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Modeling of Sediment Transport Around A Water Intake In Tigris River – Baghdad Using A Numerical 2d Model

Shams Al-Asadi[1]*, Tariq Abed Hussain[2], Mustafa Al-Mukhtar[3]
Civil engineering department, U niversity of Technology, Iraq.

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Abstract.
Understanding sedimentation behavior and its transport capacity in the Tigris River is of significant importance owing to the detrimental consequences caused by it. This study investigates the sediment amounts transported along the reach of the Tigris River in Baghdad. The CCHE2D model which is a common tool developed by the National Center for Computational Hydrological Science and Engineering (NCCHE) was applied to investigate the flow pattern and sediment amounts within 7 km reach. The model was initially calibrated and validated under steady-state conditions at the Sarai gauging station (upstream) and its performance was evaluated around the Abu Nawas water treatment plant (downstream). The result shows that the water surface level and velocity in the Sarai Baghdad gauging station and Abu Nawas raw water station cross-sections are different due to different considerations which are discharged, bank and bed soil types, channel velocity, and section shape. Moreover, the sediment concentrations ranged between 0.240 - 0.350 kg/m^3 at the cross-section of the Sarai Baghdad gauging station while the cross-section of Abu Nawas raw water station ranged between (0.040-0.090) kg/m^3. Additionally, the study investigated the average suspended sediment concentration at the river reach which ranged from 150 to 300 kg/m^3. Finally, the study demonstrated CCHE2D's capacity to simulate river flow and sediment movement.

Keywords: Sediment transport; CCHE2D; Unsteady flow; Tigris River, bed changes

نمذجة نقل الرواسب حول مأخذ مائي في نهر دجلة– بغداد باستخدام نموذج رقمي ثنائي الأبعاد

شمس الاسدي*، طارق عبد حسين، مصطفى المختار
قسم الهندسة المدنية ، الجامعة التكنولوجية ، العراق

الخلاصة
لفهم الترسيب وآلية انتقاله في نهر دجلة ، استخدمت هذه الدراسة نموذج CCHE2D وهو أداة شائعة طورها المركز الوطني للعلوم والهندسة المائية الحاسوبية (NCCHE) للتحقيق في نمط التدفق غير المستقر وكميات الرواسب في نطاق 7 كم في مدينة بغداد. تمت معايرة النموذج في البداية والتحقق من صحته في محطة سراي

Email: shmas.asadi18@gmail.com

(أعلى المنبع الوصول) وتم تقييم أدائه حول محطة معالجة المياه في أبو نواس (أسفل المنبع). علاوة على ذلك ،تم تشغيل نموذج في ظل ظروف غير مستقرة من حيث التدفق والرواسب. أظهرت النتائج أن مستوى سطح الماء وسرعته في المقاطع العرضية لمحطة سراي ومحطة أبو نواس مختلفة بسبب اختلاف أنواع التصاريف والضفاف ونوع التربة لقاع النهر وسرعة القناة وشكل المقطع. كما تراوحت تركيزات الرواسب بين 0.240 – 0.350 كجم/ م^3 عند المقطع العرضي لمحطة سراي بينما تراوح المقطع العرضي لمحطة أبو نؤاس بين (0.040–0.090) كجم/ م^3. علاوة على ذلك ، فحصت الدراسة متوسط تركيز الرواسب العالقة في مجرى النهر والتي تراوحت بين (0.150 – 0.300) كجم/ م^3 . وأخيرًا أثبتت الدراسة قدرة CCHE2D على محاكاة تدفق النهر ونقل الرواسب.

1. Introduction:

Sediment transport in rivers is associated with a wide range of environmental and engineering issues [1]. Rivers form a corridor for sediment movement between catchment areas and coastal areas [2]. Soil denudation is one of the primary sources of sediment delivery to rivers [3] and bank erosion [4]. Typically, suspended sediment load in rivers increases with increasing discharge [5]. As such, sediment transport behavior in rivers is among the concern of the riverine engineering communities [6]. Sediment is a naturally occurring component of many bodies of water, therefore it may be affected by human activities. Consequently, numerical modelling is a significant instrument for estimating river flows and sediment transport.

