Journal of Engineering and Sustainable Development

Vol. 22, No.05, September 2018
ISSN 2520-0917
https://doi.org/10.31272/jeasd.2018.5.16

THREE DIMENSIONAL MODELING OF SEDIMENT TRANSPORT UPSTREAM OF AL-BETERA REGULATOR-IRAQ

Dr. Thair Sharif Khayyun[1], Nezar H. Mouhamed [2]

1) Assist. Prof. University of Technology, Building and Construction Engineering Department
2) M.Sc. University of Technology, Building and Construction Engineering Department

Abstract: This paper represents an analytical study, simulation (flow field and sediment movements) and estimation of the sediment deposition for the Al- Betera river reach upstream of Al-Betera regulator – Maysan Governorate–Iraq. Field measurements techniques and SSIIM Model were used for these purposes. A river reach with length of 4250m was chosen and divided to 17 cross sections. The Model solves the Navier – stokes equations for calculating the water velocity with k-ε model for predication the turbulence (shear stress). The Model is a stepping stone in the field of Computational Fluid Dynamics (CFD). Sediment rating curve was established by using the historical data (1984-2014) of the suspended sediment loads and river discharge which considers as a reference for researchers who interest in the field of sediment transport. Plan form of river morphology was classified as a straight (1.07 sinuosity) for the period 1986, 2007and 2014. In this study, a new sediment load transport rate equation by using multiple linear regression analysis was developed. The results of evaluation showed that the new model performs better than many Researchers [Ackers(1973) , Yang(1996), Van Rijn(1987) , Ariffin (2004) and Jassim (2012)]. A graphical representation of 3D velocities was obtained by simulation and by using Power law Scheme (x-y,y-z,x-z planes). Good agreements were found between the simulated and measured values of the flow velocity and sediment concentration in 3D for the selected 3 nodes in the y direction and for 3 depths of flow. The Coefficient of determinations were (0.8- 94) and (0.72- 0.98) respectively. The annual trapped sediment load for a river discharge (80.2) m^3/sec was (13816) cubic meters of deposition material of sediment which represents approximately (4.1 cm/year) along the river reach. SSIIM Model is a powerful fluid dynamic model for evaluation and estimation of water flow sediment transport and bed deposition. It has given satisfactory results for the bend in the river reach of the study. However, the grid, roughness of the bed and the sediment parameters must be chosen with suitable values taken for convergence purposes and taken into account the change of hydraulic and sediment variables with time and space.

Keywords: *Three dimensional, Sediment transport, SSIIM model, Al-Betera regulator.*

نموذج ثلاثي الابعاد لنقل الرسوبيات مقدم ناظم البتيرة- العراق

الخلاصة: هذه الدراسة تحليلية ومحاكاة للجريان وحركة الرسوبيات وكذلك حساب الرسوبيات لنهر البتيرة حتى مقدم ناظم البتيرة في محافظة ميسان في العراق . لقد تم استخدام تقنيات القياسات الحقلية وبرنامج (SSIIM) لهذه الاغراض . البرنامج يحل معادلات (Navier-stoke) والنموذج(K-ε) الخاص بالجريان الاضطرابي . يعتبر البرنامج الحجر الاساس في حسابات المائع الحركية. تم تشكيل منحني تصنيف الرسوبيات (rating curve) بالاعتماد على البيانات السابقة للسنوات(1986الى 2014) التي تشمل تركيز الرسوبيات العالقة مع تصاريف النهر لتعتبر مصدر للباحثين الذين يتركز اهتمامهم في حقل نقل الرسوبيات . نلاحظ من خلال شكل النهر المورفولوجي انه يصنف كمستقيم حيث نسبة التعرج للنهر(sinuosity) هي (1.07) ولفترات (1986,2007,2014) .

**Corresponding Author* : thshkhma@yahoo.com

في هذه الدراسة تم ايجاد معادلة جديدة لحساب الرسوبيات باستخدام تقنية الانحدار الخطي المتعدد حيث بينت النتائج ان المعادلة الجديدة افضل من بقية المعادلات الاخرى لبعض الباحثين [Ackers(1973) , Yang(1996), Van Rijn(1987) , Ariffin (2004) Jassim((2012)]. تم تقسيم حالة الدراسة الى(17) مقطع ولمسافة (4250)م . تم الحصول على التمثيل البياني للسرع بالاتجاهات الثلاثة بالمحاكاة وطريقة(Power Law Scheme) . لقد وجد ان هناك تطابق جيد بين القيم المقاسة والقيم المحسوبة لكل من سرعة الجريان وتراكيز الرسوبيات في الاتجاهات الثلاثة بأخذ ثلاثة نقاط باتجاه(Y) لثلاثة اعماق جريان حيث كانت معاملات التحديد للسرع والرسوبيات (0.8الى 0.94) و(0.72الى0.98) على التوالي. معدل الرسوبيات السنوية لتصريف نهر (80.2)م^3/ثا كان (13816) م^3 اي معدل المواد التي تترسب تمثل (4.1 سم/سنة) تقريبا على طول منطقة الدراسة. يعتبربرنامج (SSIIM) من البرامج المفيدة الخاصة بحركية السائل لتقييم وحساب نقل رسوبيات الجريان والرسوبيات التي في قعر النهر اذ كانت النتائج متوافقة في انحناءات النهر لمنطقة الدراسة وعلى اية حال يمكن اعتبار شبكة الجريان والخشونة وباقي المتغيرات الرسوبية يمكن ان تختار وبقيم تكون متقاربة مع المتغيرات الهايدروليكية لتحقيق الاغراض المطلوبة مع الاخذ بنظر الاعتبار المكان والزمان.

1. Introduction

With increase in industrial and economic growth, especially over the past half a century, more and more man-made multipurpose structures (reservoirs, dams, irrigation canals, and levees) were built. Nature and man-made structures affect the forces acting on the rivers and the way they respond. Perhaps the most common response is the change in sediment transport capacity which, in turn, changes river position and shape, leading to a multiple of engineering and environmental problems. Some of the common problems are (land erosion and conservation, silting of reservoirs, degradation and aggradation of channel beds, silt excluders, navigation, coastal erosion, flooding, and ecosystem changes).

To address these problems it is important to investigate sediment transport for given conditions and how it changes with changes in conditions, so that the response of rivers or other water bodies can be predicted due to change in natural or man induced forces, and measures can be taken to mitigate damages sediment transport deals with both flow of water and sediment transport should be studies .In a water body sediment are transported as suspended and bed load, depending upon the sediment particle size. The supply of sediment to rivers can be increased by land disturbances, such as urbanization, fire and agriculture. This additional supplied sediment is finer than that found in the river bed in most cases. A study found that increasing the sand content of a channel would result in a decreasing bed slope as in [1]. This study led to the conclusion that the addition of a fine sediment supply can reduce the grain size of the bed and increase the river in transport capacity.

Bed load transport is an important physical per fining the morphological development of alluvial rivers. Bed load transport rate estimation is needed for the realistic computation of river morphological variations because the transport of sediment through river channels has a major disbursement for public safety, water resources management, and environmental sustainability as in [2]. One-dimensional numerical model for predicting sediment transport and bed evolution in Natural River that have flood plains was presented as in [3] .The sediment transport in flood plains is generally different from that in the main channel. Even when erosion in the main channel exists, the flood plain usually experiences deposition. **A** paper contained for the computation of flow field and bed evolution in a water reservoir during the flushing process a fully three-dimensional curvilinear and non-orthogonal model was presented as in[4] , using a finite volume method to solve the Reynolds Averaged Navier-Stockes (RANS) equations, has been developed and combined with a three-dimensional sediment transport model. The ε – k turbulence model is used to calculate the eddy viscosity. The sediment transport model is based on the equation of convection-diffusion of sediment concentration and sediment continuity equation for calculating the sediment concentration and bed level change in the reservoir flushing process, respectively the hydrodynamic section of the model was verified using experimental data and the sediment concentration calculations compare well with the experimental results. Also a physical model study was carried out to verify the results of bed evolution at the upstream of a sluice gate.

Good agreement is found between bed evolution in the numerical and physical models. A three dimensional transportation model for suspended solids (SS) in Zhujiang (Pearl) River estuary ,South China ,was presented as in [5], the model was validated using hourly measured data of sediment contents during 25-26,July 1999.The results showed that modeled contents matched well with measured ones and that the modeled top layer distribution agreed with remotely sensed image of suspended solids in summer**.** Three dimensional sediment transport models are most informative as they include all the space dimensions. They are most complicated and resource consuming in implementation.

Three dimensional models are avoided until very detailed distribution of desired quantity needs to be simulated and flow characteristics are important in all directions. The objectives of this study are: measure of the evolution of the 3D profile, flow velocities and sediment concentrations through the river reach(upstream of Al-Betera Regulator-Iraq); investigate the river distributions of velocities and sediment and the different fluxes between the cross sections of the reach; simulated results will compared with the measured data (field data) of the flow velocities, sediment concentrations and topographic data of river bed for many years; the modeling result is provided in a suitable GIS computable format ; verify the numerical model of SSIIM model (Sediment Simulation in Intake with multi- block option) with respect to the reproduction of the model processes and practical applications and developing a new sediment load transport by using multiple linear regressions.

