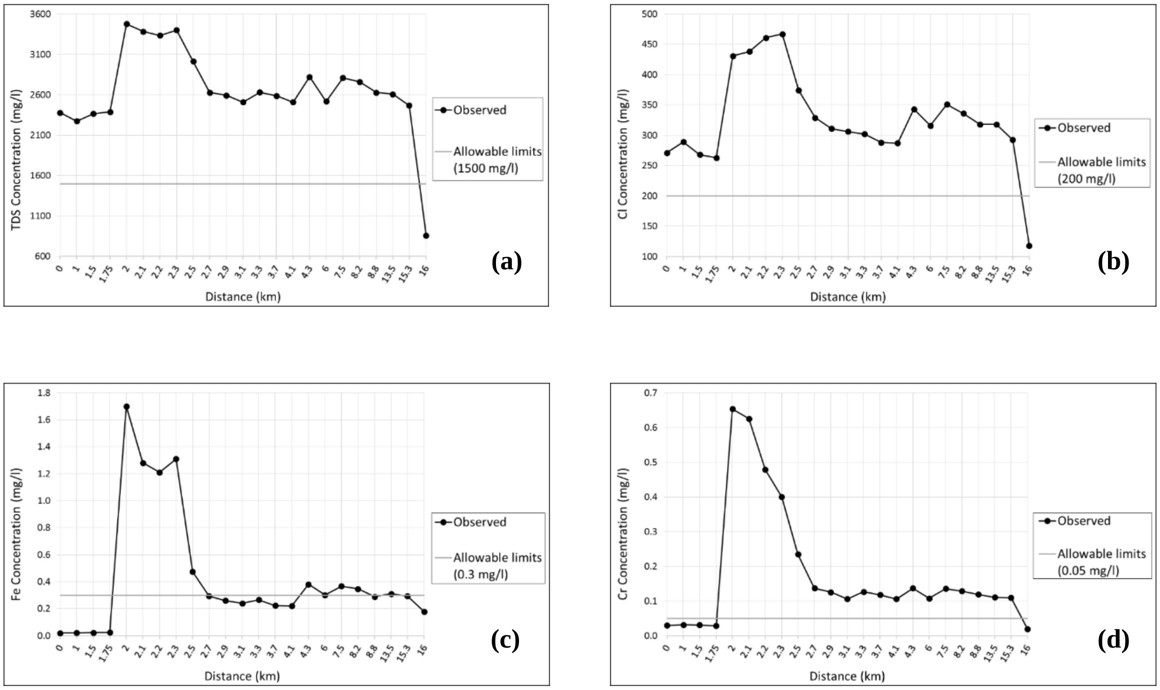

Figure (2) Variation of the concentration of different elements with distance along the study reach on Oct. 30, 2013 for:- a) Total Dissolved Solid (TDS), b) Chloride (Cl^-), c) Iron (Fe), d) Chromium (Cr)

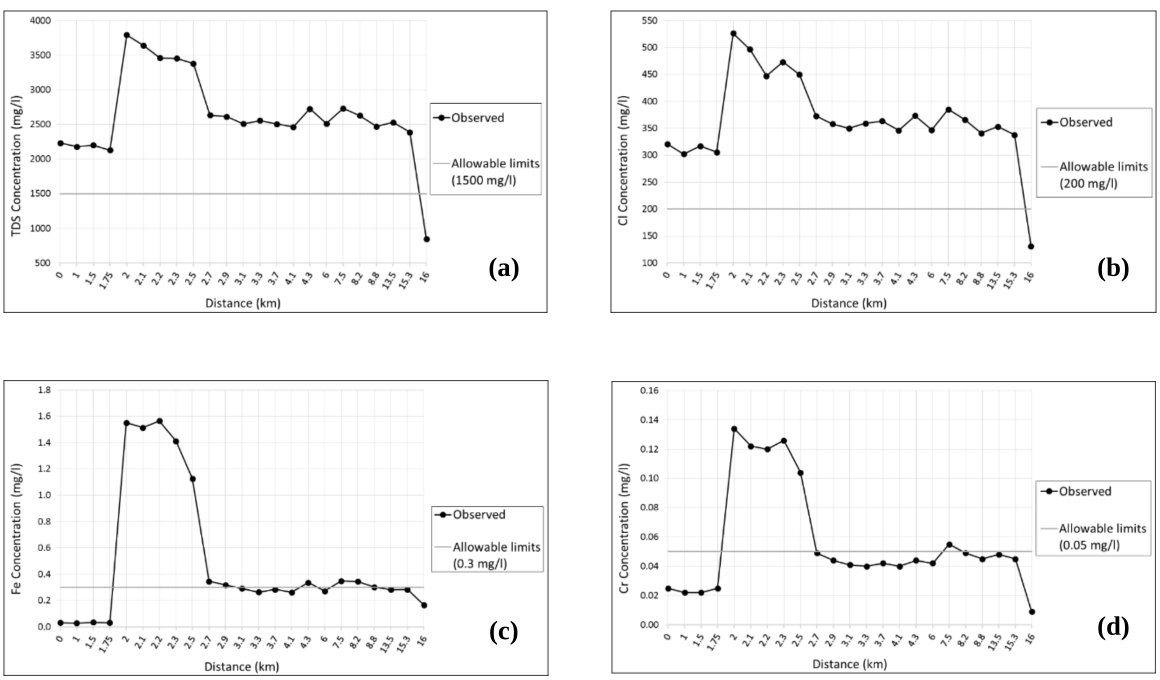

Figure (3) Variation of the concentration of different elements with distance along the study reach on Jan. 2, 2014 for:- a) Total Dissolved Solid (TDS), b) Chloride (Cl^-), c) Iron (Fe), d) Chromium (Cr)