River networks can be divided into three zones based on sedimentation activities and processes: erosion, transport, and accumulation [7]. Erosion zones are frequently observed in headwaters due to the high channel slope and flow rates. Transport zones are places between erosion and deposition zones where sediment is primarily passing due to high flow velocity. Despite its dynamic nature, silt may build briefly in transit zones during low flow, generating rare sediment storages. Therefore, the form of a river is heavily influenced by sedimentation. Because of hydrodynamics caused by flow variations, the river changes its bed. With varying discharge and sediment characteristics, the sedimentation process is followed by erosion and deposition in the river, modifying the river geometry. Therefore, physical infrastructure such as dams, locks, and levees are difficult to build and control due to erosion and deposition. [8]. Therefore, precipitation (intensity and volume), soil physical qualities (texture and detachability), topography, and land cover mostly influence the volume and concentration of sediment (vegetation).

In the literature, many authors studied river flow and sediment transport [9][10][11]. For instance, the effect of human activities on suspended sediment flow in China's Pearl River Delta was investigated by [12]. The study evaluated a 50-year monthly data set from the delta's three major rivers and discovered that the parameters of the sediment rating curve had changed over time, impacted by human actions such as damming the rivers in the early 1990s. Furthermore, sediment deposition in the headwater reservoirs has resulted in a drop in the exponent of the rating curve, which in turn has led to a large decrease in the delivered sediment load to the estuary. Human activities have resulted in a mean annual sediment deficit of 26.80 106 t/yr in the 1990s and 50.46 106 t/yr in the 2000s, as determined by comparing the potential sediment load in the absence of major human influence to the recently recorded. Anthropogenic activities such as land usage, dredging, and dam construction can greatly raise or decrease river sediment loads [13]. The erosion and sediment of the Beshar –bed river in Yasuj, Iran was studied using the CCHE2D model. The study compared the model output with the empirical formulas of Einstein, Vilkanov, Lane– Kalinske, Brooks, Englund and Bagnold. The study proved that

CCHE2D was superior in estimating suspended sediment load than other applied methods in terms of statistical indicators [14]. The dynamic process of hydrodynamics and associated temporal and spatial distributions of sediment, salinity and phytoplankton in Lake Pontchartrain in the USA due to flood diversion was analyzed [15]. The study calibrated to that end the CCHE2D model against three different cases representing the maximum, average, and minimum discharges. It was concluded that the model successfully analysed the influence of flood release events on the aquatic ecosystems in the lake.

However, the applications of numerical modelling of sediment transport in the Tigris river have been rarely reported in the literature. As such, the main objective of this study is to analyze the sediment transport along the reach of the Tigris River in Baghdad and estimate the amount of sediment transported. In addition, the aim was to study the effect of sediments around the intake structure of the Abu Nawas raw water treatment plant and suggest measures that could decrease the amount of sediment accumulating close to the intake. The data collected for that purpose included streamflow, sediment data, and geometrical cross sections of the river along the studied reach extended from upstream of the Sarai station up to two kilometers downstream of Abu Nawas station.

2. Materials and Methods

2.1 The CCHE2D model:

The National Center for Computational Hydroscience and Engineering created CCHE2D, an integrated modelling analysis system (NCCHE). It is a generic surface water flow model that is used to simulate the dynamic processes of water flows, as well as the unsteady and steady open channel flows, sediment transport, pollution transport, and water quality in rivers, lakes, estuaries, and coastlines. Hydraulic engineers can also utilize it in natural rivers [16]. The model used the wave dynamic modelling approach to simulate the flow and sediment in open channels and rivers i.e. Saint Venant equations of which the Continuity equation (equation 1) and the Momentum equation (equation 2).