2. Region of Study

The region of this study (Al-Betera regulator-Iraq) was located between longitude E47"9 to E46"52 and latitude N31"33 to N31"49. The reach length is about (4.25) km long with an average width (250) m,see Fig.(1). Al-Betera regulator lies on the Al-Betera river, off the right side of the Tigris River about 11.5 km west of the city of Amara (Maysan), designed governing the discharge of 700 m^3 / s and the purpose of its establishment to regulate irrigation water for agriculture and raise the levels of the Tigris at the forefront of regulating and determining the discharge at the nape of governing. Al -Betera regulator consists of six semi-circular shape gates; the widths for each gate are eight meters and operate electrically and manually. There are many structures in Al -Betera regulator, a shipping lane with a length of 50 m and width 4m contain two gates a fish passage, it's dimensions 4x4m and openings in the form drawer to cross the fish. The most important reasons for the selection of this region are: Al-Betera River consists of sedimentary materials disassembled in the study area with a loose condition , so this processes led to morphological activities (erosion, sculpture and deposition processes) and the morphological process in the river reach of the study area depends on the magnitude of river discharge, which fluctuates from time to time. This led to a fluctuation in river bed levels due to climate changes, human control on reservoirs, and other regulators.

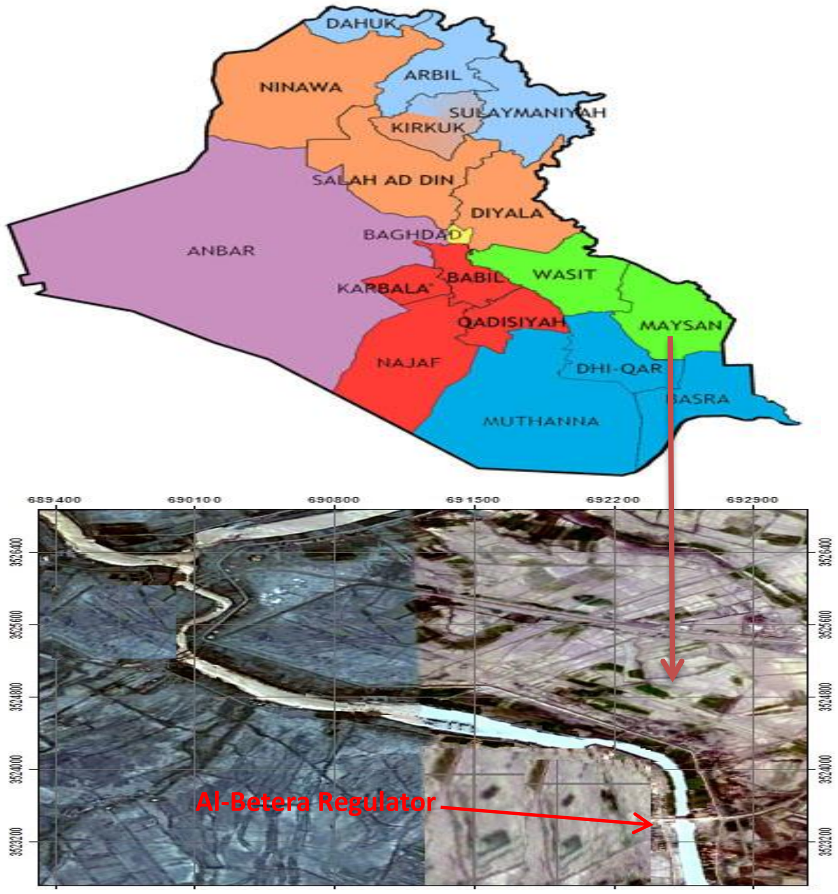


Figure (1): Study Reach Location

3. Theory of Sediment Transport

3.1. Theory of Sediment Flow

Sediment transport is traditionally divided in bed load and suspended load. The suspended load can be calculated with the convection – diffusing equation for the sediment concentration, c (volume fraction in SSIIM model) as in [6]:

$$\frac{\partial c}{\partial t} + U_j \frac{\partial c}{\partial X_j} + W \frac{\partial c}{\partial_z} = \frac{\partial}{\partial X_j}\left(\boldsymbol{\Gamma}_T \frac{\partial c}{\partial X_j}\right) \qquad (1)$$

The Navier –stokes equation for non-compressible and constant density flow can be modeled as:

$$\frac{\partial U_i}{\partial t} + U_j \frac{\partial U_i}{\partial X_j} = \frac{1}{\rho} \frac{\partial}{\partial X_j}\left(-P\delta_{ij} - \rho U_i U_j\right) \qquad (2)$$

The left term on the left side of the equation is the transient term. The next term is the convective term. The first term on the right – hand side is the pressure term. The second term on the right side of the equation is the Reynolds stress. To evaluate this term, a turbulence model is required. The fall velocity of the sediment particles w . The diffusion coefficient $\boldsymbol{\Gamma_T}$, is taken from the k - £ model:

$$\Gamma_T = \frac{\nu_T}{S_c} \tag{3}$$

Where ν_T is the eddy viscosity and Sc is the sediment number, set to 1.0 as default. A different value can be given on the F 12 data set in the control file. For suspended load as in [7] ,developed a formula for the equilibrium sediment concentration , C_{bed} , close to the bed :

$$C_{bed} = 0.015 \frac{d^{0.3}}{a} \frac{(\frac{\tau-\tau_c}{\tau_c})^{1.5}}{(\frac{(\rho_s-\rho_w)g}{\rho_w V^2})^{0.1}} \tag{4}$$

Where d is the sediment particle diameter, a is a reference level set equal to the roughness height,$(\tau)$is the bed shear,τ_c is the critical bed shear stress for movement of sediment particles according to Shield s curve , pw and ps are the density of water and sediment , v is the velocity of the water and g is the acceleration of gravity . The empirical parameters in the equation (0.015, 1.5 and 0.3) may be changed by using a data set in the control file. The sediment concentration from Eq. (4) will be fixed in the cell closet to the bed. For time – dependent computations it is also possible to use an algorithm that converts the concentration from the formula into a sediment entrainment rate.

The decrease, K, in critical shear stress for the sediment particles as a function of the sloping bed was given below as in [8] :

$$K = -\frac{Sin\emptyset\ Sin\alpha}{\tan\theta} + \sqrt{\left(\frac{Sin\emptyset\ Sin\alpha}{tan\theta}\right) - Cos^2\emptyset(1 - (\frac{tan\ \emptyset}{\tan\theta})^2)} \tag{5}$$

Where ά is The angle between the flow direction and a line normal to bed plan, ø is the slope angle and θ is a kind of angle of repose for the sediment ϴ is actually an empirical parameter based on flume studies. The factor K was calculated and multiplied with the critical shear stress for a horizontal surface to give the effective critical shear stress for sediment particle. In addition to the suspended load, the bed load, q_b , can be calculated by using Van Ran s formula:

$$\frac{q_b}{D_{50}^{1.5}\sqrt{\frac{(\rho_s-\rho)g}{\rho}}} = 0.053\ \frac{\left[\frac{\tau-\tau_c}{\tau_c}\right]^{2.1}}{D_{50}^{0.3}\left[\frac{(\rho_s-\rho)g}{\rho\nu^2}\right]^{0.1}} \tag{6}$$

The bed form height, Δ, calculated as in [7]:

$$\frac{\Delta}{d} = 0.11\left(\frac{D_{50}}{d}\right)^{0.3}\left(1 - e^{\left[\frac{\tau-\tau_c}{2\tau_c}\right]}\right)\left(25 - \left[\frac{\tau-\tau_c}{\tau_c}\right]\right) \tag{7}$$

The empirical parameters in the equation (0.053, 2.1, 0.3 and 1.5) may be changed by using the function data set in the control file.

3.2. Theoretical and Empirical Estimations of Near Bed Concentration

The transportation of bed and it is entrapment has been estimated of up-stream Al-Abassiya Barrage as in [9]. Derivation of this formula required the selection of (20) section along entire study reach in order to measure the hydraulic parameters of different cross section and the properties of sediment . Well estimated of sediment load of study reach had been found by a new proposed formula (8) which had no significant difference with the observed value **:**

$$Q_s = \rho * W * Rh^2 \left(\frac{V}{W}\right)^{1.5} \left(\frac{Rh}{d_{50}}\right)^{-0.5} \left(\frac{\nu}{WRh}\right)^{0.43} \left(Sg * \frac{B}{Rh}\right)^{0.67} \qquad (8)$$

where**:** Qs: total sediment load (kg. sec^{-1});W: settling velocity (m. sec^{-1}); V: mean velocity of water (m. sec^{-1}); B: width of river (m); d_{50}: is median grain size (50 % by weight of finer material); Rh: hydraulic radius (m); $\boldsymbol{\nu}$: Kinematic viscosity (m^2. s^{-1}) and Sg: specific gravity. ρ: density of fluid (kg. m^{-3}).

A general sediment discharge function in terms of three dimensionless groups was developed as in [10].These are : Dgr (size), Fgr (mobility), and Ggr (discharge). The procedure for the computation of concentration of bed- material discharge is as follows**:**

$$\frac{C*D}{S_g} d_{35} \left(\frac{U*}{V}\right)^n = C1 \left(\frac{Fgr}{A1} - 1\right) \qquad (9)$$

Where**:** C: Concentration by weight; F_{gr}: sediment mobility number; A1: initial motion parameter; d_{35}: particle size for which 35 percent by weight of sediment is finer; n: sediment size-related transition exponent; C1: sediment transport function coefficient ;U_*: shear velocity; D: water depth; m: sediment transport function exponent; V: average velocity and S_g: specific gravity.

