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Investigating Flow Pattern and Sedimentation of Karun River regarding Meandering Removal

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Abstract

Rivers are the main sources of water supply for various uses, so investigating the hydraulic and sediment conditions of rivers is of great importance. Understanding the morphology changes in rivers is necessary due to the complex process of erosion and sedimentation of rivers as well as the importance of river's morphology changes in organization of flood control and design of hydraulic structures. The Karun River is in Khuzestan province and has a meander pattern; also due to the formation of islands and sedimentation of the river within the city of Ahvaz, an increase in water level is observed during the floods. In this study, using the two-dimensional software of CCHE2D and assuming the existence of shortcuts, we have attempted to remove the meanders of Choneibeh and Krishan 2. The hydraulic and sedimentary results show that the removal of meanders causes an increase in energy slope of the river, flow rate, and thereby an increase in erosion. According to the predictions of the model, the average flow rate is increased by 50% compared to the current path, which reduces the sedimentation for 40%.

Keywords: Meanders, Karun River, the Mathematical Model of CCHE2D, Erosion and Sedimentation

Introduction

Water is an important erosion factor on the Earth's crust and is able to transport materials in its passing. These materials, are washed away from the slopes and plains, and cause erosion of the soil, lack of vegetation and environmental degradation. Sedimentation leads to different kinds of damages every year. Rivers, being affected by erosion and sedimentation, are subjected to various changes, including changes of direction, transverse and longitudinal displacements, and the occurrence of shortcuts, changes of river types and the elevation of the bed, changes of texture and transformation of geometric features of the route. Cross and parallel structures in the path of the rivers, such as bridges, dikes, dams, flood walls, protecting structures of the beds and banks, as well as existing facilities of the surrounding area, including roads, farms, industrial areas, urban and agricultural processes are directly affected by erosion and sedimentation. The fact becomes more important when it causes the flooding and claims the lives of people (Guo, 1999). The Karun River has long been exposed to the severe floods; one of the main causes of these floods in recent years, has been the increased erosion and sedimentation which reduces the river's inflow capacity. Formation of sedimentary islands in the river, confirms this phenomena. Considering the significant decrease in the slope of the river and low transmission capacity, has resulted in the reoccurrence of this topic - the sedimentation of the Karun River in the city of Ahvaz and its vicinity- to be one of the main topics of the researches on the Karun River.

Studying the Karun River's erosion and sedimentation are of great importance due to their direct effect on the flow control structures, as well as the implementation of preventive measures in the improvement plan and flood control. The purpose of this study is to compare the hydraulic and morphological changes of two directions of the Karun River, which are in the vicinity of Ahvaz and extended to the upstream of Farsiat station with a length of three kilometers. In addition, a reformed path is suggested that removes two meanders of Choneibeh and Krishan 2. Also we attempt to create a new shortcut with a length of 23 km using a two-dimensional model of CCHE2D.

Materials and Methods

The area under study

The Karun River's catchment with an area of 42754 square kilometers is located in the east longitude of 48 ° 4' to 51 ° 55' and the north latitude of 20° 17' to 32 ° 4'. It is supposed to be one of the country's largest catchments. The perimeter of the catchment is about 1620 kilometers and dimensions of the rectangle are 56 and 756 kilometers. The Gravelius compactness coefficient is 24/2. From the perspective of the general hydrology of Iran, the Karun River's catchment, is a part of the Persian Gulf and Oman Sea's catchment area. From the north, the catchment area is limited to the catchments of Dez, Qara-Chai of Saveh, Golpayegan and Zayandehrud, from the west to Karkheh, from the east to Kor and Zayandehrud's catchments and watercourses of Abade, and from the south it is limited to catchments of