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q \quad (1)$$

$$\frac{\partial}{\partial t}\left(\frac{Q}{A}\right) + \frac{\partial}{\partial X}\left(\frac{BQ^2}{2A^2}\right) + g\frac{\partial h}{\partial x} + g\left(S_f - S_0\right) = 0 \quad (2)$$

In these equations, t and x are time and place parameters, A = flow space, Q = flow discharge, h = depth of flow, S_0 = steep of the river bed, b = correction factor of momentum factor, g = gravity speed, q = discharge per unit width and Sf represents frictional steep. In the dynamic wave method, we use the complete momentum equation. Numerical techniques are required to solve the whole momentum equation in addition to the continuity equation. The momentum equation for the wave spreading model is given in Equation 3. While the equation for non-uniform sediment transport is given in Equation 4.

$$\frac{\partial h}{\partial x} + S_f - S_0 = 0 \quad (3)$$

$$\frac{\partial (AC_{tk})}{\partial t} + \frac{\partial Q_{tk}}{\partial x} + \frac{1}{L_s}\left(Q_{tk} - Q_{t*k}\right) = q_{lk} \quad (4)$$

Where C_{tk} = the mean (average) of sediment density for the size of k units, Q_{tk} = is the rate of actual carried alluvia for the size of k units, Q_{t*k} = is the capacity for carrying sediments, L_s = the length of the distance that sediment is carried inconstantly and q_{lk} = is the side discharge or output sediments in the width unit.

2.2 The Study Area

The studied reach of the Tigris River in Baghdad city in Iraq (7 Km in length) extends from Al-Sarai gauging station at 33° 20′ N latitude and 44° 23′ E longitude up to the 14th July suspension bridge at latitude 33° 29′ N and 44° 40′ E longitude (Figure 1). Therefore, the study area includes five bridges (Al-Shuhada Bridge, Al-Ahrar Bridge, Al-Sinak Bridge, Al-Jumhuriya Bridge, and the 14th July Suspension Bridge). The width of the Tigris River inside Baghdad is about 190-500 meters, and the average slope is about 7 cm/km.

Abu Nawas raw water station is located downstream of this reach (Figure 2), which is monitored by the Mayoralty of Baghdad. The station is conveyed water to seven residential compounds (Municipalities Project, Obour Complex, Tank, the old Kamaliya complex, New Kamaliya Complex, Al-Batool Complex, Al-Nasr District Complex, and Al-Fath Al-Mubin Complex). The water treatment plant has two intake structure with a total number of 6 pumps which has a 12 m height and operating horsepower of 840 kw. Hence, the design capacity of the water treatment plant has 438 m^3/day.