Dimensional analysis was used as in [11], to modify a relationship for rivers with high concentration of suspended materials (higher than 100 ppm by weight), Yang's relation is:

$$\mathrm{Log}\, C_t = 5.165 - 0.153 \log \frac{\omega\, d_{50}}{\nu} - 0.297 \log \frac{V_*}{\omega}$$

$$+ \left(1.78 - 0.36 \log \frac{\omega\, d_{50}}{\nu} - 0.48 \log \frac{V_*}{\omega}\right) \log \left[\frac{VS}{\omega} \frac{\gamma_m}{\gamma_s - \gamma_m}\right] \qquad (10)$$

In which C_t concentration of sediment in ppm, ν is kinematic velocity of sediment-laden flow, γ_m is specific weight of sediment-laden flow and ω is particle fall velocity**.**

A sediment transport equation based on regression as derived as in [12]. She conducted tests on the robustness on the variables used in her equation **.** Her proposed equation is:

$$C_v = 1.156 \left(\frac{R_h}{d_{50}}\right)^{0.716} \left(\frac{u_*}{w_s}\right)^{-0.975} \left(\frac{u_*}{V}\right)^{0.507} \left(\frac{V^2}{g\,H}\right)^{0.524} \qquad (11)$$

Where**:** $C_v =$ The total sediment concentration, $w_s =$ Fall velocity, $V =$ Average flow velocity, $u_* =$ Shear velocity; g is gravity constant, H =Mean depth, R_h =Hydraulic radius, $d_{50} =$ Median grain size (50% by weight of finer material).

A combined model was established as in [7], in which the sediment transports is calculated with a three dimensional approach and the flow with a depth-average approach in combination with the assumption of a vertical logarithmic velocity profile, which is valid only for gradually varying open channel flow. He used dimensionless numbers of shear stress and particle diameter to correlate empirical coefficients against observations from the field and flume experiments.

3.3. Input / Output Files in the Model

Normally SSIIM model runs start by reading input files, or generating the grid using the Grid Editor. Then the data should be saved in the koordina files. As an input for model, four main types of data needed are as follow: geometry of the hydraulic structure; water inflow/outflow data; sediment data and different controlling parameters. Hydraulic geometry modeled by means of x, y and z co-ordinates with a structured grid (SSIIM1.0). These coordinates represent the points of grid lines intersect. Cells formed from the intersection of gridlines in three dimensions. The variables calculated in the center of each cell. The cell geometry consists of six surfaces. Also by blocking out cells, geometry can changed.

4. Field Measurements and Experimental Works

4.1. Sampling of Sediment

Transect sampling involves establishing one or more transect lines across a surface. Samples were collected at regular intervals along the transect lines at the surface and/or at one or more given depths. The length of the transect line and the number of samples to be collected determine the spacing between sampling points along transect. Multiple transect lines may be parallel or non-parallel to one another, or may intersect. If the lines are parallel, the sampling objective is similar to systematic grid sampling. The primary benefit of transect sampling is the ease of establishing and relocating individual transect lines. Transect sampling is applicable to characterizing water flow and contaminant characteristics and contaminant depositional characteristics in sediments, such as distinguishing erosional versus depositional zones.

4.2. Transect Sections in Study Reach

The study involves seventeen transect sections, approximately 250m apart, along the reach of study (on Tigris river); the entire reach is approximately 4.25km long upstream the regulator; Figure (2). Geometric data were determined for each section in order to construct a complete mesh as input data for the SSIIM model.

4.3. Geometric and Hydraulic data measurements

Bed elevation, top width, water level, area of cross sections, water velocity and discharge were measured using the ADCP technology. The field measurements were carried out during the season from (April to May of 2014).SonTek river tracker surveyor and its software version 4.3 were used for this purpose. The ranges of the velocities and flow rates of the river reach (for the 17 cross sections) were 0.21 to 0.43 m/s and 55.18 to 89.93m^3/s respectively.

4.4. Suspended Sediment Concentration

In this study, the sampling verticals selected at ¼, ½ and ¾ of the river width of stream at each cross section. This procedure was very convenient and more practical for study reach. At any given vertical, the suspended load can be sampled by a depth integration method or by a point metered (point-integration) method one or more points along the vertical. The depth integration is useful for determination of the suspended-load rate. The point method used if the vertical suspended-load distribution itself desired.

Proper selection of sampling points in a vertical is of importance, and discussed by the Interagency Committee on Water Resources. In this study a three samples were taken at each vertical at three depths *0.8d*, *0.6d* and *0.2d*, where *d* is the depth measured from water surface. Nine samples for measuring sediment concentration (mg/l) in each transect section and nine values of flow velocities were measured. Minimum and maximum sediment concentrations were 21 and 444 mg/l respectively.

4.5. Bed Material Load

The researcher manufactured a device that is quite similar to Van Veen Grab Sampler as in [13] ,which is suitable in its shape, dimensions, weight and way of working to take samples from the bottom of the river reach.

4.6. Laboratory Measurements

The laboratory work is essentiial for the size distribution of sediment that represents the configuration of bed level materials to obtain specific gravity , texture , size and sediment concentration.The ranges of specific gravities were 2.64 to 2.77. Fig. (3), shows the average bed-material size distribution in study reach. These results were considered as an input data to run the SSIIM1.0 model.

Fig (2): Transect Sections Locations.

4.7. Sediment Discharge in Study Reach

Suspended sediment transport rate (discharge) may compute from the following equation as in[14]:

$$Q_s = C\,Q \tag{12}$$

Where: Q_s =Sediment discharge (load) in (kg/sec); C=Average concentration of suspended sediments (mg/l) and $\boldsymbol{Q}$ =Water discharge (m^3/sec). The ranges of values of suspended sediments in load of the 17 sections were 2.73 to 11.11 kg/sec.

4.8. Bed Load Transport Meter Type Arnhem

Bed load transport is difficult to measure, since the development of the BED LOAD TRANSPORT METER ARNHEM in 1936 and the Zurich calibration1937. Large numbers of measurement have been carried out including calibrations by the Delft Hydraulic Laboratory.This sampler is used to measure bed load of coarse sand and fine gravel in rivers and other water courses .The streamlined sampler is mounted in a frame and consists of a mouth followed by a basket of fine wire meshing (width of the mesh 300µm). The bed load measurements ranges were 0.000005 to 0.0004 kg/sec .The bed load transport rate values are very small as compared to the suspended sediment load.

5. Results and Discussions

5.1. Analysis and Discussion of Experimental Works

Verification of hydrodynamic and sediment transport models express real tests of numerical solution to estimate the flow and sediment load variations by employing a set of observations. However to verify numerical model with field measurements, the results have been divided into two parts. The first part deals with flow calculation while the second part deals with sediment calculation. In an alluvial river, there is a relationship between sediment discharge and river discharge. The sediment transport cannot be viewed as a simple function of hydraulic conditions because many factors are influencing this relationship, such as boundary shear, bed roughness, temperature, fall velocity of the bed material and hydraulic conditions of the river.

But generally, the sediment discharge increases with an increase in river discharge, so, sediment rating curves is a good empirical method to convert discharge into suspended load estimates. Measuring the average suspended-sediment concentration in stream-flow is a time-consuming and expensive operation and for these reasons we make considerable use of suspended sediment rating curves.

Sediment rating curves are widely used to estimate the sediment load being transported by a river. Such as relationship is usually established by regression analysis, and the curves are generally expressed in the form of a power-law type equation. The statistical relationship between suspended sediment concentration, or sediment load, and stream discharge “the sediment rating curve” is commonly takes the power law form as in [15]:

$$C_s = a\,Q^b \tag{13}$$

Where, C_s = suspended sediment concentration; Q = discharge; and *a*, and *b* are sediment rating coefficient and exponent, respectively**.** For the study reach, the power equation for the data of suspended sediment (mass and load) (1984-2014) are shown in Figs.(4) and (5).The coefficient of a and b are 0.21 and 2.0 respectively, Fig.(4).

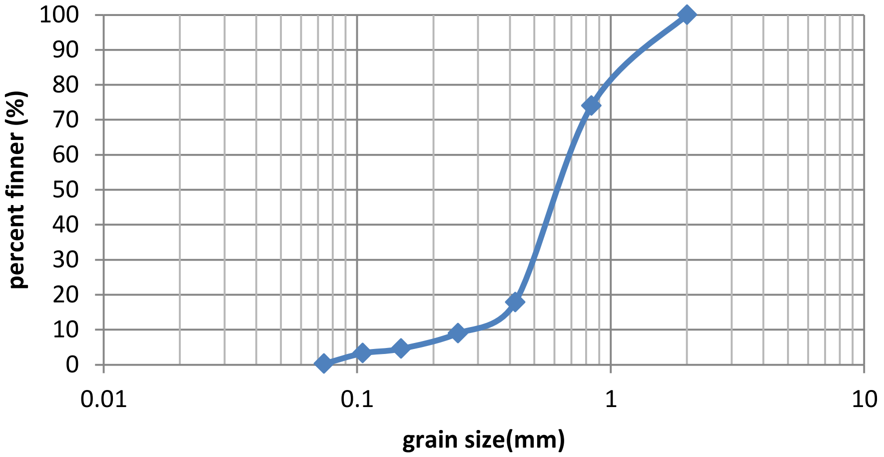


Fig. (3): Average Sieve analysis for all sections.

5.2. River Plan Morphology

River morphology is an important subject for the management and river engineering**.** The changes in river plan morphology must be under stand for short& long terms due to environmental changes (naturally, climatic, variation and human activities). The deposition and erosion locations has been identified based on the topographic maps with detailed measurements for the river reach under investigation for years 1986 and 2007, and the image satellite for 2014.Acomparsion of these types of maps was make to check the areas of deposition and scouring .The shaded and apparent sediments on the waterway were verified by field visual inspection to make sure it has been aligned precisely on the topographic map and satellite image. Fig (6) shows that the scouring during the year 2007 is very small as compared to the scouring during the year 1986 and approximately is equal as compared the scouring during the year 2014 except some sections (4, 5, and 15) where the deposition is quite obvious for the area under consideration, especially in sections (1, 2, 3, 7, 8, 9, 11, 12, 13, 16) where the deposition processes exist because of the following reasons:

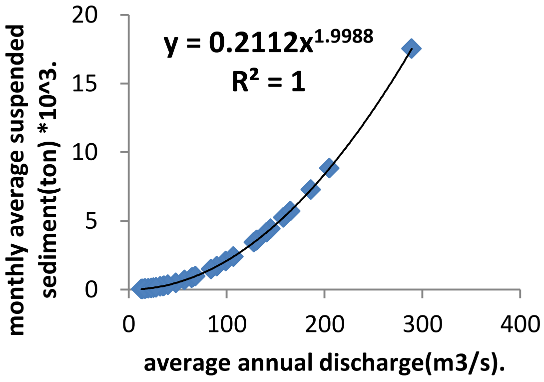


Fig.(4) Suspended Sediment Rating Curve .