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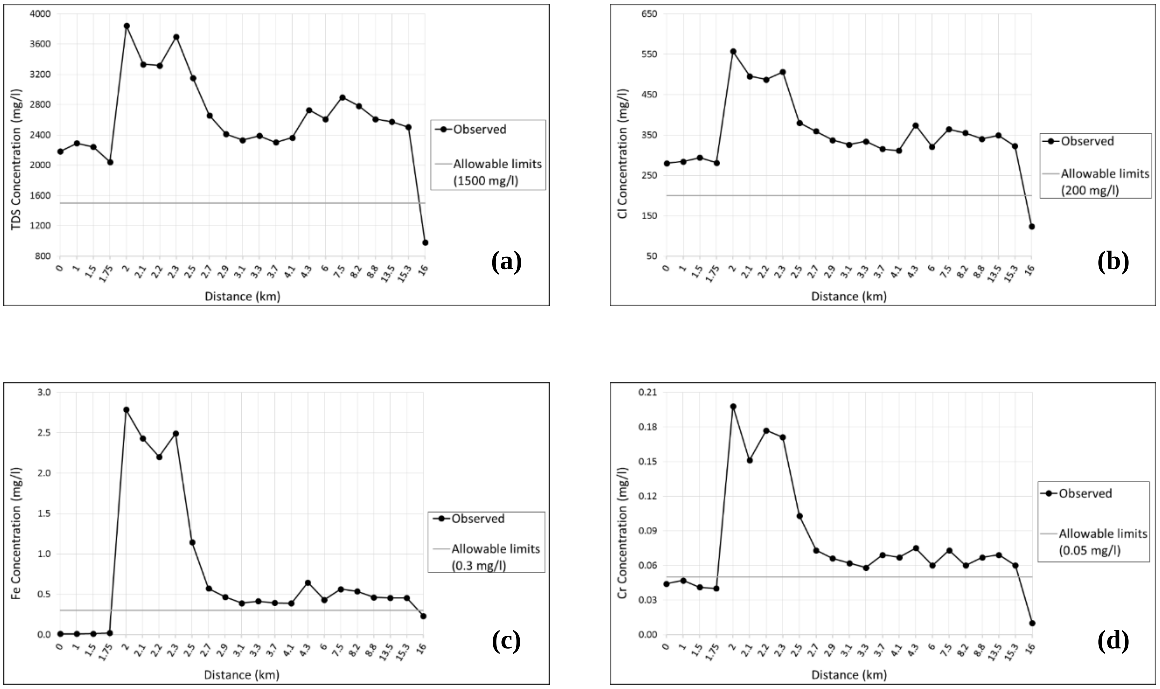

Figure (4) Variation of the concentration of different elements with distance along the study reach on Apr. 8, 2014 for:- a) Total Dissolved Solid (TDS), b) Chloride (Cl^-), c) Iron (Fe), d) Chromium (Cr)

Model description

The problem that is considered in the present work is a two-dimensional contamination distribution into a Diyala River. This model contains two parts: K-ε turbulent equation used to simulate the flow field and estimate the viscosity variation along the river, and an advection-dispersion equation for simulating the variation of the selected conservative substances along the river. In order to simplify the analysis, the following assumptions are used: the river reach is not sufficiently straight or uniform, therefore a two-dimensional model is to be considered; the pollutant is well-mixed over depth; it is of conservative non-decayable substance; the fluid motions are prominently horizontal so that vertical velocity is negligible, and almost constant depth of water is assumed along the river; rough bed longitudinal velocity distribution is taken into account; the velocities at the riverbanks are considered equal to zero; the fluid is incompressible and uniform; the turbulence is isotropic i.e.; the river eddy viscosity is considered constant in all directions.

Governing equations

The mathematical model base on the equations that simplified into two-dimensional longitudinal and lateral directions (x and y-direction), which are compatible with the above assumptions. These equations are listed as following:

K-ε Turbulence Model

The distribution of (K) and (ε) is determined from the following equations [5], [13]:

K-Equation

$$\rho\frac{\partial K}{\partial t}+u\frac{\partial \rho K}{\partial x}+v\frac{\partial \rho K}{\partial y}=\frac{\partial}{\partial x}\left[\left(\mu+\frac{\mu_t}{\sigma K}\right)\frac{\partial K}{\partial x}\right]+\frac{\partial}{\partial y}\left[\left(\mu+\frac{\mu_t}{\sigma K}\right)\frac{\partial K}{\partial y}\right]+G-\rho\varepsilon \quad (1)$$

ε-Equation

$$\rho\frac{\partial \varepsilon}{\partial t}+u\frac{\partial \rho\varepsilon}{\partial x}+v\frac{\partial \rho\varepsilon}{\partial y}=\frac{\partial}{\partial x}\left[\left(\mu+\frac{\mu_t}{\sigma\varepsilon}\right)\frac{\partial K}{\partial x}\right]+\frac{\partial}{\partial y}\left[\left(\mu+\frac{\mu_t}{\sigma\varepsilon}\right)\frac{\partial \varepsilon}{\partial y}\right]+C_{\varepsilon 1}\frac{\varepsilon}{k}G-C_{\varepsilon 2}\frac{\varepsilon^2}{k} \quad (2)$$

where:

$$G=\mu\left[2\left(\frac{\partial u}{\partial x}\right)^2+2\left(\frac{\partial v}{\partial y}\right)^2+\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right)^2\right] \quad (3)$$

Eddy viscosity

$$\mu_t=C_\mu\times\rho\times\frac{K^2}{\varepsilon} \quad (4)$$

Advection-Dispersion Equation

The two-dimensional advection-dispersion equation for conservative substance can be written as [10], [24]:

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_L\frac{\partial^2 C}{\partial x^2}+D_L\frac{\partial^2 C}{\partial y^2} \quad (5)$$

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where:
ρ: Fluid's density (kg/m^3); μ: Dynamic fluid viscosity (kg/m.s); x: longitudinal direction, and y: lateral direction; D_L and D_T: are the dispersion coefficient in x and y-directions, respectively; C_μ: Empirical constant represented by the dissipation coefficient in K-ε turbulence model; K: Turbulence kinetic energy per unit mass (m^2/s^2); ε: Dissipation rate of turbulence kinetic energy per unit mass (m^2/s^3); G: Rate of production of turbulence kinetic energy; $C_{\varepsilon 1}$, $C_{\varepsilon 2}$, and C_μ: empirical constant; σ_K: Empirical constant, which is the Prandtl numbers for the turbulent kinetic energy; σ_ε: Empirical constant, which is the Prandtl numbers for the dissipation rate. The (K-ε) turbulence model involves five empirical constants. Values of these constants are [16], [17]: $C_{\varepsilon 1}$=1.44, $C_{\varepsilon 2}$=1.92, C_μ=0.09, σ_K= 1.0, σ_ε= 1.3.

Mathematical solutions

Numerical solutions were obtained with COMSOL Multiphysics (formerly FEMLAB) software, a general purpose finite element code developed for the MATLAB environment. In COMSOL Multiphysics 3.5a the prototype domain of flow process has to be described in the mathematical model. As the geometry of the river is usually complex and it is not sufficiently straight or uniform, the digital image of the lower reach of Diyala River was imported from (www.maps.google.com) site and input directly into the AutoCAD Software for creating the parameters objects such as points and arcs. Then, the resulted domain is input into COMSOL Multiphysics 3.5a. The geometry of the river domain, as shown in figure (5), is represented by a river with a length of 16 km and an average width of 60 m. A finite element method was used to solve this model by breaking the problem area into many small triangular elements.

Creating a mesh is the second step in this model after model drawing. The triangular mesh is better to fit the river domain than the rectangular mesh, although the rectangular mesh is easier to generate. The mesh quality is important here since a low mesh quality will significantly affect the efficiency and accuracy of the model. The domain was meshed into 4941 nodes and 8644 non-uniform triangular finite elements. Finer triangular mesh with small triangles was used at the five pollutant sources and at the confluence of the Tigris-Diyala Rivers for better simulation. The position of these sources on the river segment was presented in figure (5).

Rough bed longitudinal velocity distribution is obtained from the following equation [23], [13]:

$$U = 5.75 U_* \log\left(\frac{30H}{K_S}\right) \tag{6}$$

Where
U: stream velocity (L/T); U_*: Shear velocity (L/T); H: depth of flow (L); K_s: Roughness height, which is the effective height of irregularities, forming roughness elements (L).

Based on equation (6) with roughness coefficient is equal to 0.024m and water slope is equal to 9cm/km [20], the average water velocity in Oct. 30, 2013, Jan. 2, 2014, and Apr. 8, 2014 become 0.43m/s, 0.51m/s, and 0.36m/s, respectively. These values were obtained when the hydraulic radius is equal to the water depth.

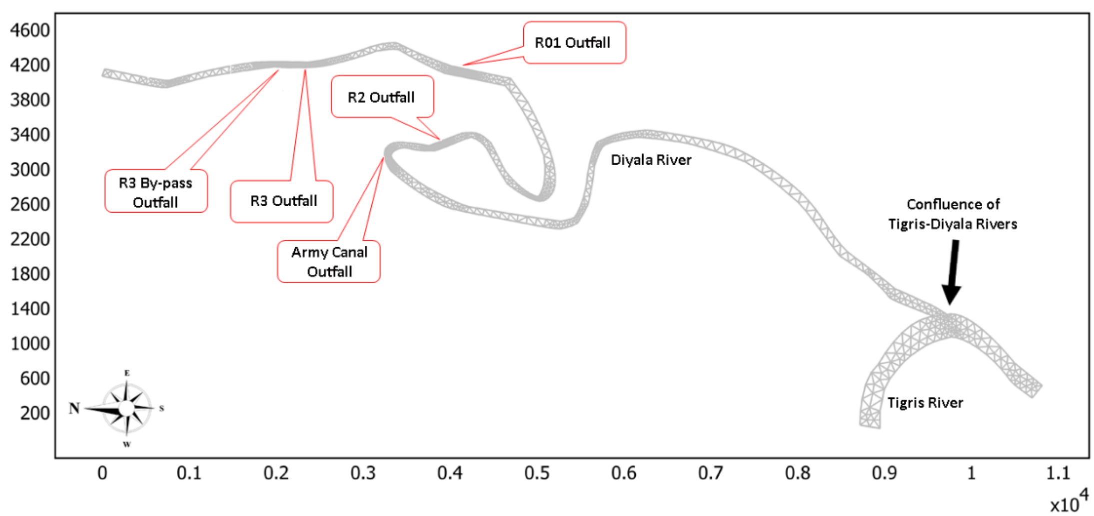

Figure (5) Representation of domain geometry in COMSOL Multiphysics 3.5a

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Initial and Boundary Conditions

Two-dimensional mathematical model is used in the present work. Equations (1 and 2) are used to simulate velocities distribution along a river when the viscosity variation is taken into account. Equation (5) is used to simulate the pollutant distribution along a river. These equations are partial differential, therefore initial and boundary conditions must be identify. K-ε turbulent model equations (1 and 2) are applied generally at steady state phenomena especially when there is no grand source which effects on the river water flow rate [13]. Concerning the advection-dispersion equation (5), generally the initial condition for any pollutant is equal to zero but in especial cases it can be subjected to an equation [15]. Also, the initial conditions comprise known value of horizontal profiles for the longitudinal velocity components (u), and the lateral velocity components (v) at every point in the horizontal plane. There are three types of boundary conditions used at any model, Neumann boundary conditions, Dirichlet boundary conditions, and mixed boundary conditions, the latter is a combination of the Dirichlet and Neumann conditions. When describing flow problems, a Neumann boundary is an insulated boundary (or impermeable boundary) which means there is no flux at the boundary, while a Dirichlet boundary indicates that the value of concentration is constant at the boundary. In additional, the boundary and initial conditions used in solving the model are shown in figure (6).