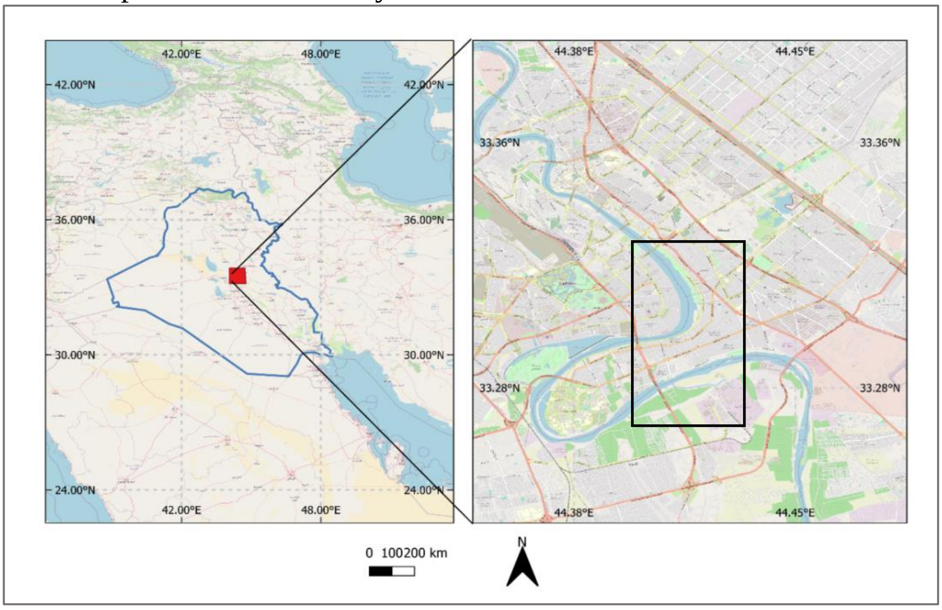

Figure 1: The study area

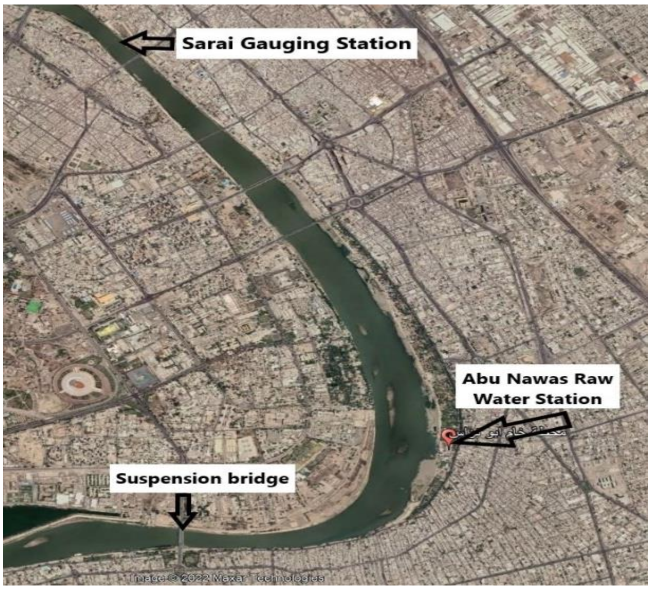

Figure 2: The location of Sarai gauging station and the intake of Abu Nawas raw water plant.

3. Methodology

3.1 River geometry

The surveyed cross sections' data of the study area were collected from the Iraqi Ministry of Water Resources. The cross sections covered 7 km of the river reaching from the Sarai gauging station in the north to the Hanging Bridge in the southern part. A total of 23 cross-sections were surveyed at intervals of 250 m (some cross-sections were conducted at lesser intervals especially, at meanders). The data from this survey have been used in the present investigation to create a 2D unsteady flow model by the CCHE2D model**.**

3.2 Boundary conditions

The daily discharges of the river at Baghdad were calculated for a period from 1 Jan to 30 September 2019 and were used in the model to define the upstream boundary conditions. The stage hydrograph (water surface level) was used on the other side to define the downstream boundary condition. Figures 3 and 4 show the daily discharges and water levels at the upstream and downstream reach respectively. Moreover, the boundary conditions of simulated sediment were also identified as a sediment rating curve at the upstream river (Figure 5).

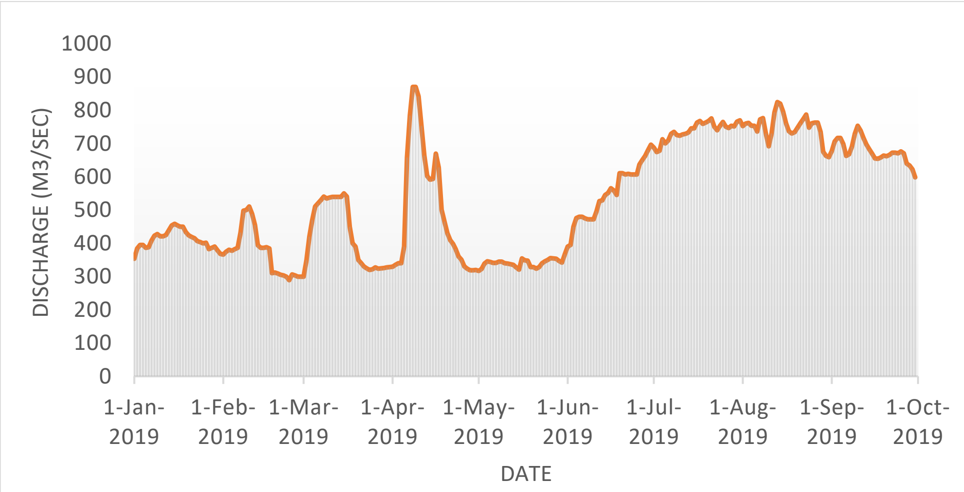

Figure 3: The discharge hydrograph of the river upstream.