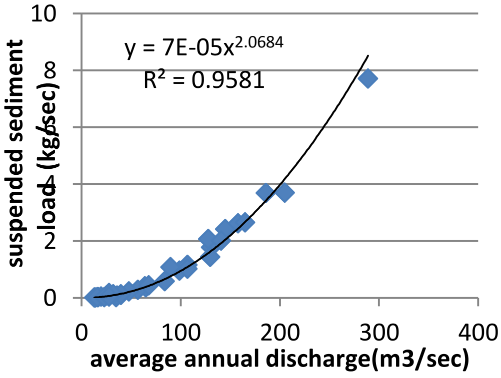


Figure (5): Suspended Sediment load Rating curve.

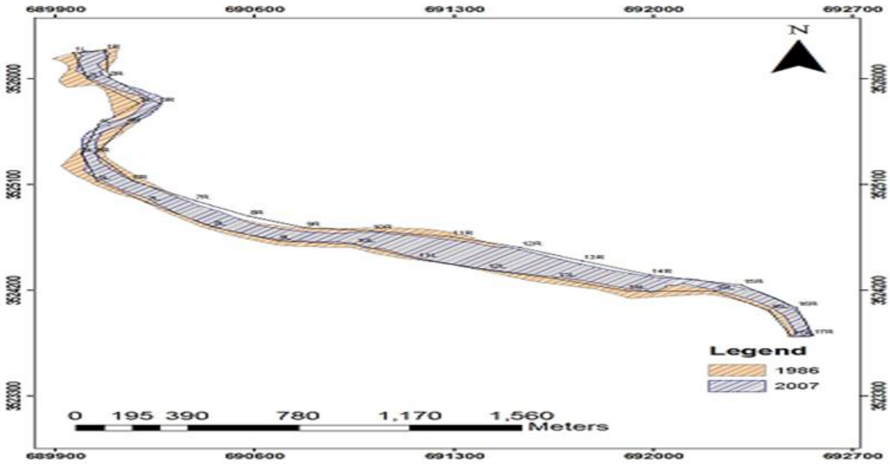


Figure (6): River Plan Morphology for Years (1986, 2007 and 2014).

1. Slight slope which makes the suspended sediments to be deposit in the bed of river.
2. Shallow water and high frictional forces with the water bed and water sides.
3. Imbalance between the suspended sediment materials and the water discharge which flows in the river reach. This helps in settling higher sediments because of low discharge and low water level in the river in general. Some other parts of the river experienced sedimentation on the sides, the width of the river reduced in return due to heavily growing natural plants on the river banks. However, there are certain advantages beside this process like protecting the banks from scouring and a sedimentation process on the long run may result in some parts of the river reach. The study of the plan morphology showed that the actual length of river reach was 4540 m while the optimum length was 4220 m , which means that the sinuosity ratio was 1.07 or the plan forms of river can be classified as straight (see Fig 3-2). However, the river reaches in this study which flowing through alluvium bed no obvious lateral migration with time. In the river reach of this study no clear bed changes were observed during the measured period .So, the computations for all ranges of discharges were carried out to compere the velocity and sediment concentrations with the field measurements.

5.3. Total Sediment Load Formula

The Buckingham π theorem is one of the approaches that researches used in developing general total sediment. Based on this theorem, the proposed influential parameter is the general form of the intensity of the total sediment load, Eq.(14 and 15):

$$Q_t = \emptyset(V, D_*, d_{50}, W_s, U_*, \rho_w, \rho_s, \theta, D) \tag{14}$$

$$F(Q_t, V, d_{50}, W_s, U_*, \rho_w, \rho_s, D_*, \theta, D) = constant \tag{15}$$

The final form of the equation has been determined by the using of the multiple regression analysis for the observed data. The multiple regression equation was:

$$Q_{t=}\ \rho_w V D^2 (D_*)^{-0.8912} (\theta)^{0.4393} (G_s)^{7.465} (\frac{V}{W_s})^{0.9132} (\frac{V}{u_*})^{-0.2425} (\frac{D}{d_{50}})^{-1.856} \tag{16}$$

Where: Q_t= Total sediment load (kg/sec); ρ_w=Density of water (kg/m^3) ; D=Depth of water (m); u_*= Shear velocity (m/sec); W_s=fall velocity of particle (m/sec); d_{50}= Median grain size(m);$\rho_s$is Density of sediment(kg/m^3); $D* =$ particle parameter $= [(Gs-1)g/\vartheta^2]^{\frac{1}{3}}D_{50}$; $\theta =$ Shield parameter $= u*^2/[(Gs\text{-}1)gd_{50}]$ and $\vartheta =$ kinematic viscosity (m2/s). The parameter θ , or the particle mobility number (dimensionless bed- shear stress) is used due to its important in the initiation of motion of flow. The initiation of motion occurs when θ parameter is larger than the critical of θ (θcr) which depends on the particle shape and the hydraulic condition. To simplify the computations for the initiation of motion, the dimensionless particle parameter D* is used when the grain size is known. D* values for this study, vary from 3.91 to 10.99 while the parameter θ values vary from 0.03 to 0.18, Table (1). For initiation of motion (bed load transport) most of the sediment transport is due to motion of bed material (θ_{cr} =0.032, Van Rijn (1993)) and the motion within the suspended load , θ_{cr} is equal to 0.06 ($D^* \geq 3.0$).

Table (1) : π parameters and its values.

π	π_1	π_2	π_3	π_4	π_5	π_6	π_7
Parameter	$Q_{t/\rho_{w\,V\,D^2}}$	D_*	θ	Gs	V/Ws	V/u_*	D/d_{50}
Range of values	0.000138- 0.00213	3.914- 10.994	0.03- 0.18	2.58- 2.78	12.69- 37.89	4.20- 25.31	942- 3433

The coefficient of determination of equation (16) was found to be equal (R^2=0.787).Figure (7) shows a relationship between the predicated and the observed values of sediment load for the 17 sections of the study reach. There are two general categories of sediment transport model equations used to simulate the movement of sediment in natural rivers. One set of transport model equations separates the total sediment load into suspended and bed load, whereas the other combines the two modes of transport and tracks only the total load.

Table (2) shows the summary of the sediment discharge variables which used by the researchers of other studies. Two methods are used in this research to evaluate the performance of each formula through comparing the measured sediment discharge with predicted sediment discharge. A mean normalized error was used in order to select the best formula since due to the high difference between predicted and measured sediment rates at various intervals as in [15]:

$$MSE = \frac{100}{N}\sum_{n=1}^{n}|(S_o - S_c)/S_o| \tag{17}$$

In which: MSE is a Mean Normalized Error; S_o an observed sediment load; S_c is a predicted sediment load and N is the number of the predicted values. In this method, a lower statistical value (close to zero) shows a higher accuracy in the model performance. Table (3) shows these results. This method gives a general evaluation for all results by each used formula. The new formula gave the Mean Normalized Error (MSE) equal to 20% as it is stated in the Table (3).

It is much less than the (MSE) for all the equations used in the comparison. Therefore the new formula produced good results to estimate the amount of total sediment load in the study reach. A graphical comparison is conducted on the formulas by calculating the deviation of predicted sediment discharges from measured or by means of discrepancy ratio as shows in Figure (8).

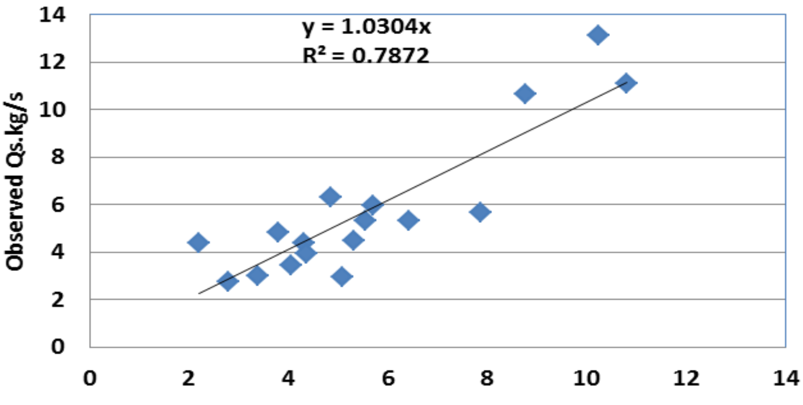


Fig.(7):Relationship between calculated and observed sediment load.

Table (2): Summary of sediment parameters.

Author	Input parameters used
Ackers-White(1973)	d_{50}/h , V/U_* , γ_s/γ , C_s , ν
Yang(1996)	$V S/W_s$, V/u_* , $W_s\, d_{50}/\nu$
Van Rijn(1987)	$\frac{(V-V_{cr})}{(G_s-1)\, g\, D_{50}}$, $\frac{D_{50}}{H}$, $\frac{d(G_s-1)\, g}{\nu}$
Ariffin(2004)	R_h/d_{50} , U_*/W , U_*/V , $V/g\, D$
Jasem(2012)	$\rho\, W\, R_h$, V/W , R_h/d_{50} , $\nu/w\, R_h$, $Gs\, B/R_h$

Table (3): Comparison using Mean Normalized Error.