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Zohreh, and Maroon and Jarrahi rivers. The Karun River is located in the alluvial plain of Khuzestan, which consists of sand, clay and silt. The anticlines of Sardar-Abad in the south of Shushtar prevent Karun from advancing towards the West. In the downstream of Sardar-Abad's anticlines, the Karun River continues to be an alluvial river which flows towards the south. After Bande-e-Qir, three Rivers of Gorgor, Shatit and Dez combine and flow towards Ahvaz, where they intersect with sandstone anticlines of Ahwaz. After crossing the anticline of Ahwaz, the river reaches the Bahmanshir- Arvand cross, then it flows again into the alluvial plain of Khuzestan- whose depth is already measured-; due to the low slope of the Karun River and its sinusoidal factor which is close to 2, we conclude that the river is a suspended load river. The area understudy is consisted of a part of the Karun River in the center of Ahvaz between hydrometric stations of Ahvaz and the hydrometric station of Farsiat – by the length of 32 km. The range is consisted of two meanders called Choneibeh and Krishan 2. In order to implement the model and simulation, data of hydrometric stations was required.

Figure 1- The area under study

The introduction of the two-dimensional model of CCHE2D

The CCHE2D Software is a two-dimensional system used for the analysis of unsteady flow, rivers with turbulent flow, sediment transport and water quality. The purpose of the model is to predict erosion and river banks in the uniform and non-uniform sedimentations, meandering migration and water quality. Model is also used in the assessment of hydraulic structures like water control structures, dikes, etc. In addition, the model helps the engineers in the original design of new structures and helps them to economically improve the plan. Numerical modeling is based on solving the Navier-Stokes equations as initial value problems.
The modeling is based on five steps:

- Production of computational networks (mesh)
- The initial and boundary conditions
- Adjustment of parameters, including hydraulic and sediment parameters
- Implementation of simulation
- Observation and interpretation of results

Various researchers including (Zorkeflee, 2007), investigated the two-dimensional mathematical model of CCHE2D and the one-dimensional model of HEC- RAS in the Merdeka River. They came to the conclusion that although one-dimensional models such as HEC-RAS have been widely used, they don't have the ability to analyze some hydraulic parameters such as flow pattern and sediment of meanders, structures and obstacles in the rivers. (Jia and Wang, 2008) developed the two-dimensional hydrodynamics and sediment transport model of CCHE2D. They attempted to study the changes in the bed and flow of open channels. In this model, a two-dimensional integration moment's equation of depths is used for turbulent flow in a Cartesian's coordinate system. Due to the boundary conditions, the model used three types of border that include input, output and solid walls. In the CCHE2D model, level changes are calculated due to the bed load and secondary flow rates; these factors have an influence on the process of transport in the meander channels. The results show that this model can be used in the study of stable, unstable and turbulent processes, as well as sediment transport and morphological changes of alluvial channels.

In the context of meanders' removal (Tirol et al, 2008) stated that the erosion and sedimentation in the constructed shortcut path were more than usual compared to the former meander path because the flow rate in the shortcut channel had increased. (Ichim and Radon, 1986) in their study indicated that the modification of meanders influenced the hydraulic behavior; the morpho-dynamic branches of modified meanders were seen as sedimentations; however, the newly established channels also experienced erosion. (Seljuks et al, 2012) Using a one-dimensional model of MIKE11, compared the shortcut path with the removal of meanders and the current path of Gap River in Bushehr. Their results showed that the removal of meanders increasesd the energy slope for 65% and consequently the erosion of the river increased as well. (Azam et al, 2013) investigated the Improving methods in Karun River to remove the downstream horseshoe-shaped meanders (meanders Jongieh); the mathematical model of Hec-Ras4 was used. Their results showed that the removal of meanders had considerable effects on the hydraulic flow, enhanced the effectiveness of dredging and effectively decreased the sedimentation process and the flood level.

