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Mathematical Modeling of the Effect of Meanders Removal on Changes in Erosion Rate: A Case Study in Karun River's Gangieh Meander

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Abstract

One of the nonstructural methods of increasing aqueduct and decreasing flood balance in rivers is to create a shortcut to remove steeped arches. With regard to the dynamic system of river, any type of change in the stable structure of the river may lead to possible changes in the river morphology and creates new problems. In this study, after removing Ganjieh meander in downstream Ahvaz with the aim of organizing and increasing Karun River's aqueduct around Ahvaz city, hydraulic changes of flow and erosion and sediment level after removing meander were modeled using Hec-Ras4 mathematic model. This model was conducted in Karun River in an interval of 16 kilometers around Zargan – Farsiat for 25 years. Results of this research showed that, in the first 16 kilometers, in low to medium discharges of Karun in upstream meander, the water surface balance was high and decreases over time and in high water, discharge does not change significantly over time. In downstream meanders, in medium to high water, discharges, after removing meander water level balance increase compared to conditions before remove. Overall, before and after removing meander, in 16 to 18 kilometer as well as 35 to 40 kilometers, the cumulative weight of erosion and or sedimentation has the maximum value and their density increases over time.

Keywords: river improvement, Meander removal, Meanders Gangieh, Karun River, Hec-Ras4 software

Introduction

Changes and displacements caused by natural or artificial changes occur in geometric direction and characteristics of the river are a logical result of river system's reaction to establish a new balance between erosion and sedimentation process. Thus, doing organization measures and interference in river system requires knowing certain rules governing them and predicting river's reaction is necessary before any action. Erosion and sedimentation studies enables us to recognize rivers' morphology behavior, and to analyze the impact of various organizational actions on river's behavioral performance both quantitatively and qualitatively and this way the instability factors and practicing appropriate protection criteria and engineering measures can be already identified. Different ways of river organization can be divided into two general structural and nonstructural methods. Spur dike, floor fixtures, slope breakers, submerged and overflow pages among the transverse structures and embankments, flood walls and protective coatings are longitudinally aligned structures. Nonstructural methods include reformation of the route by clearing the bed from sediments and anomalies as well as creating a shortcut to remove steep oxbow and establishment of appropriate direction. One of the purposes of river remediation is to reduce flood in an interval of the river. This is done by increasing the spur dick power of waterway and plain flood with reforming the direction and river stabilization and includes all works leading to rout reformation, widening, deepening cross-sectional, regulation of flow depth and longitudinal slope, the bed roughness coefficient, removing unnecessary barriers in the flow path and stabilization of river's sides and bed.

Karun River is one of the most problematic rivers with regard to sedimentation and erosion. The mechanism of this river's sediment transfer is so complicated and different factors such as adhesion of suspended sediment, high percentage of washed load (basin) and numerous acres made it more complicated. Changes in flow regimen in the river created by successive dams in Karun caused a large quantity of the river to be filled with sediments and each year we see life and property damages by floods with fewer discharges. The large cities along Karun River and the necessity of protecting these cities, farms and large industrial centers against floods, necessity of conducting flood control plans in this river seem clear. Numerous mazes in meander rivers cause an increase of resistance against flow path and thus the capacity of flood pass decreases and creates problems in flood path. In order to reach balance in acres with narrow necks, sediment and shortcut phenomenon occur. Existence of shortcut channels causes shortening of the path, increasing hydraulic slope and reduction of resistance against flow. Methods to increase flow path capacity include upper reduction of river bed (removing sediment barriers and loads), increase of wet surface of the river or deepening the bed (dredging), shortening waterway length and consequently increasing floor slop (establishment of shortcut). By shortening the river length, the cost of protecting river sides against sedimentation decreases and embankments length of flood control reduces. Saving cost of dredging is another benefit of establishing shortcut channel. In establishing artificial shortcut, other objectives are taken into account, in addition to increasing the capacity of flood pass, including reformation of the path for shipment, bank sediment prevention, reduction of stabilization costs and protection against beaches as well as the flood control structures and oxbow surrounding farms' exit from the flood impact zone and protecting important structures and facilities against river displacement.

Shortcut channel is built in form of circular chords with central radius of river arch. Shortcuts usually have two internal and external shortcuts. The New curvature radius of shortcut channel should conform to the following relationship (Zayng et al. 2002):

1) $R > (3-5)B$

2) $R > (4-6)L$

B is the river width in filled discharge state and L is the ship length. 1 and 2 equations are applied in order to provide the condition of river stabilization and shipment.