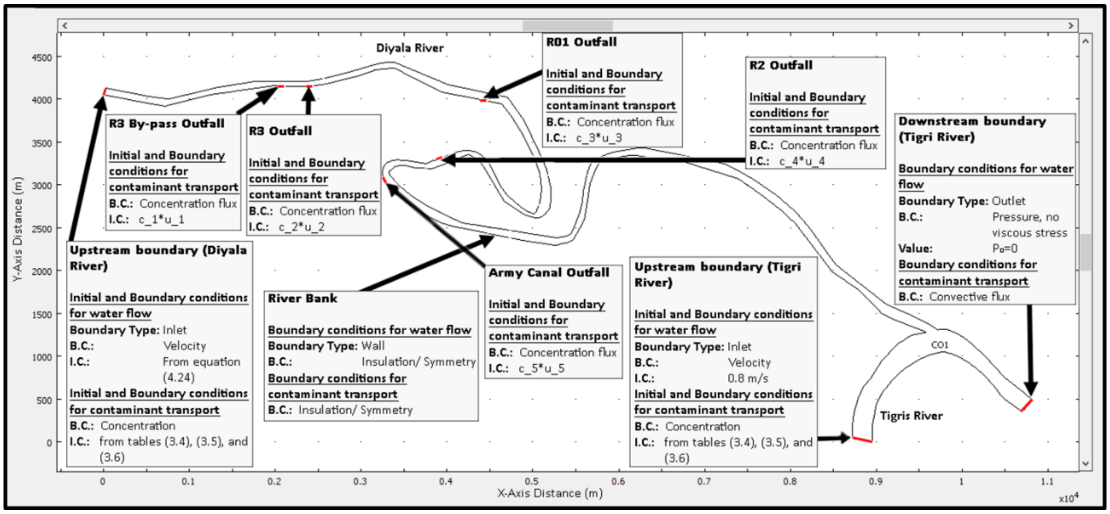

Figure (6) Boundary and initial conditions used in the present model along the study reach

Model Calibration

In the present work, two-dimensional mathematical model is based on the strong coupling between k-ε turbulent model with advection-dispersion equations to simulate hydrodynamic parameters govern the pollution transport along the study reach. COMSOL Multiphysics 3.5a is operated under different conditions, in order to test the convergence of the solution, and to study the sensitivity of the model results to different parameters. The calibration of the model is based on the data collected on Oct. 30, 2013 and Apr. 8, 2014 for Total Dissolved Solids (TDS), Chloride (Cl^-), Iron (Fe), and Chromium (Cr) concentration at twenty three stations started from 2km upstream Rustimiyah third Expansion plant (R3) and extends to the confluence of the Tigris-Diyala Rivers.

The parameters tested herein are the roughness height (K_s), the water slope (S), water depth (H), and the dispersion coefficient (D). Equation (6) is used to simulate the approximate value of the river velocity. Velocity value depends basically on the water depth, the bottom slope of the channel, and the roughness height (K_s). It is not uncommon for engineers to think that the channel has a single value of K_s in all locations. In reality the value of K_s is highly variable and depends on many parameters such as flow variables, the sediment transport rate and seasonal variation [Chow, 1975]. The values of K_s in the study reach have the range between (0.01-0.03) [20]. Four value of K_s are tested at the present work, which are 0.012, 0.024, 0.036, and 0.048, it found that the best value is (K_s=0.024), as shown in figure (7). Three values of water slope (S) are tested, which are 7cm/km, 9cm/km and 13cm/km, it found that the best value is obtained at (S=9cm/km), as shown in figure (8). The average water depth (H) on Oct. 30, 2013 and Apr. 8, 2014 are equal to 0.73m and 0.55m, respectively. Two values of water depth are tested in the present model

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with the actual water depth value, which are 0.2m (low discharge period) and 2m (high discharge period), it found that the best value of (H) is 0.73m and 0.55m on Oct. 30, 2013 and Apr. 8, 2014, respectively, as shown in figure (9). Three types of computations are conducted to compute the longitudinal dispersion coefficient (D_L), as the following:

Fischer et al. (1979) derived the following simple and approximate expression for longitudinal dispersion coefficient of streams [11]:

$$D_L = 0.011 \frac{U^2 T^2}{H U_*} \tag{7}$$

Kashefipour and Falconer (2002), using dimensional and regression analyses on published river data, developed the following expression for DL in natural streams [14]:

$$D_L = 10.612 (HU) \left(\frac{U}{U_*} \right) \tag{8}$$

McQuivey and Keefer (1974) solved the continuity equation with the dispersion equation successively to represent the dispersion coefficient [19]:

$$D_L = 0.058 \left(\frac{Q}{ST} \right) \tag{9}$$

where: U: stream velocity (m/s); D_L: Longitudinal dispersion coefficient (m^2/s) ; H: Cross-sectional average flow depth (m); U_*: Shear velocity (m/sec); T: Top width of water (m); Q: Discharge (m^3/sec); S: Slope of bed channel (m/m). It noticed that McQuivey equation provides closer results to the observed once, as shown in figure (20).