The equations of water flow and sedimentation

Numerical model of CCHE2D, uses depth-integrated, Reynolds-averaged equations to solve the flow of the field (Depth-Average). To simulate the state of turbulence, the model, uses two zero models of Parabolic Eddy Viscosity, a model of Mixing Length eddy viscosity and the two-equational model of k-ε (Zhang, 2009).
Two main equation modeling are:

A) The continuity equation

$$\frac{\partial Z}{\partial t}+\frac{\partial(hu)}{\partial x}+\frac{\partial(hu)}{\partial y}=0 \quad (1)$$

B) The equation of motion

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+\nu\frac{\partial u}{\partial y}=-g\frac{\partial Z}{\partial x}+\frac{1}{h}\left[\frac{\partial(h\tau_{xx})}{\partial x}+\frac{\partial(h\tau_{xy})}{\partial y}\right]-\frac{\tau_{bx}}{\rho h}+f_{cor}\nu \quad (2)$$

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In these equations, u is the velocity component on vector x, V is the velocity component on vector Y, G is the acceleration of gravity, Z is the Water Surface Elevation, h is the water depth at the assumed point, ρ is the water density, f_{cor} is the Coriolis effect, $\tau_{yx}, \tau_{xy}, \tau_{xx}$ and τ_{yy} are the components of Reynolds' shear stress, and τ_{by}, τ_b are shear stress components on the bed surface.

C) The equation of turbulence

The model of CCHE2D is used to simulate the effect of turbulence on the flow pattern and solve the system of equations. The model CCHE2D also benefits from the models of eddy parabolic viscosity, mixing length and k – ε. For simulation of turbulent flow, the standard model of k - ε was used; in this model, k equation is defined for kinetic energy of turbulence and ε is defined for energy distribution rate of turbulence. The following equations show the combined model (4, 5) -for further studies see the references part:

$$K=\frac{1}{2}\overline{U_i}'\overline{U_j}' \quad (4)$$

$$\varepsilon=\mu_t\frac{\bar{\partial}u'_i}{\partial x_i}\frac{\bar{\partial}u'_j}{\partial x_j} \quad (5)$$

D) Sedimentation equation

Modeling the sedimentation transport is achieved through the averaged-depth, displacement- distribution equation for suspended load (6) and the continuity equation for bed load (7)(Wu, 2009).

$$\frac{\partial(hC_k)}{\partial t}+\frac{\partial(UhC_k)}{\partial x}+\frac{\partial(VhC_k)}{\partial y}=\frac{\partial}{\partial x}(\varepsilon_s h\frac{\partial C_k}{\partial x})+\frac{\partial}{\partial y}(\varepsilon_s h\frac{\partial C_k}{\partial y})+E_{bk}-D_{bk} \quad (6)$$

$$(1-p')\frac{\partial z_{bk}}{\partial t}+\frac{\partial(\delta\overline{c_{bk}})}{\partial t}+\frac{\partial(q_{bkx})}{\partial x}+\frac{\partial(q_{bky})}{\partial y}=-E_{bk}+D_{bk} \quad (7)$$

Index K is indicative of the sedimentation of particles' class . C_k And ε_s are the concentration of sediment's suspended load and eddy diffusivity, respectively. They are calculated through the equation $\varepsilon_s = {}^{v_t}/_{\sigma_s} . v_t$ And σ_s are eddy viscosity and Schmitt number- Prandtl turbulent (a number between 0.5 and 1), respectively. E_{bk} And D_{bk} are the entrance rate of sediment particles of the bed load to the suspended load point and the sediment rate of particles between bed load and suspended load.

$$E_{bk}-D_{bk}=\alpha\omega_{sk}(C_{*k}-C_k) \quad (8)$$

Coefficient α is a parameter for modeling the sediment's transport called the non-equilibrium comparative index of suspended load. Factor ω_{sk} is the fall velocity related to the sedimentation of the size of particles' class. Factor C_* represents the sediment concentration at equilibrium state (sediment's transport capacity). Factor p' represents the porosity of bed's materials. Factor $\overline{C_{bk}}$ represents the average concentration of bed load in the movement area of bed. Factor δ is the thickness of the bed, q_{bkx} and q_{bky} are the components of load's transport rate in the vectors of X and Y, respectively.