So far, numerous researches have been conducted about Karun River sedimentation and erosion resulted from different methods of river organization. The first research about the condition of sedimentation of Karun River was conducted by Kheirollah (1991) to organize this river for flood pass with minimum sedimentation. Using HEC-6 model, findings indicated that the average height rate of sedimentation is approximately 3-5 centimeters. Abbassi (2007), using neural network model QNET-2000, concludes that according to the flowing suspended sediment from Ahvaz and Farsiat stations, this interval of Karun River has a sedimentation condition. Pur Asef and Abdol Shah Nejad (2009) by suggesting artificial establishment of six shortcuts on Karun River and the impact of establishing this shortcut in reducing flood balance shows that by establishing each shortcut in arches under study and for discharge values with 25 year return period at the entrance point of the arch, the reduction level of flood would be more than one meter and removing the impact of the total energy fall derived from available arches leads to significant reduction of flow pass balance. Azarang et al. (2009) using a one-dimensional model of CCHE, represents a hydraulic and sedimentary simulation of Karun River in Ahvaz-Farsiat interval and then validates results of applying the model by field measurement. Finally, according to results of CCHE model, the sedimentation in Ahvaz-Farsiat interval was estimated approximately 2.5 million tons a year. Mosavi et al. (2010) analyzed the impact of dredging of islands formed on Karun River using CCHE2D mathematical model and information resulted from cross-sectional plans of 1998 and

2005. Results showed that for 2, 25 and 100 years old floods with complete dredging of islands, the flood balance decreases to 0.44, 0.24 and 0.27 meters. Shahi Nejad et al. (2009) studied sedimentation and erosion around Ahvaz using GATARS mathematical model. Research results showed that Ikerz-White and Tofalti sedimentary relationships compared to other relationships give a better estimation. Also, results showed that higher coefficient of 0.035 is more consistent with upper Karun. In Azm et al. research (2010) hydraulic flow and sediment after dredging operation was analyzed using Hec Ras 4 model. By analysis of model results, we found out that dredging in Ahvaz interval in a form of digging does not significantly affect water surface profile and only the procedure of sedimentation and erosion changes in this interval. Additionally, the dredged sections after a maximum of 6 years will return to the condition before dredging.

In this research, we aimed to investigate another method of organizing Karun River i.e. removing Gangieh meander to reduce path fall and consequently reducing water surface balance in flood condition. On the other hand, according to the active system of river and hydraulic changes of flow and especially energy line slope as a result of meander remove, changes in sedimentation and erosion changes of the river should be investigated.

Methods and materials

Geographical location of the area under study

Karun River is one of the longest and largest rivers in Iran and the basin of Persian Gulf and Oman Sea. The length of Karun River is about 890 kilometers and its basin is an area with 62570 square meters and its annual input according to measurements of Ahvaz station was estimated about 22 billion cubic meters. In order to organize Karun River around Ahvaz, various measures were taken including river dredging, flood deflection to Bahreh natural watercourse in southern Ahvaz and building a dyke for controlling Dez flood from north to the south of Ahvaz. In order to evaluate these plans, their interactions on river system should be exactly analyzed. In addition, with regard to the sedimentation process of Karun river and the problems arose in this regard, we need to identify morphological changes of this river especially around Ahvaz. With regard to the complexity of the issue and longevity of the interval under study, the use of appropriate mathematical model is one of the best ways in this regard.

Geographical location of this research is based on UTM system about 32 22' 33" North latitude to 32 17' 45" 'East longitude. Figure 1 shows the location of the area under study. The length of the entire path under study is 64.1 kilometers before removing meander. Before removing meander with an approximate length of 13.4 km and connecting the two ends of the arc with a path length of approximately 2 km, the final path is modeled on the HEC-RAS software. In Fig. 2 the removed direction and the new one are shown.