In (1967), Fischer derived an equation, which is considered the most popular equation to compute lateral dispersion coefficient (D_T), as the following [25]:

$$D_T = 0.6 H U_* \tag{10}$$

where: D_T: Lateral dispersion coefficient (m^2/sec); H and U* as mentioned before.

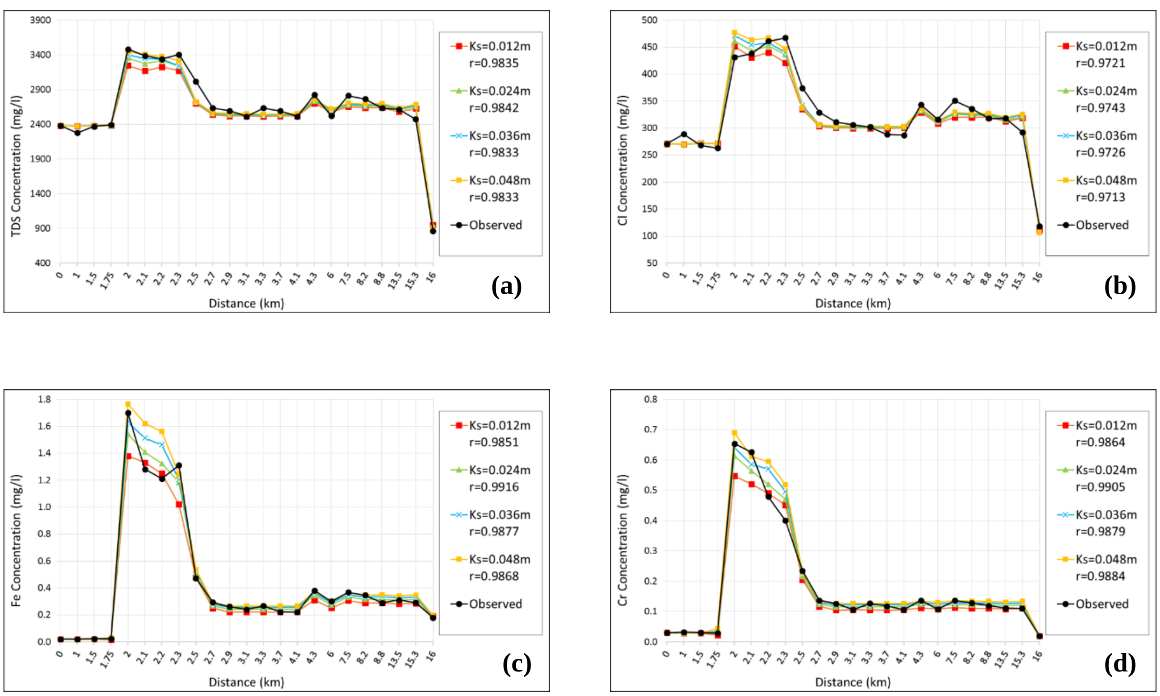

Figure (7) Comparison between observed and predicted concentration with different values of roughness height (Ks) along study reach on Oct. 30, 2013 for:-
a) Total Dissolved Solid (TDS), b) Chloride (Cl^-), c) Iron (Fe), d) Chromium (Cr)

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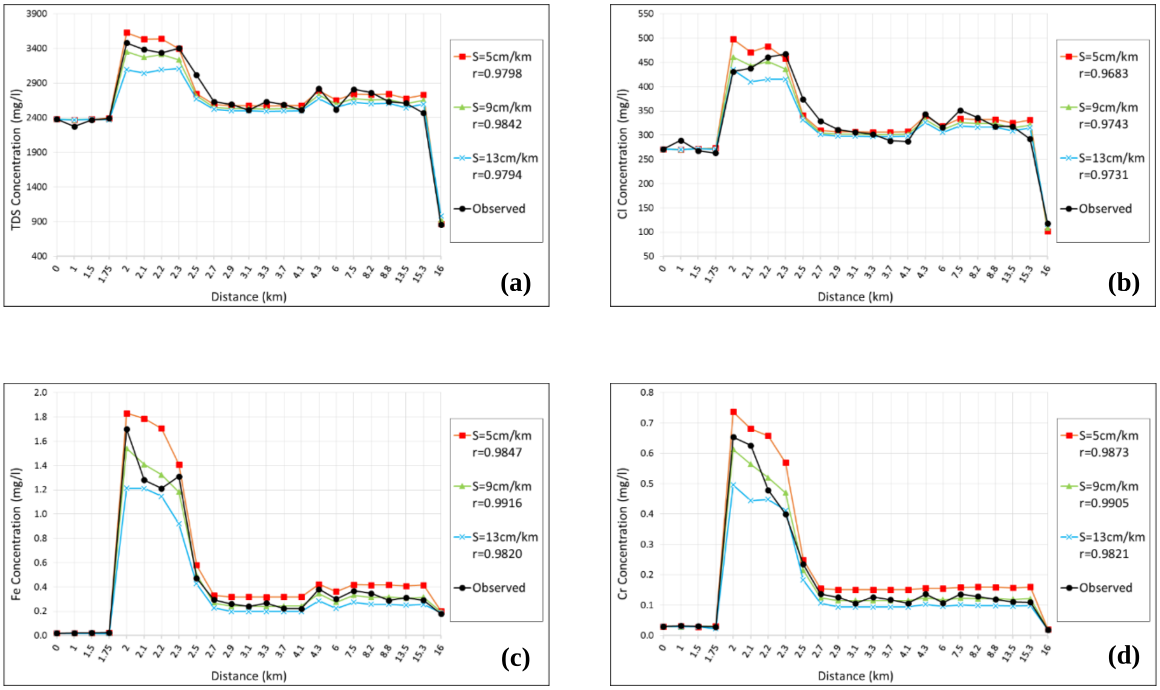