Formula	Van Rijn (1987)	Ackers-White (1973)	Yang (1996)
MSE	114%	62%	86.5%
Formula	Ariffin (2004	Jasem (2012)	New formula
MSE	127.4%	185.3%	20%

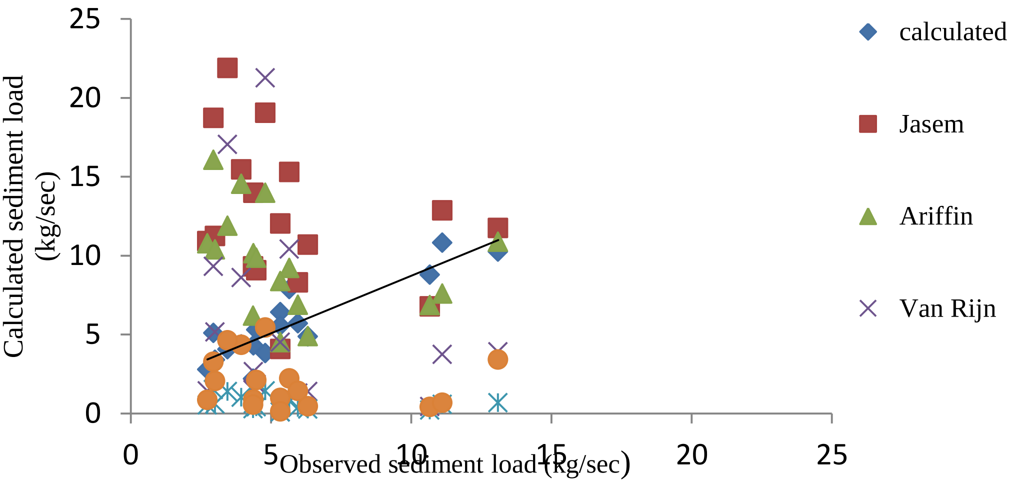


Figure (8): Comparison between calculated and observed sediment load by using all formulas .

Figure (8) shows that the extent of agreement between measured and predicted sediment discharges with respect to the new formula are very good. The scattering of the points is around the fit Line.

5.4. Numerical SSIIM Model

The flow and sediment transport was done by using (CFD) model. The SSIIM solves the Navier- Stokes (3D) equations in order to compute the water flows. The mesh and control file must be prepared with high efficiency. The minimum error or convergence will achieve by the selection of suitable flow and sediment parameters.The composition and quality of the grid is important for the accuracy and stability of the solution of the equations.

Grid generation is the first step in the model process and it is very important to make convergence between the natural regimes with the model regime. The numerical grid consist of 248 nodes in X-direction (i.e. *i=1 to 248*), 15 nodes in Y-direction (i.e. *j=1 to 15*), and in vertical direction, the river depth was divided to 8 layers (8 nodes in Z-direction , *k=1 to 8*), in order to construct geometrically a three dimensional model for the river reach.

A sensitivity analysis was used to obtain bed roughness of Van Rijn equation and sediment parameters in the sediment concentration equation in which the error is minimum for the simulated velocities and sediment concentrations. Roughness parameters are needed for computation the initial water surface elevation and shear stresses at the boundaries by using wall law. It depends on the flow variables (velocity and depth) and sediment rate. The default wall law in SSIIM is given below. It is an empirical formula for rough walls as in [16] :

$$\frac{U}{u_x} = \frac{1}{K} \ln\left(\frac{30y}{k_s}\right) \tag{18}$$

The shear velocity is denoted u_x and k is a constant equal to 0.4. The distance to the wall is y and the roughness, ks, is equivalent to a diameter of particles on the bed (the equivalent roughness was $3{*}d_{90}$). It can be specified on the *F16* (Function using in control file in SSIIM program). If the roughness varies at the bed, a roughness for each bed cell can give in the bed-rough file, if not set, is the coefficient calculated from the manning-Stricker's' friction coefficient . The default values of the roughness variables are given by converting the Manning – Stricker of the W1 data set to roughness height [Ks = $(26/M)^6$, where M =1/n, (n is the manning number). To run the model it must prepared some data as initial data for first running Table (4). 17 different river discharges were used in the SSIIM Model which it is values vary from (55 to 90) m3/sec.

When the input value of river discharge was (55) m^3/sec, the optimum value of manning's roughness (n) was (0.015) in which the error in sediment concentrations was a minimum, Fig. (9). This value of (n) was used for all sections in the SSIIM Model and converted to a bed roughness (roughness height Ks).

Table (4): Data of Some Input Parameters for using the Model.

Factors variables	Value
Inlet discharge (m^3/s)	55-90
Length of river reach (m)	4250
Average top width (m)	80
Average Hydraulic radius (m)	3.11
Average depth of flow (m)	4.62
Average flow area (m^2)	230
Average velocity (m/sec)	0.33
Hydraulic slope	0.000133
Manning coefficient (n)	0.010 -0.030
Specific gravity of bed materials	2.69

Bed materials size fraction	Diameter (mm)	Fall Vel. (m/sec)	Sediment Discharge (kg/sec)
Size 1	0.3	0.08	1.5
Size 2	0.75	0.11	3
Size 3	1.250	0.15	0.75
Size 4	1.75	0.18	0.75

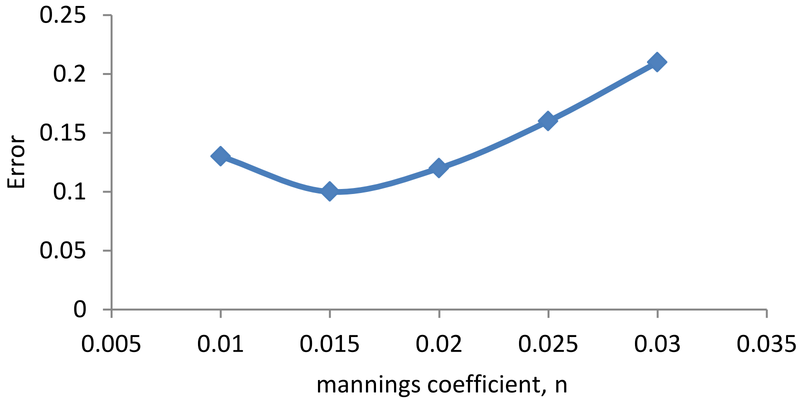


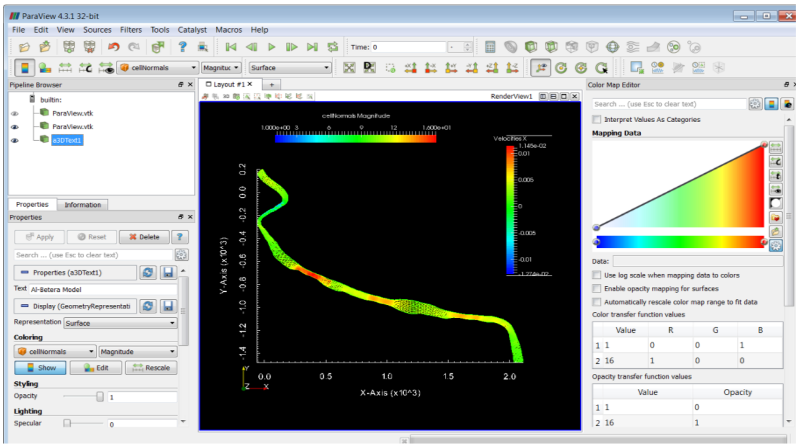
Fig. (9): The optimum value of manning's roughness.

The boundary condition has to be defined to simulate velocity field. In control file by G8 data set, the initial values have been given. Velocity at input are not needed to be correct by value, but that be collect in direction .A graphical representation of velocity in all bed is obtained by simulation and by using Power law scheme (3D particle, Six cells are used).

The results of the model for the (80.2) m^3/sec river discharge were the distribution of velocity in two directions at each node. The velocities along the X-Y plane (horizontal plane) at different levels are given by means of velocity vector (with scale). The upper layer of the water flow has higher velocities as compared to lower one (near bed layer). The maximum velocity was about 4.2m/s. Fig.(10) and Fig.(11) represent the data analysis which exported from SSIIM Model by TECPLOT and Para View Software's respectively .The results were displayed by gradient color or vectors for many hydraulic and sediment variables. The data consisting of a parameterized array or points, indexed by up to three values: I,J, and K. Two or three-dimensional ordered data may often be referred to as "color surface" data in 2D or 3D. Figure (12) shows the distribution of velocities at horizontal plan (X-Y) for the eight vertical levels. The maximum velocity is located at the positions of convergence in the cross sections of the river reach and at the outer bank of the bends. The differences in velocities distributions are due to the geometric of the cross sections, bends and the characteristic of the sediment transports.

From the build three-dimensional simulated model, it can find two types of velocity at each section, these two types of velocity can recognized in Y-Z plane and in x direction (longitudinal velocity). First type is the secondary velocity as shown in (Y-Z) plane. The vector arrows represent the velocity component in y &z directions (v&w), Figure (13) and Figure (14) .