In fixed boundaries such as islands or shores, the load's transport rate and the changes of bed load's concentration -being perpendicular to the border- are considered to be zero.

$$q_{bk}=0 \quad (9)$$

$$\frac{\partial C_k}{\partial n}=0 \quad (10)$$

At the output border, the bed load's calculations require no special provision, but the changes of suspended load's concentration in the direction of flow are equal to zero.

$$\frac{\partial C_k}{\partial s}=0 \quad (11)$$

Preparation of solution field's Geometry and its meshing

After entering the information to the software and determining the boundaries of the field, the defined area was meshed in two ways. It should be noted that the network lines were sufficiently smooth and also the lines were in an orthogonal mode in two directions. Also due to the high speed gradient curvature of flowing lines and the possibility of the formation of eddy flows within the upstream and downstream of the island, this area found to have a more compact meshing compared to the rest of the areas. Figure 2 shows the initial state of digital information of points within the city of Ahvaz and the new selected path for modeling. According to the information below, the dotted pattern can be well recognized. The Network is consisted of non-uniform structured and adapted network with dimensions of 50 x 400, which is produced and improved by CCHE-Mesh.

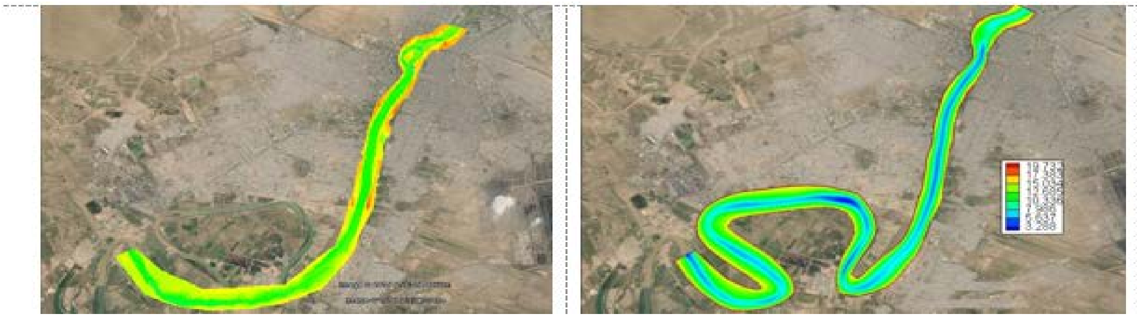

Figure 2. The geometry of the solution field and the situation of digital information of the points in the current path and the shortcut path of Karun River

The application of boundary conditions and initial flow

For the modelling of the flow and sediment's transport, we need to apply boundary conditions to the model. In this study, the annual average of flow rate is used as the input flow field of the hydrodynamic simulation. The flood peak, which is equivalent to 284 cubic meters per second, was applied as a constant value of the input field. The lower boundary of zero gradient in boundary condition- for normal output- and the parameters of the border were considered. In the downstream boundary, the output boundary condition was used and zero gradient condition in the normal direction was considered for the parameters of the field. Hydraulic resistance of the river's bed was applied with Manning roughness coefficient. According to the previous studies and the situation of the bed materials and vegetation of the sedimentary island, first the general index of 0.028 was applied to the field. For plains' flood, areas with vegetation and river sides, the Manning roughness coefficient were considered higher than the main sections (Shoshtari et al, 2011).

The initial conditions of the surface water were applied to the model; in the upstream, the digit field of 13 and in the downstream the digit field of 12.5 were considered as the basic digits of surface water. The interpolation of the boundary between the values was used for the rest of the points. Also, the standard model of k turbulence was used for simulating the turbulence of the field and the representation of Reynolds' stresses. The solution of the flow field has continued until the rest of the factors reached 0.001.

After the implementation of the model with different time-steps, the implementation of the program was conducted for a period of one year, with 60 second steps in order to achieve an appropriate convergence.

In the Section of sediment Information, suspended sediment rating curves of Ahvaz station were used as the total input sediments (Fig. 3). Given that the data of sediment grading curves of bed materials play an important role in flow simulation, grading curves were analyzed in the last few years and finally were used in the model. Figure 4 shows the Gradation curve used in the model.