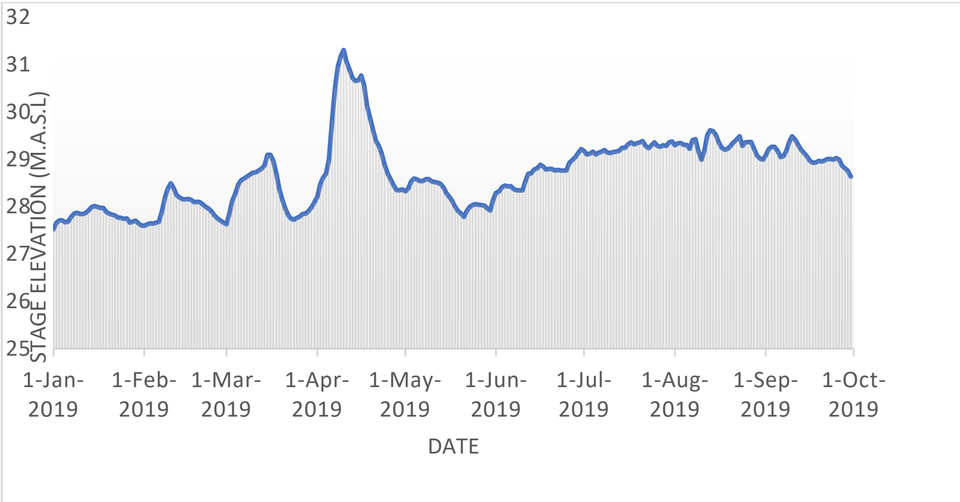

Figure 4: The hydrograph data (water surface level) of the river downstream.

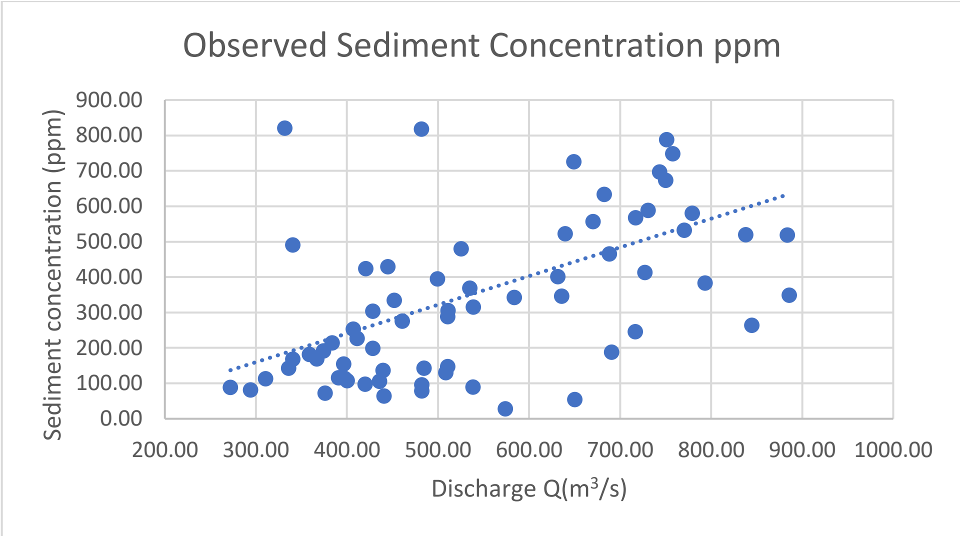

Figure 5: The sediment rating curve of the river discharges

3.3 Model calibration and validation

Calibration is an essential aspect of any modelling system since it helps find the right values for all of the model's parameters and capture the real behavior of the studied case. Therefore, the hydraulic model used in this study to simulate the suspended and bed load sediment in the Tigris River was initially calibrated and validated in a previous study by the authors. The parabolic eddy viscosity (PEV) code was used to examine two types of turbulence closures: parabolic eddy viscosity and mixing length model, to represent the flow analysis and prediction in the research range. Furthermore, observed water level fluctuations were used for model calibration at specific points of the studied reach at the min, average, and max discharges i.e. 289, 530, and 870 m^3/s respectively. Hence, the suitable value of the manning roughness modulus was specified for the calibrated model. Subsequently, the verification of cross section profile at Sarai station was carried out as it is very important before considering flow modelling outcomes. The model was successfully applied as both the observed and modelled flow rates were approximately compatible. Suggesting that the bed elevations, banks, and flow regime were rather consistent and well-represented through the model. The calibrated model was eventually run under unsteady state conditions to obtain the sediment data series during the period from 1 September to 1 January 2019.