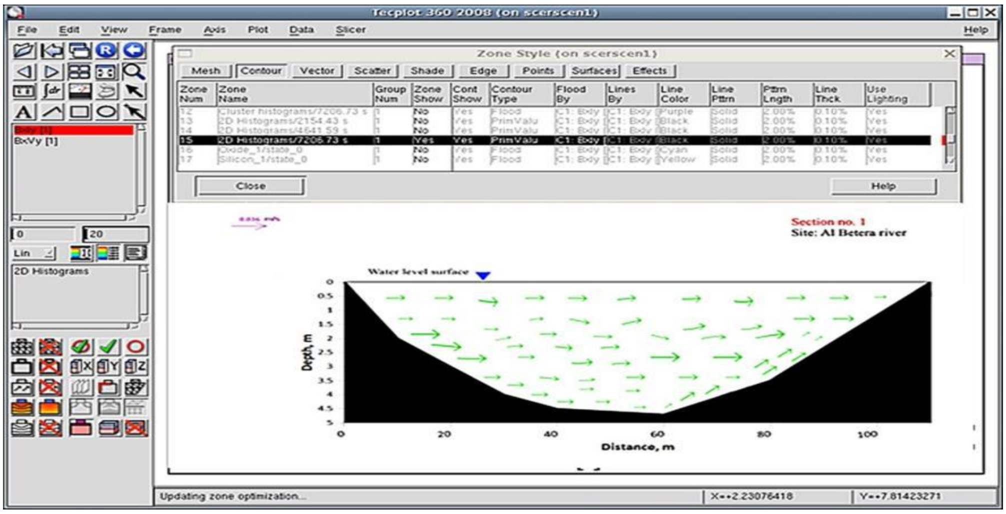
The maximum secondary velocity for study reach is easily noted at the upper region of each section. The behavior of secondary velocity is different in some other sections such as section no. 4, 12 and 13. This variation in behavior is due to the sudden enlargement in water depth. The same variation in behavior occurs in bend zones, such as sections 4, 12, 13 and 14. This is due to the elongation in path of stream in the outer bank of bend. In addition, the model can noted to the regions of scours in each section and where the scour region is happening without using advanced or expansive tools to recognize the secondary velocity flow. Due to the centrifugal forces acting on the primary flow causing that the fluid element will follow a curvilinear trajectory.



	Value	R	G	B
1	1	0	0	1
2	16	1	0	0

	Value	Opacity
1	1	0
2	16	1

Figure (10): The interface of Para View program.



Zone Num	Zone Name	Group Num	Zone Show	Cont Show	Contour Type	Flood By	Lines By	Line Color	Line Pttrn	Pttrn Lngth	Line Thck	Use Lighting
12	Cluster histograms/7206.73 s	1	No	Yes	Flood	C1: Body	C1: Body	Purple	Solid	2.00%	0.10%	Yes
13	2D Histograms/2154.43 s	1	No	Yes	PrimValu	C1: Body	C1: Body	Black	Solid	2.00%	0.10%	Yes
14	2D Histograms/4641.59 s	1	No	Yes	PrimValu	C1: Body	C1: Body	Black	Solid	2.00%	0.10%	Yes
15	2D Histograms/7206.73 s	1	Yes	Yes	PrimValu	C1: Body	C1: Body	Black	Solid	2.00%	0.10%	Yes
16	Diode_1/state_0	1	No	Yes	Flood	C1: Body	C1: Body	Cyan	Solid	2.00%	0.10%	Yes
17	Silicon_1/state_0	1	No	Yes	Flood	C1: Body	C1: Body	Yellow	Solid	2.00%	0.10%	Yes

Section no. 1
Site: Al Betera river

Figure (11): The interface of TECPLOT program.

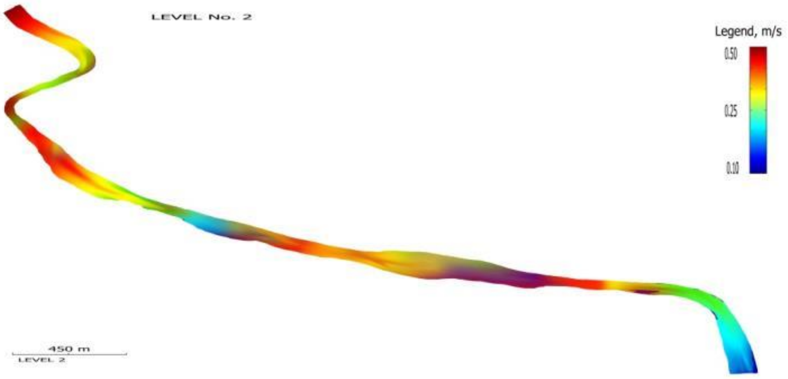


Figure (12): The distribution of velocities as color gradient at level 2.

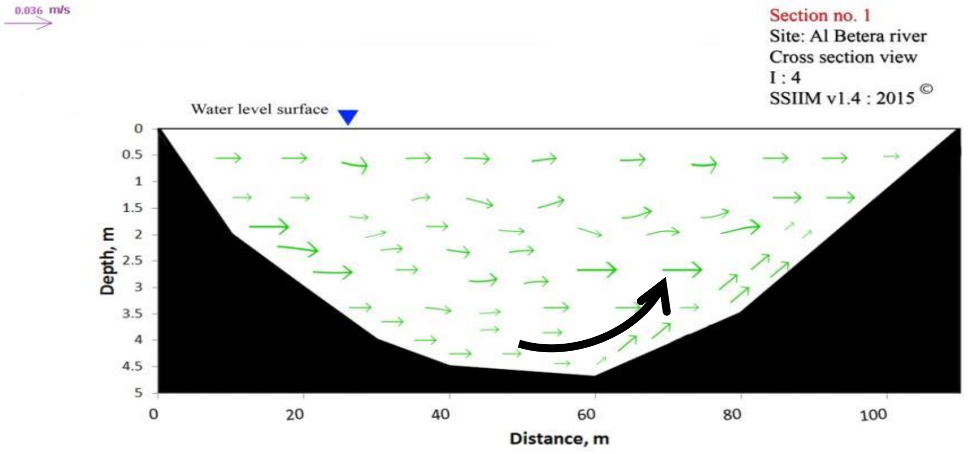


Figure (13): Secondary flow as velocity vector at section no. 1 in y-z Plane, in this section the secondary flow vectors toward the right direction. By SSIIM model.

Figure (13) illustrates the effect of concavity while Figure (14) illustrates the effect of convexity of the banks on the flow regime. The length of each arrow in these Figures represents the magnitude of the velocity according to its scale and direction.

The results of sediment distribution by SSIIM Model show that the study region have high sediment concentration values at the bottom of the cross section of the river reach due to low velocity of flow , and this is clear in most of the cross sections. Sediment concentrations have an inverse proportion with the flow velocity. Therefore, internal banks of river bends have higher sediment concentrations than the center and outer banks of river. The Sediment concentration for selected cross-sections and for 1 to 12 j nodes as contour lines is shown in Figures (15 to 17). Based on the data and Figures obtained from the SSIIM Model, the vertical distribution of the suspended sediment concentration is changed from high values near the bed to low values and the water surface of the river reach. These data are very important in studying the mechanism of sediment transportation and river bed evolution. The analysis of SSIIM Model results help us to locate the positions at the river reach where the high concentrations of sediment occur. These results support the water resources management for this site to make all arrangements to avoid any problems in futures also to know locations in which the amount of deposition is larger than the others.

According to the SSIIM results in which 17 river discharges were used. There is fairly good agreement between measured and calculated velocities. The coefficients of determination (R^2) vary between (0.8 to 0.94) for different depths (layers) and v node locations (A, B and C). One reason for the deviation between measured and calculated velocities can be due to some instrumental errors in the measurements of the velocities and to the geometry of the reach, Fig.(18).

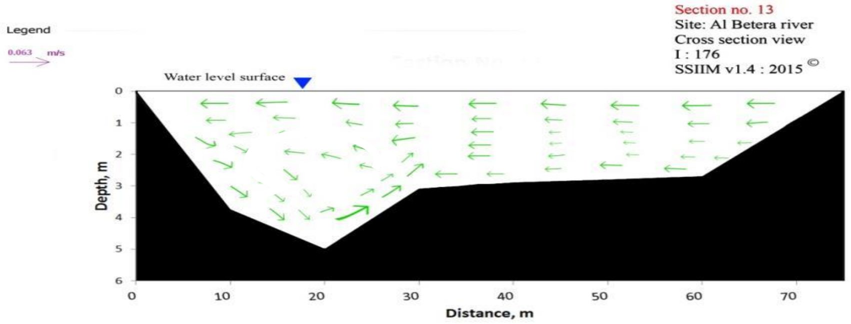


Figure (14): Secondary flow as velocity vector at section no. 13 in y-z Plane, in this section the secondary flow vectors toward the left direction with scour in deep part of section. By SSIIM model.

Simulations results for the 17 river discharges were found to be useful for the predication of the sediment movement and its concentration distribution upstream of the regulator. This will lead to obtain the most suitable operational case in order to avoid sediment accumulation in the study region. The alluvial channels are considered systematically in equilibrium. The cross- sections of the river reach and slope are depending on the quantity of sediment and water discharge. So the objective of this study is to know the changes in bed morphology (scour &fill) for short-time, changes and to show if there are changes in bed of the river that have taken place downstream the Al- Betera Regulator. There are a good agreement between the measurements values of sediment concentration and model calculations. The values of the Coefficient of determination vary from (0.72 – 0.98). In general, it can be said that the results are very good, Fig.(19).

The software results for average river discharge (80.20) m^3/sec, show that suspended sediment concentration increase in the river section at the inner bank of the bends. Deposition will take place due to low velocity as shown in Figure (20B). Fig. (20A) shows the deposition regions, which locate near the inner bank and it is agreed with the satellite image. This process is repeated between section (10) and section (1).The presence bends in the river reach will give a especial case for the hydraulic operation of the regulator to avoid the accumulation of sediment masses as described above.