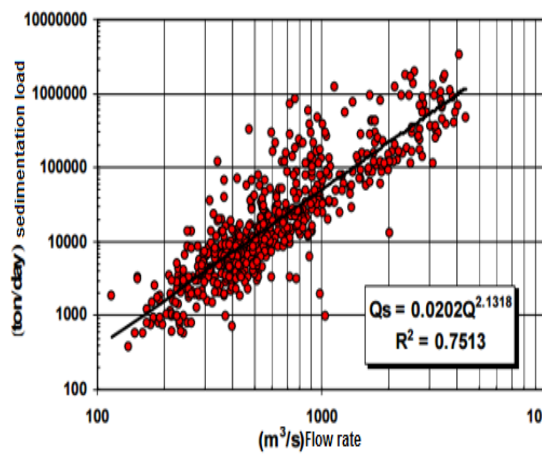

Figure 3- Suspended sediment's rating curves in Karun River of Ahvaz station

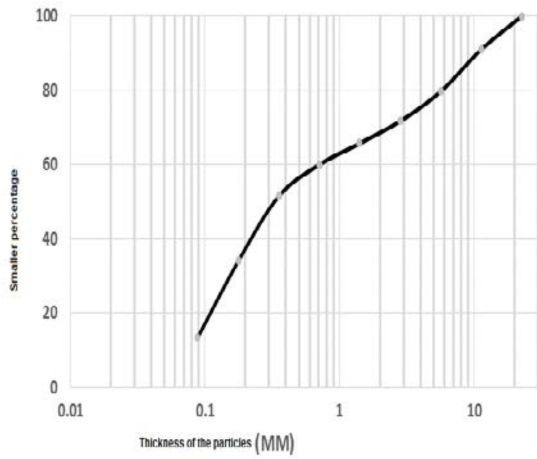

Figure 4- Sediment's gradation curves of Karun River's bed In the Ahvaz station

Results and Discussion

Both models were implemented according to the above-mentioned steps and necessary data. The models were implemented for a period of 12 months; the flow pattern and sediments in the periods, the amount of input sediment and the amount of output sediments of the river were estimated and analyzed.

The simulation of the flow pattern

To determine the flow pattern in the computing field, trends and values of the velocity vectors were investigated in two projects of Karun River. When the river channel, was in the direct mode, the maximum speed occurred in the middle of the channel; it happened mostly due to reduced frictional effects. But at the site of bending and shortly thereafter, the maximum speed, inclined to external walls (concave) was created. This was due to the formation of secondary flows on the arrival of the location of the arc and the development of secondary flow shortly after that; the removal of river meanders and changing them to a straight line caused the secondary flows be removed. According to the figure 5-A in the current direction of the river, the upstream of the flow rate in the general range was generally high and the maximum flow rate of the entire field happened in this area which was 0.38 meters per second. It was because of the limitation of the area by walls on both sides of the river and the lack of flood's spreading to the plains. Another reason for this phenomenon could be the relatively high slope of the river bed in the area.

According to Figure 5-c, the changes of flow rate around the island indicated an intense rate on the left coast in a way that the range between the left coasts in this area had a high speed. This area corresponded to the maximum width of the island. Slow upstream and downstream areas of the island are evident that this was caused by the rotations - meanders. Due to the formation of meandering areas, speed reduction occured in upstream and downstream areas of the island. In the downstream area of the island, there existed an area with a relatively uniform flow pattern. However, in the downstream of the range, due to the local changes of bed elevation and side's situation, local speed increased in some areas, including the two meanders. Finally, by increasing the relative depth and the average speed of 0.18 meters per second, the discussed flow reached the end of the period. Flow pattern in the shortcut path is shown in Figure 5-B. Due to the figure, the velocity distribution of this state was more uniformed than the current state. By eliminating the two meanders, an increase in the energy slope and shear stress occurred; also the flow rate decreased as the average speed at the end of the interval reached 0.27 meters per second. The 50% increase in flow rate could reduce the sedimentation and increase the capacity of the flow of the river.