4. Results and Discussion

The model was run under the unsteady flow state to capture the real system behavior of sediment transport and its results were analyzed. At first, the results of velocity show the maximum velocity at Sarai station reached 1 m/s in the mid of the river and approached to akin zero near the banks (Figure 6). The higher flow velocity found at the water treatment of Abu Nawas was equal to 1.4 m/s (Figure 7), which could be attributed to the curvature shape of the river at that station. However, the average velocity of the river along the studied reach was 0.75 m/s. Therefore, the relationship between the flow parameters (depth and velocity) and the amount of sediment transported was investigated in this study.

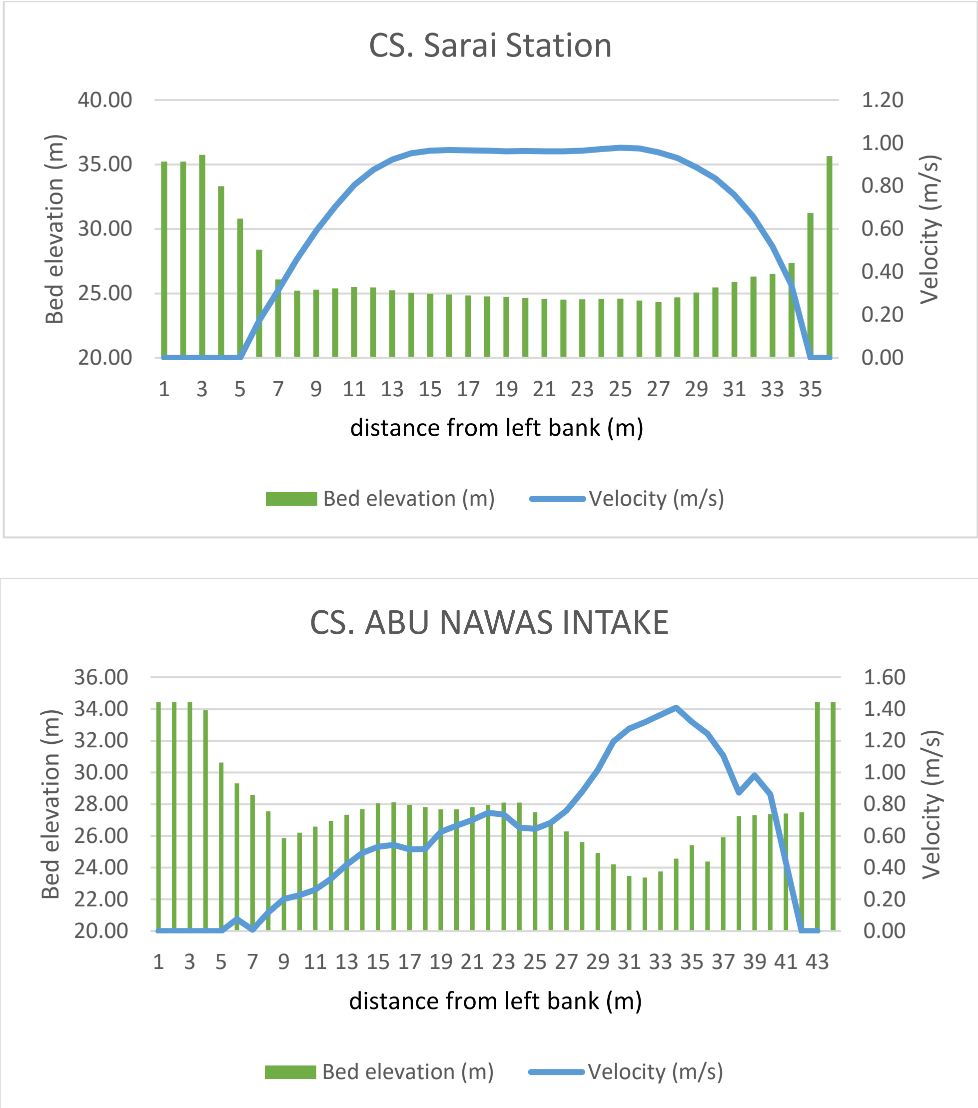

Figure 7: The velocity rate distribution at the cross-section of Abu-Nawas raw water station.