Figure (8) Comparison between observed and predicted concentration with different values of water slope (S) along study reach on Oct. 30, 2013 for:-
a) Total Dissolved Solid (TDS), b) Chloride (Cl^-), c) Iron (Fe), d) Chromium (Cr)

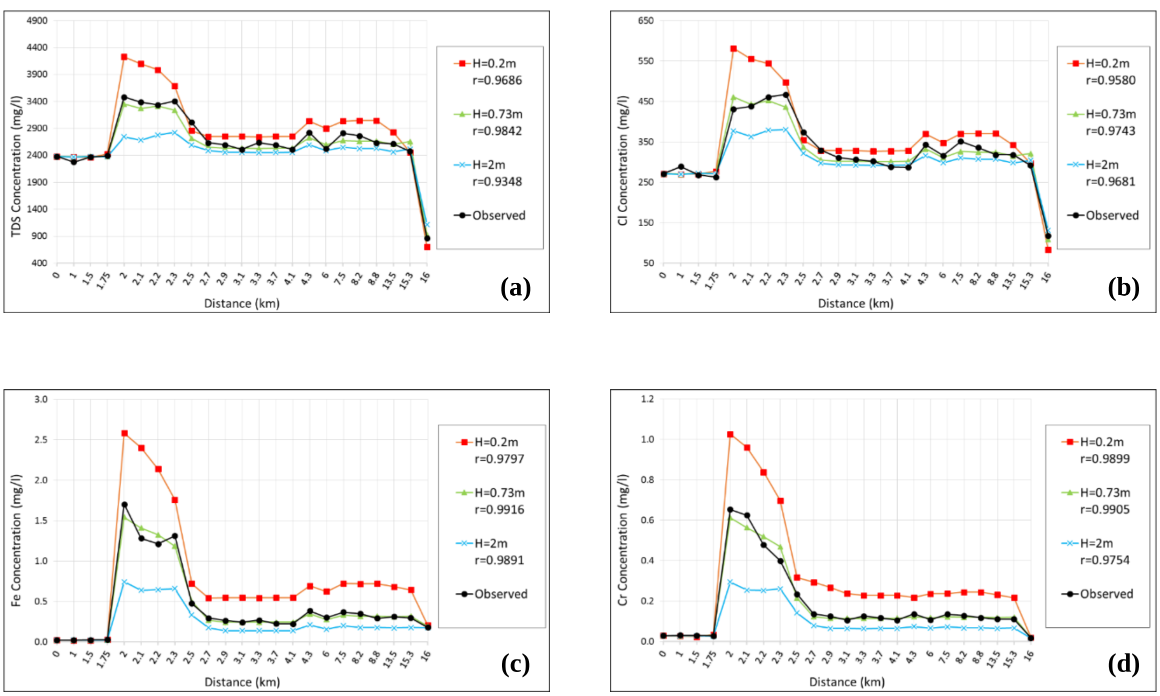

Figure (9) Comparison between observed and predicted concentration with different values of water depth (H) along study reach on Oct. 30, 2013 for:-
a) Total Dissolved Solid (TDS), b) Chloride (Cl^-), c) Iron (Fe), d) Chromium (Cr)

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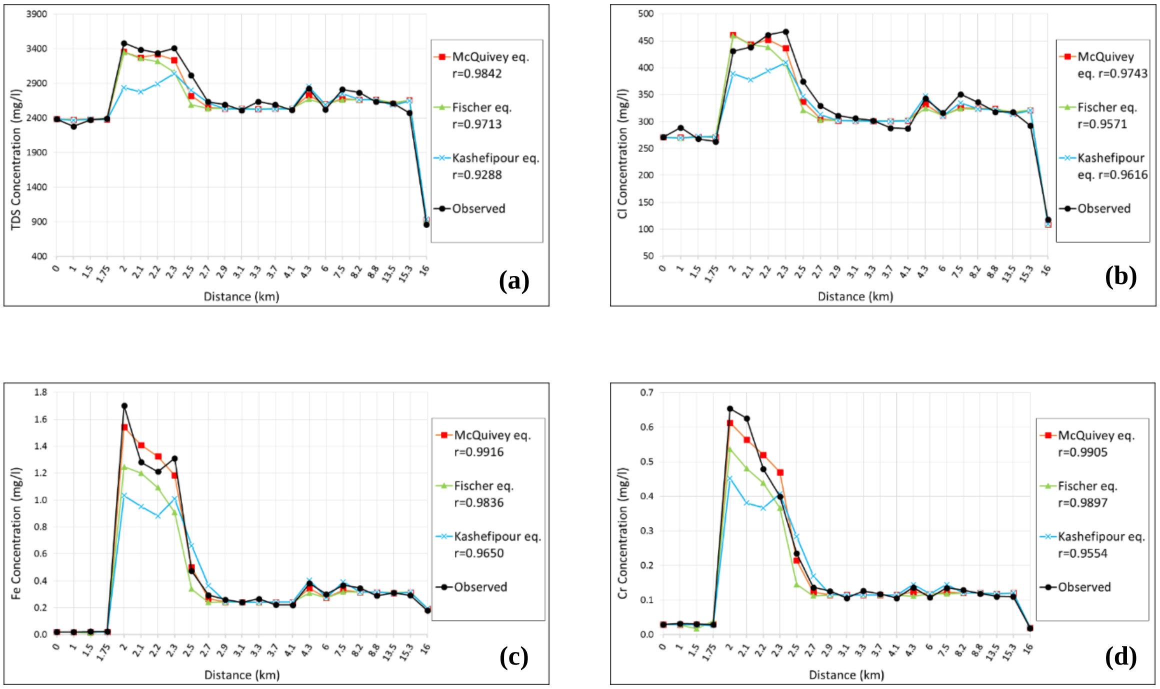