As mentioned before, SSIIM Model solves the 3D Navier-stokes equations with k-ε model (predict the turbulence). A power law scheme together with a control volume method was used for the discretization. Table (5) shows the annual trapped sediment load for the sections (1-17). The annual deposition was 22797 Ton which equals to 13816 cubic meters of deposition material of sediment depended on submerged density of the sediment of 1690 kg/m^3.The average depth of deposition material was

(4.1cm/year) along the total length of the river reach. The velocities in 3D, which were estimated before, were used for solving the convection and diffusion equations for different sediment sizes to obtain the trap efficiency and sediment deposition at different sections of reaches. It is a obvious from the results of SSIIM Model, that the quantity of material of deposition per year is very small, so measurement of bed morphology is very difficult over relatively short time , it must be use a technical devices for measuring the bed elevation and for long term periods (climatic changes).The use of optimum constant roughness for all the scenarios and the error in input data & Boundary Conditions may be lead to reduce the sediment concentrations for all sections of the river reach.

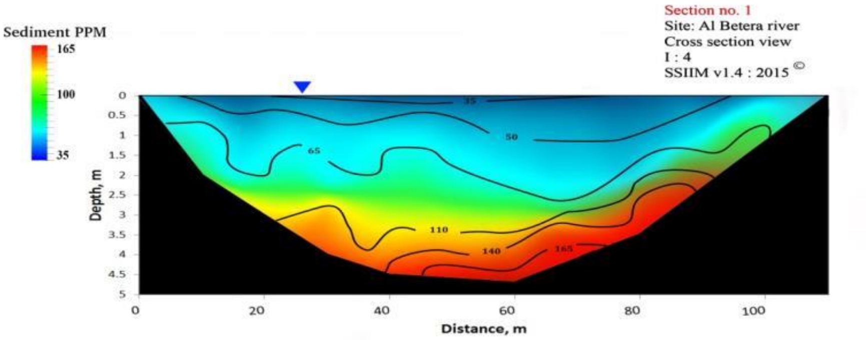


Figure (15): Sediment concentration distribution as gradient color with contour lines at section no.1 .

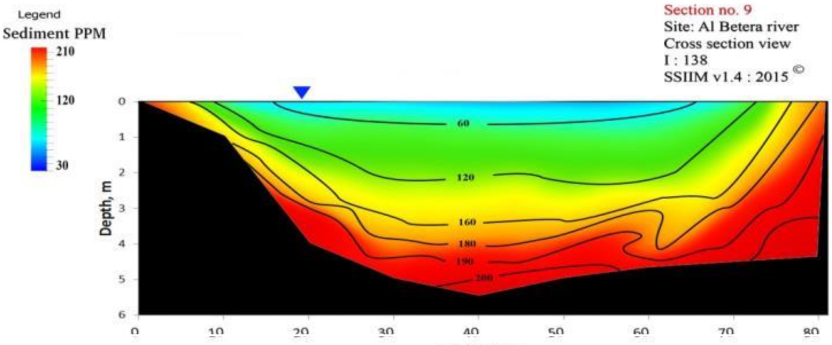


Figure (16): Sediment concentration distribution as gradient color with contour lines at section no.9 .

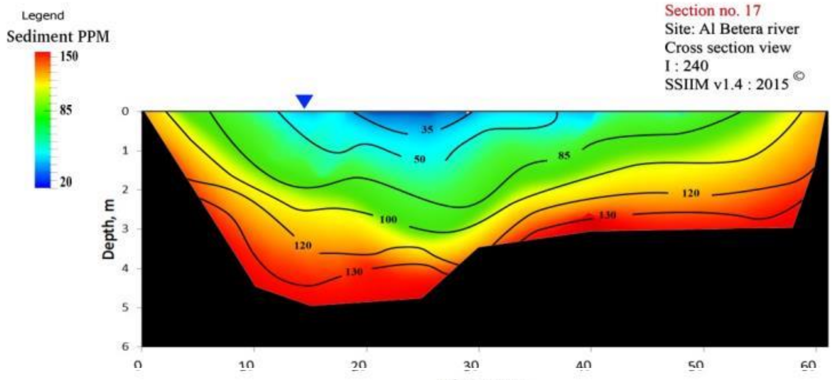


Figure (17): Sediment concentration distribution as gradient color with contour lines at section no.17.

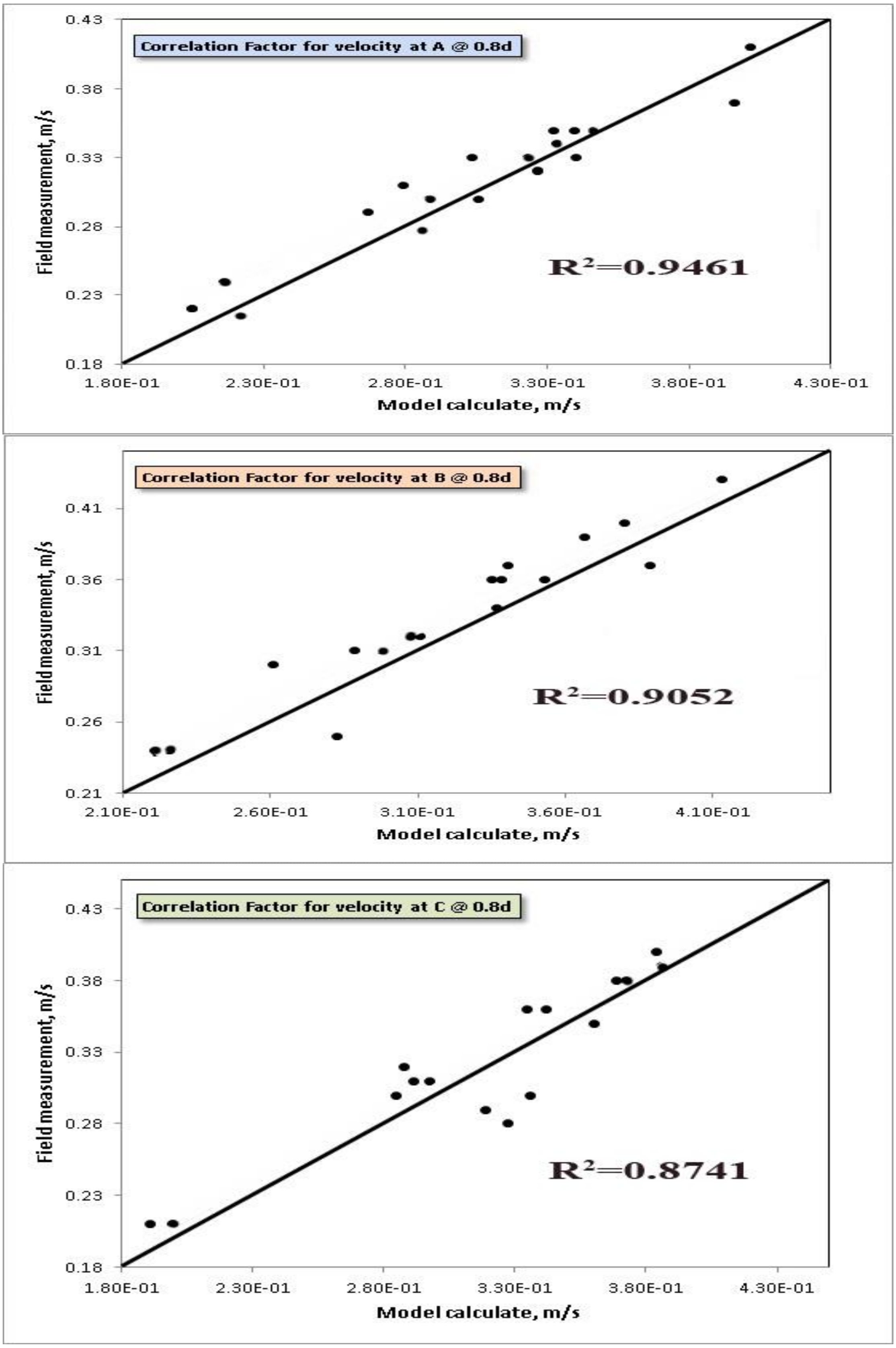


Figure (18): The relationship between the simulated and measured velocities at 0.8d for (A.B and C) .

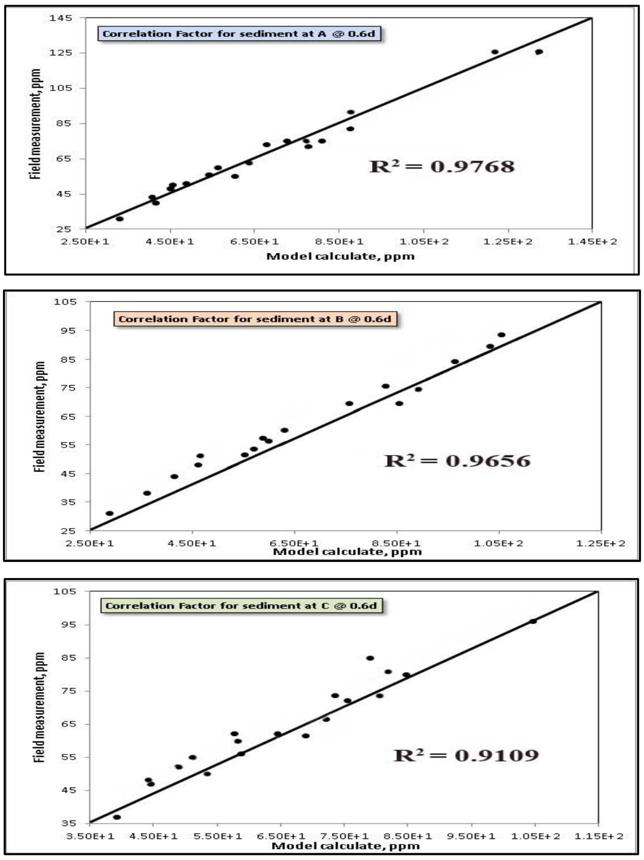


Figure (19): The relationship between the simulated and measured sediment concentration at 0.6d for (A,B and C) levels .