The relationships between the river bed elevation and suspended sediment concentration at Sarai station and Abu-Nawas station cross-sections were visually analyzed as shown in Figures 8 and 9. Figure 8 depicts the bed elevation and suspended load at the Sarai station. It can be noticed that the suspended sediment amount at the cross-section of the Sarai gauging station ranged between 0.240 - 0.350 kg/m^3. At the same time, the amount of bed elevation at the same cross-section was between 35-23 m. On the other side, Figure 9 shows the Abu Nawas intake station's bed elevation and suspended load. At the cross-section at the Abu Nawas gauging station, it can be seen that the suspended sediment concentration varied between 0.040 and 0.090 kg/m^3. At the same time, the amount of bed elevation at the same cross-section was between 34-23 m. Surprisingly, higher flow velocity at the water treatment plant incurred less sediment flow. One reason for that discrepancy might be the higher shear stress recorded in the area. In other words, the greater the bed shear stresses, the less erodible the material.

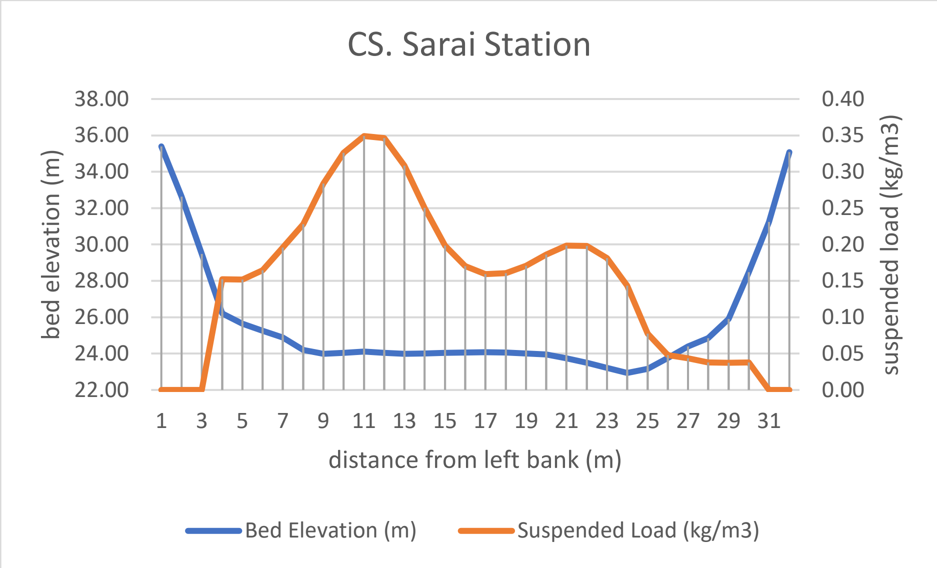

Figure 8. The concentration of suspended sediment at the cross-section of Sarai station.