Figure (10) Comparison between observed and predicted concentration with different equations of longitudinal dispersion coefficient (DL) along study reach on Oct. 30, 2013 for:-
a) Total Dissolved Solid (TDS), b) Chloride (Cl^-), c) Iron (Fe), d) Chromium (Cr)

Model Verification

Verification is the ability of the model to replicate prototype using an independent set of observation (i.e. observation not employed in calibrating the model) [2]. For this purpose COMSOL Multiphysics 3.5a is run to simulate the water velocities behavior and the distribution of contaminant along the case study using the parameters derived from the calibration runs, which are roughness height equal to 0.024m and the water slope equal to 9cm/km. Longitudinal dispersion coefficient (D_L) and lateral dispersion coefficient (D_T) are evaluated using McQuivey equation (9) and Fischer equation (10), respectively. The predicted values of TDS, Cl^-, Fe, and Cr, concentration are compared with the observed filed data on Jan. 2, 2014, as shown is figures (11) to (14). These figures illustrate a good agreement between observed and predicated values with a percentage of less than 10%, hence the model is verified. Error of the verification step is slightly higher than that of the calibration step, but in both cases the errors are within the acceptable limit (10%).

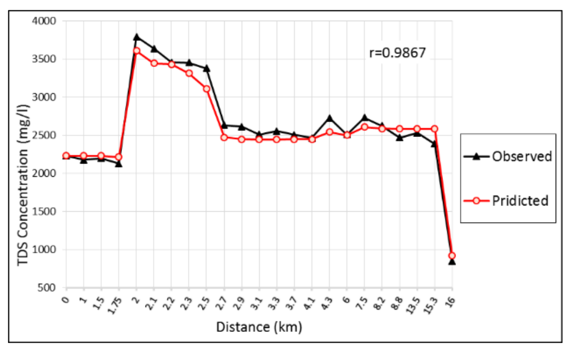

Figure (11) Comparison between observed and predicted TDS concentration along study reach on Jan. 2, 2014

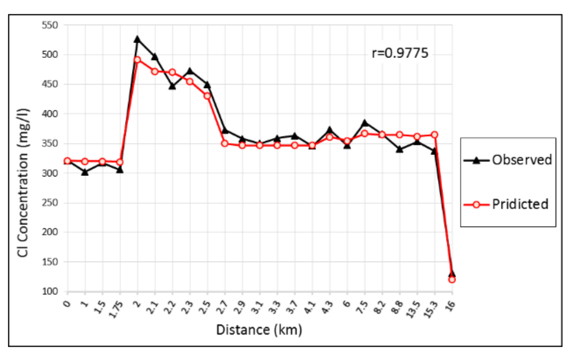

Figure (12) Comparison between observed and predicted Cl^- concentration along study reach on Jan. 2, 2014

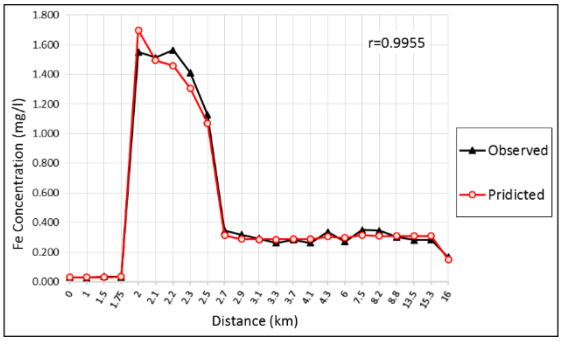

Figure (13) Comparison between observed and predicted Fe concentration along study reach on Jan. 2, 2014

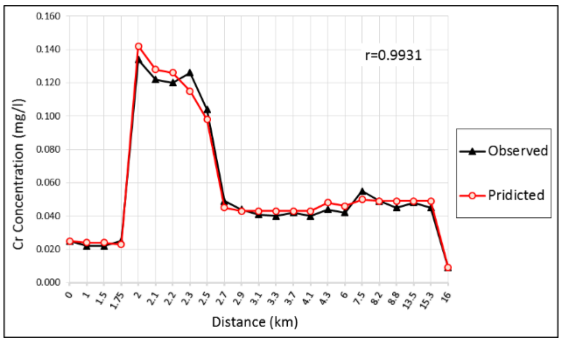

Figure (14) Comparison between observed and predicted Cr concentration along study reach on Jan. 2, 2014

Results and discussion

The present mathematical model examines the contamination transport along the case study in the Diyala River by coupling the advection dispersion equation with K-ε turbulent model equations. Velocity distribution along the case study on Jan. 2, 2014 is shown in figure (15). From this figure, it can be seen that the velocity has maximum value at the midpoint of the river width and minimum value at the bank of the river. The boundary and initial hydraulic conditions used to solve the model is explained in figure (6).

In the advection-dispersion equation, the hydrodynamic dispersion coefficient is applied as anisotropic dispersion coefficient, where the longitudinal dispersion coefficient (D_L) and lateral dispersion coefficient (D_T) are computed using equations (9) and (10), respectively.

COMSOL Multiphysics 3.5a has been used to simulate the pollution scenario described above, in order to assess consequences of the continuous release of conservative pollutant over 24 hours. For example, the Model has been used to predict the distribution of TDS concentration along the case study reach measured on Jan. 2, 2014, as shown in figure (16). This figure indicates that maximum TDS concentrations occurred at sites S5 in the vicinity of R3 By-pass outfall (2km), S6 (2.1km), S7 (2.2km) and S8 in the vicinity of R3 outfall (2.3km) with concentration 3611 mg/l, 3447 mg/l, 3433 mg/l and 3314 mg/l, respectively. These values of TDS concentration caused by R3 By-pass outfall, which is located on the right bank side of the Diyala River and represented the most important point source of contamination that affects badly on the water quality of the river.