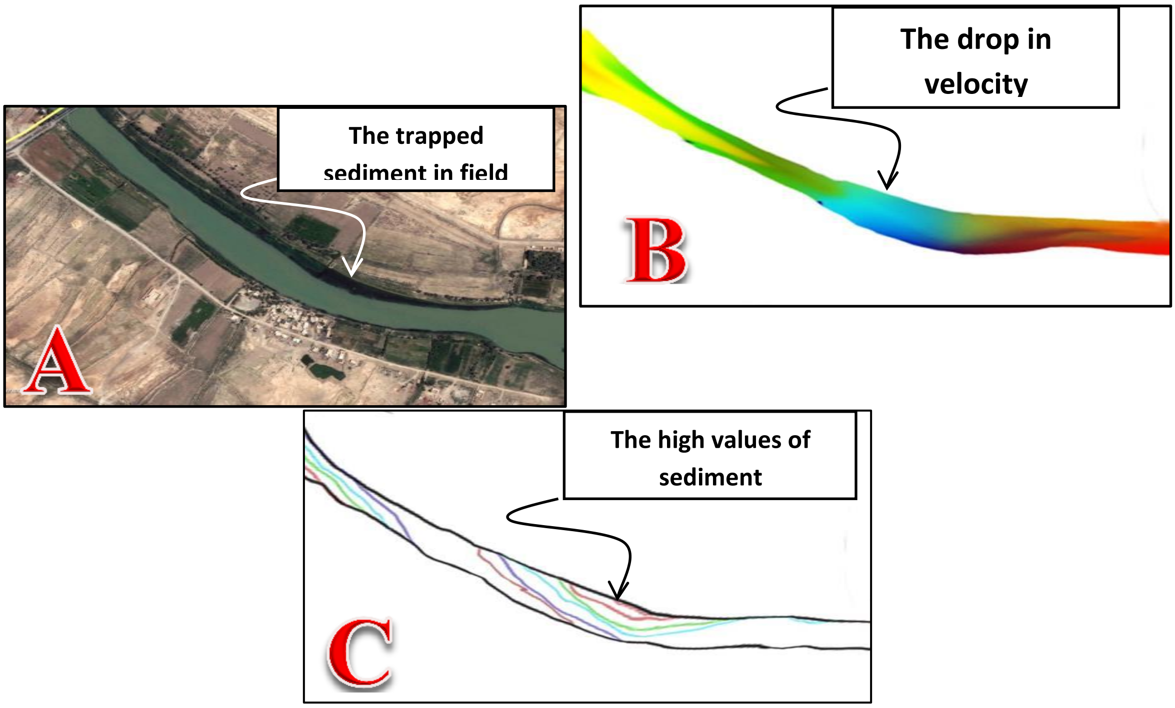


Figure (20): The Comparison between the Field observations and SSIIM Model.

Table (5): The Total Sediment Discharge and Bed Sediment Load Annually computed by the Model.

Section No.	Total flow of sediment Discharge Kg/s	The annual total Sediment load by Ton	The annual trapped sediment load, Ton	The annual deposition, m^3
1	5.77E+00	1.82E+05	2.09E+04	7.75E+03
2	4.82E+00	1.52E+05	1.89E+04	7.04E+03
3	4.51E+00	1.42E+05	1.45E+04	5.40E+03
4	4.10E+00	1.29E+05	1.70E+04	6.34E+03
5	5.54E+00	1.75E+05	1.69E+04	6.28E+03
6	5.90E+00	1.86E+05	2.21E+04	8.22E+03
7	5.24E+00	1.65E+05	2.17E+04	8.05E+03
8	4.72E+00	1.49E+05	1.53E+04	5.68E+03
9	7.31E+00	2.31E+05	3.03E+04	1.13E+04
10	6.99E+00	2.21E+05	2.89E+04	1.08E+04
11	8.53E+00	2.69E+05	3.83E+04	1.42E+04
12	1.18E+01	3.72E+05	4.54E+04	1.69E+04
13	6.46E+00	2.04E+05	2.87E+04	1.07E+04
14	3.56E+00	1.12E+05	1.59E+04	5.90E+03
15	5.00E+00	1.58E+05	2.23E+04	8.28E+03
16	3.79E+00	1.19E+05	1.34E+04	4.99E+03
17	3.81E+00	1.20E+05	1.71E+04	6.36E+03

6. Conclusions

According to the results obtained by this study, the following conclusions may be drawn:

-This study presents a new technique to reduce the hard work to assumption the amount of sediment and reduce in the time consumption to arrive to the good decisions in the river reach by making the analytical study and predicating a new model for estimating the sediment load before using SSIIM Model.

-The concentration profile was suitable for calculated in all directions horizontal direction (Plan View), vertical direction (section view) and longitudinal view. Before using this model it was difficult to calculate sediment and its concentrations.

-The SSIIM Model, after it running produced a good accuracy in simulation distribution values of (velocities and sediment concentrations) which compared with the field measurements.

-This study presented the new analytical study about the secondary flow and it’s affected on the configuration of bed and banks.

-This study demonstrates that there is a valid relationship between the hydrodynamic and sediment transport. The relationship was an obvious between low velocities values and high concentration of sediment when the layers analysis was used.

-Both observation data and simulation results indicate that there is a problem in the management of the sediment transport of Al-Betera Regulator which must be considered in the future.

-The amount of sediment for this reach it was the total annual trapped sediment load it was (22797 ton) that equal to(13816 cubic meters) of deposition material of sediment depended on submerged density of 1690 kg/m^3.The average depth of deposition material was 4.1 cm/year.

-No bed morphology changes and lateral movement of the river alignment were observed due to small quantity of deposition material during the short term.

-A high scour to the river bed was observed for some cross sections of the study reach due to existing of a strong velocity gradient.

-When the grid and control files will prepare for a proposed river reach, the grid, roughness of the bed and sediment parameters must be chosen with suitable values for convergence purposes.

-SSIIM Model is a powerful fluid dynamic model for evaluation and estimation of water flow, sediment transport and bed deposition. It has given satisfactory results for the bend in the river reach of the study.

- For future works, a Transient Sediment Computation (TSC) must be applied in the SSIIM model by using velocities flow, Sediment Concentrations and grain size curves to make different Combinations.

- In this study, the results which obtained from SSIIM were for short term. Results for long terms must be recommended due to its imported in river training and sediment transport.

- Further studies must be applied for predicating bed roughness which changes with time and positions of the river reach.

7. References

1. Curran,J.C. (2003).*" The Effect Of Sand Supply On Transport Rates in A gravel – Bed Channel “*Journal of Hydraulic Engineering.

2. Edwards, T.K. and G.D.Glysson (1999),*"Field Methods for Measurement of Fluvial Sediment."* Techniques of Water –Resources Investigations of the U.S.Geological Survey.Book3, Applications of Hydraulics.

3.Huang and Fan,(2004),*”Effects of Water Discharge and Sediment Load on Evolution of River Bed”,* www.biogeosciences.net/8/2427/2011/bg-8-2427-2011.pdf.

4.Khosronejad, A., Rennie, Salehi, A.,and Moghimi, S. (2007), *"3D Numerical Modeling of Flow field and Sediment Transport in Laboratory Reservoir Flushing Process"*, Dept. of Water Engineering, University of
Guilan, Rasht, Iran.

5. Xiaohong, C., (2005*),"Modeling Transportation of Suspended Solids in Zhujiang River"*, Aalborg University, China.

6.Melaaen, M.C. (1992*),”Calculation of Fluid Flow with Staggered and with Non-Staggered Curvilinear Non-Orthogonal Grids”,* Numerical Heat Transfer, Part B, Vol .21,pp . 1-19.

7.Van Rijm, L.C. (1987), *"Sediment Transport, Part II: Suspended Load Transport"*, Delft University of Technology.

8.Brooks, H. N. (1963*),”Discussion of Boundary Shear Stresses in Curved Trapezoidal Channel”*, ASCE Journal of Hydraulic Eng., Vol. 89, No. HY3.

9.Jasem, M., Hyder (2013*),"Estimation of Sediment Quantity upstream of Al- Abbasiya Barrage in Euphrates River"*, MSc. Thesis, Department of Civil Engineering, University of Kuffa.

10.Akers, P. and W.R.White (1973), *" Sediment Transport: New Approach and Analysis"*, Journal Division ASCE, Vol.99, Hy11.

11. Yang C.T (1996*)," Sediment Transport: Theory and Practice “,* McGraw –Hill Series in Water Resources and Environmental Engineering ,Singapore.

12. Ariffin, J. and Suhaimi, A., T.(2004), *"Development of Total Sediment Load Equation for Selected Rivers in Selangor"*, Research Management Institute, University Technology Mara, 40450 Shah Alam, Selangor, Malaysia,
October .

13. Royal Eijkelkamp Earth Sampling Group, http.//en.eijkelkamp.com

14.Hubert Chanson, (2004), *“The Hydraulics of Open Channel flow: An Introduction”,* Elsevier Butterworth Heinemann, Oxford, England, Second Edition.

15.Hassanzadeh, H., Faiznia, S., Shafai, B., M. and Motamed, A.( ), *"Estimate of Sediment Transport Rate at Karkheh River in Iran Using Selected Transport Formulas"*,World Applied Sciences Journal 13 (2).

16. Schlichting, H. (1979*),”Boundary Layer Theory”,* McGraw-Hill.