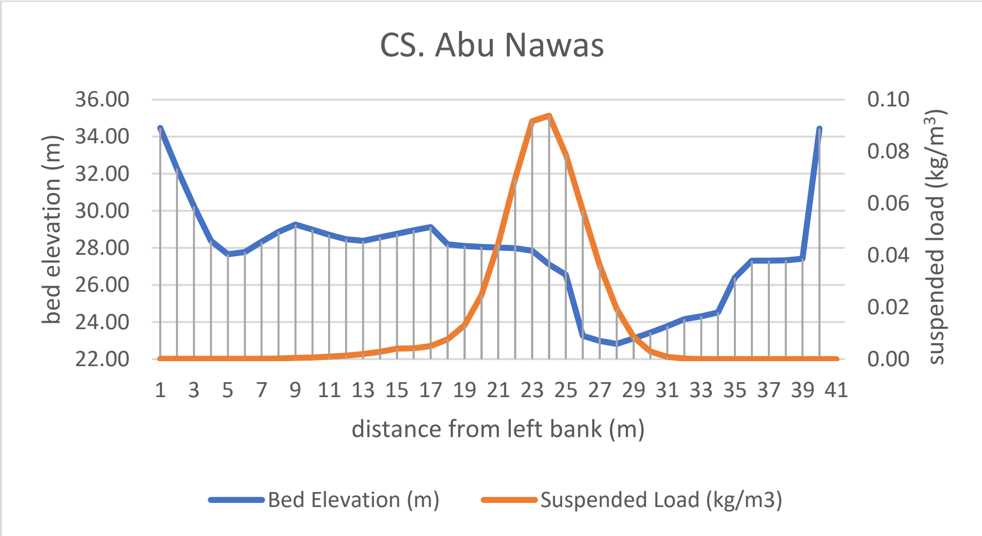

Figure 9: The concentration of suspended sediment at the cross-section of Abu-Nawas station.

Furthermore, the distribution of sediment along the river reach indicates that the average sediment concentration ranged between 150 – 300 ppm. Lastly, the results of sediment concentration at the center line of the studied river at steady flow conditions for minimum, average, and maximum discharges were analyzed as shown in Figure 10. The highest values of sediment were recorded at the inlet of the river at the Sarai station which could be explained by the geotechnical nature i.e. alluvial layers of the river bed and in addition to its straight shape.

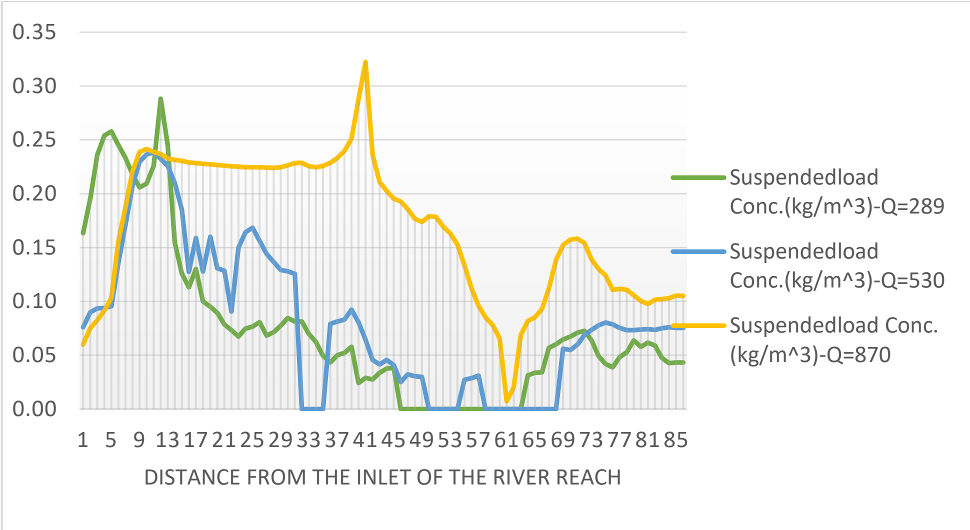

Figure 10: Results of sediment concentration at the center line of the studied river at steady flow conditions for minimum, average, and maximum discharges.

5. Conclusion

In this study, the CCHE2D model was applied to estimate sediment transport load along a 7 km reach of the Tigris River in Baghdad. The studied reach extends from the Sarai station upstream to the suspended 14 July bridge downstream. Initially, the model was hydraulically calibrated and validated and its performance was evaluated using several statistical metrics. According to the modelling results the following conclusions were concluded:

• The study proved the capability of the CCHE2D model to investigate the unsteady flow pattern of the Tigris River as well as variations of river bed elevation and sediment transport.

• The study shows that the high flow velocity occurs at the narrow meander parts of the river, caused by changes in riverbed elevation and the presents of islands, especially at the meander parts of the river.

• The sediment amounts ranged between 0.240 - 0. 350 kg/m^3 at the cross-section of Sarai station while at the cross-section of Abu Nawas ranged between (0.040-0.090) kg/m^3

• The average suspended sediment concentration along the river reached ranged between 150 – 300 ppm.

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