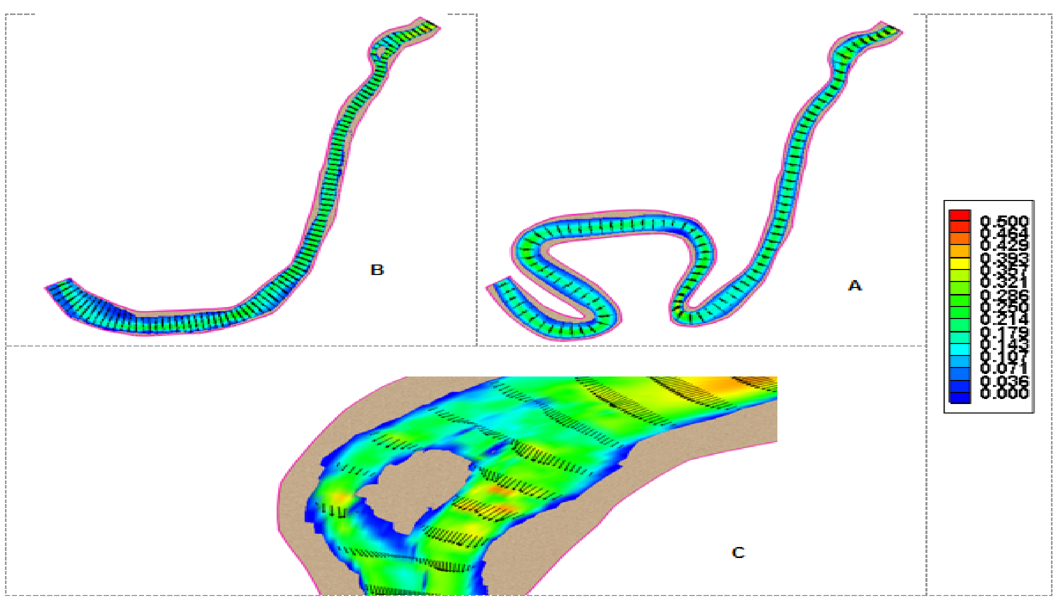

Figure 5. The velocity distribution in a) current route in b) the designed route and around c) upstream of the island.

Simulation of sediment pattern

The sediment data of the river was applied to the model of both paths. Figure 6 shows the distribution pattern of erosion and sedimentation after two months of simulation for the current path of the river. Due to the meandering areas at the beginning of the period, the sedimentation was less than the area located on the other side of the island and the flow of the river was slower. Figures 7 and 8, indicate a more averaged bed changes after twelve months of simulation. According to Figure 7, the maximum amount of sedimentation before the third and fourth arc is 1.8 m. In Figure 8, the maximum amount of sedimentation in the upstream and in the territory of the island is 0.8. The amount of erosion and sediment production in the shortcut path was more than the maximum amount and equaled 0.35 meters. In Table 1, the input and output sediment balance for both paths are indicated. According to Table 1, it could be stated that the removal of meanders, reduces the river's sedimentation for 40%.

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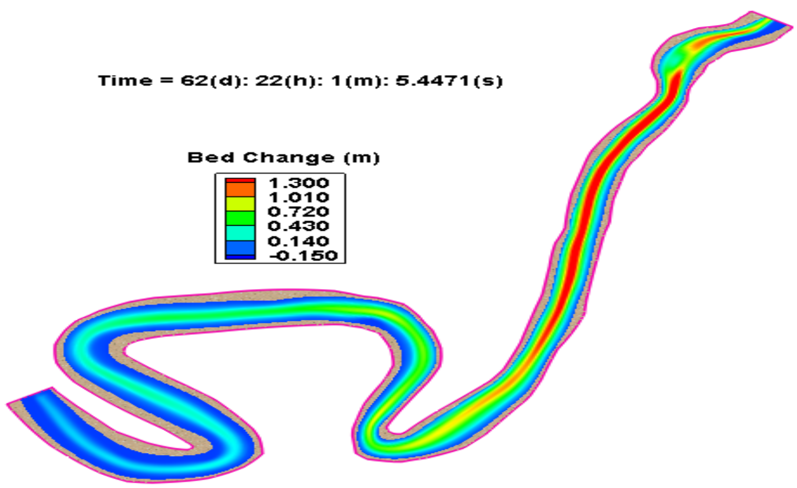

Figure 6. Bed changes, erosion and sedimentation in the current path of the river after two months of simulation