Minimum TDS concentration occurred at the upstream sites S1 to S4 with concentration range between (2216-2234 mg/l), where these sites located before any pollutant source. At sites located vicinity to the R01 outfall (4.3km) and R2 outfall (7.5km), continuous effluents discharged directly to the Diyala River caused an increase in river concentration reached to 2546 mg/l and 2611 mg/l, respectively.

Pollutants released from the sources will be transported along all investigated area in less than one day, the concentration distribution of TDS changed from two dimensions to one dimension at nearly 0.5km downstream army canal outfall. The pollutants reached the downstream boundary (Tigris River) after 11 h from the release start (if discharged pollutant flow and hydrodynamic conditions of the river are constant), while the pollutants reached the downstream boundary after 9 h and 8 h on Oct. 30, 2013 and Apr. 8, 2014, respectively. These pollutants released from Diyala river caused increasing in Tigris TDS concentration to 921mg/l (TDS concentration in Tigris river before mixing with Diyala river was 526mg/l), as shown in figure (16).

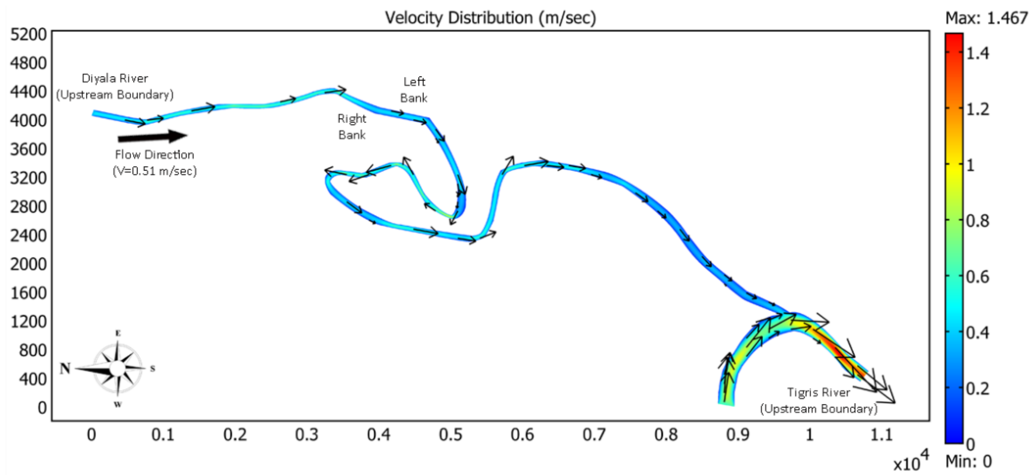

Figure (15) Velocity distribution along study reach on Jan. 2, 2014

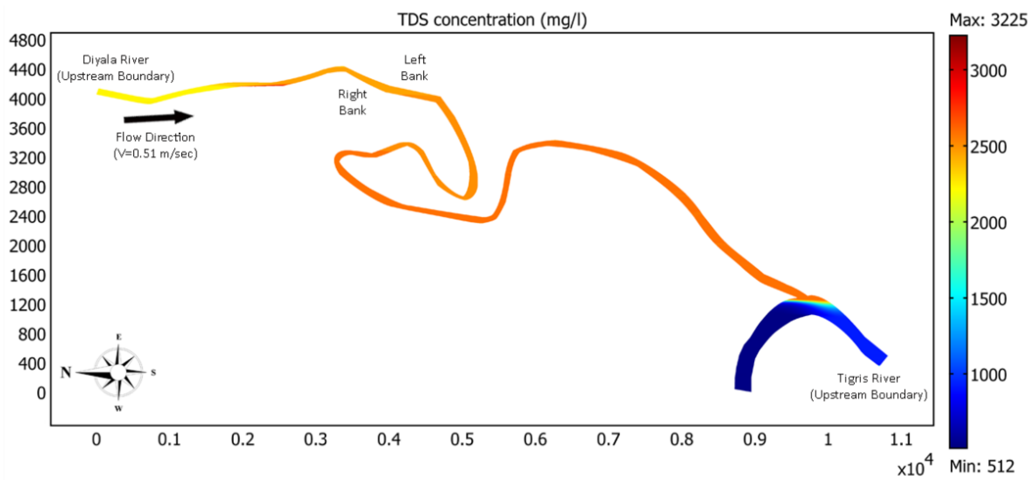

Figure (16) Distribution of TDS concentration along study reach on Jan. 2, 2014

Conclusion

The frequently dump of untreated waste water from the outfalls directly to the Diyala River may also cause some appreciable increase in the pollutants concentration. R3 By-pass outfall is the most important point source of contamination that affects badly on the water quality of the river. The highest concentration of pollutants is occurred in the route between R3 By-pass outfall and R3 outfall. It can be concluded that the model is sensitive to the variation of roughness height. Increasing the roughness height, which causes an increase in TDS, Cl^-, Fe, and Cr concentration levels due to the decrease in the velocity of the river and vice versa. The distribution of TDS, Cl^-, Fe, and Cr concentration increases with the decrease in the velocity of the river due to the decrease in the water slope and vice versa. It can be concluded that TDS, Cl^-, Fe, and Cr concentration increases if the velocity of the river decreases due to the decreasing in the water depth. The verification of the model indicates that a good agreement between the observed and the predicated data with a percentage error less than 10%. This means that the model is able to predict well. COMSOL Multiphysics 3.5a software based on the finite element numerical solution showed to be an efficient tool in solving the present problem. Water quality data collected indicated that Diyala River conditions within the study area were not suitable for potable water supply and the protection of aquaculture life. It was recognized that Diyala River suite navigation and agriculture.

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