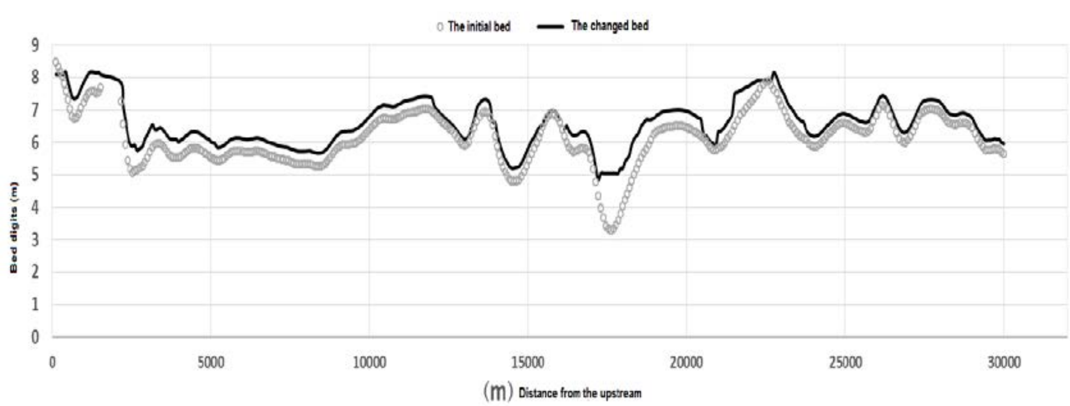

Figure 7. The average bed's elevation changes for the current path of the river

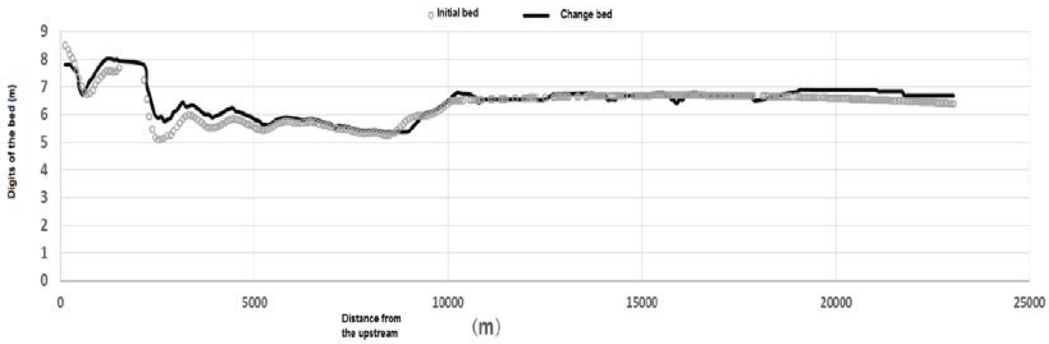

Figure 8. The average bed's elevation changes for the new path of the river

Table 1. Balancing the input-output sedimentation by the CCHE2D model

	Input Tonnage (tons)	output Tonnage (tons)	Sediment balance (tons)
The current plan (curved path)	1396529	1519481	122952
The new plan (the shortcut)	1642433	1716205	73771

Conclusion

The results of this study are as follows:

1. Erosion and sedimentation of a part of the Karun River shows the sedimentation of the river. The study utilized a two-dimensional, numerical computational fluid dynamics model (CFD), called CCHE2D, and simulated the pattern of water flow and sedimentation in this meandering range. Natural meanders were simulated and compared with the results of the shortcut's creation.
2. Based on the results of the comparison of the two paths in the numerical model, it was concluded that the removal of meandering, the energy slope and the average amount of speed are increased for 50% compared to the current state.
3. The comparison of the annual sediment balance shows that the removal of meandering reduces the sedimentation ability for 40 %.
4. The distribution of sedimentation pattern, shows that in the current path, the maximum amount of sedimentation before the third and the forth arcs is 1.8; however, this amount in the shortcut path reduces to 0.8. Also, the amount of erosion and sediment production in the shortcut path reaches 0.35 meters, due to the increase in shear stress.

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