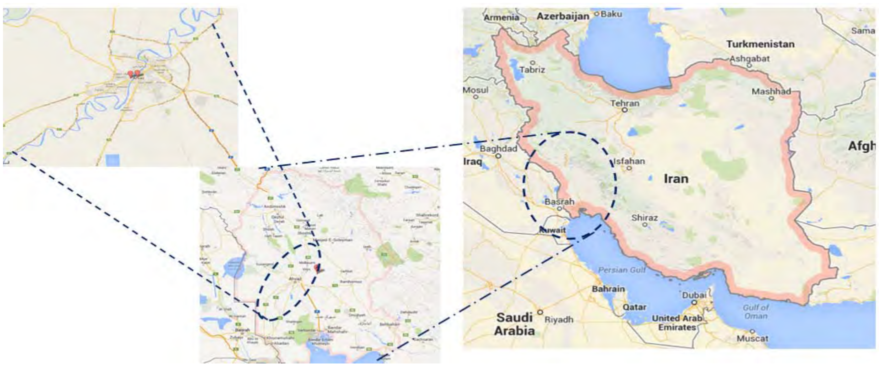

Figure 1: **Geographical location of the research**

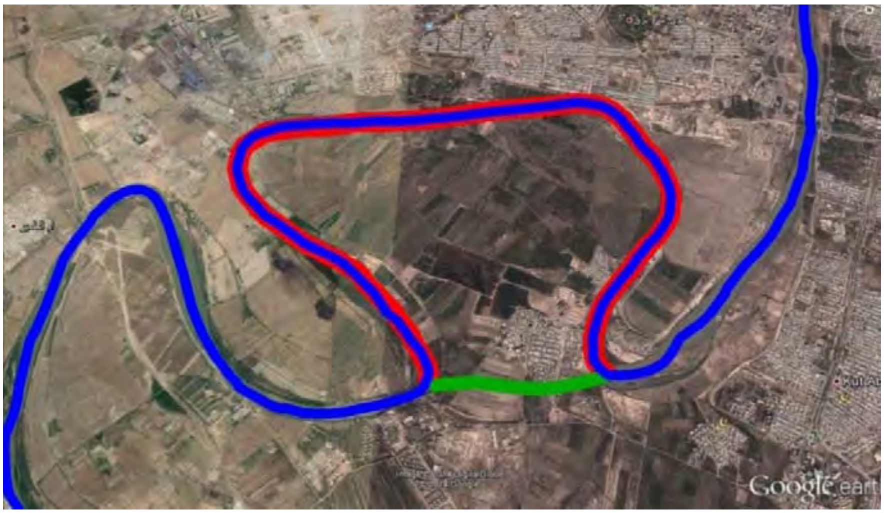

Figure 2: Removed Meanders (red path) and the path connecting the two ends of Meanders (Green path)

HEC-RAS4 Model is designed to calculate one-dimensional hydraulic flaw in a complete network of designed channels. The model includes four components of one-dimensional hydraulic analysis for: 1-calculating water surface profile in the state of stable flow 2- simulation of unstable flow 3- calculation of sediment transfer in the mobile boundary 3- calculation of sediment transfer in the mobile boundary and 4- modeling water quality. The component of stable flow has the capacity to model water surface profiles in sub-critical, super-critical and mixed flow regimens. The sediment transport sector of this model is developed to simulate one-dimensional sedimentation and or erosion and water wash of the bed is developed in 2006. The results of sediment transfer model totally depend on the type of selected model. The order of hypotheses, hydraulic conditions and size of seeds created for each model and choosing the method under conditions which is very close to the system, should be closely taken into account (USA army engineers group 2008) for hydraulic simulation of the flow and Karun River sediment by HEC-RAS4 model requires geometric information (latitude sections, distance of sections from downstream control section, meaning upper coefficient and widening and narrowing coefficients), hydraulic (flow daily input discharge statistics and water surface balance in downstream station), meteorology (water temperature) and sediment (statistics of flow discharge – sediment granulation of floor bed) of river. In the geometry sector of river schematic plan, river cross-sections, meaning upper coefficient and widening and narrowing coefficients are given to the model. In figure 3 schematic plan of Karun River in Zargan River from Zargan to Farsiat interval with 155 lattitude section called mathematical model is shown.

After drawing the schematic form of the interval under study, sections taken from the area, kilometers and their Meaning roughness coefficient voltage entered into the specific corresponding cross section. In order to estimate the approximate maximum amount of meaning in the position of different cross-sections, previous experiences and reports were used by calibrating the model based on manning maximum coefficient, the 0.035 value was chosen for the section. According to Tavakoli Zadeh research (2006), the maximum meaning coefficient around Ahvaz station equals to 0.0356 and around Farsiat station equals to 0.035 and also this maximum coefficient is consistent with research results by Shahi Nejad et al. (2008). The hydraulic part of the software includes information about flow discharge and upstream and downstream boundary conditions that can be represented three states of steady flow, semi unsteady flow and unsteady flow. In order to investigate the erosion and sedimentation trend of the desired range, the model was run as unsteady. For upstream boundary conditions of Ahvaz Station, daily discharge data, and for the downstream boundary conditions, discharge-architect scale of Farsian hydrometric station and in the erosion section, Ahvaz station's data (1989-2013) was used. In table 1, geographical locations of hydrometric stations used are represented.

Figure 3. Schematic plan of Karun River in Zargan interval - Farsiat

Table 1: The selected stations and analyzed data

Station	River	Longitude	Latitude	Information used
Ahvaz	Karun	3469350.4	280701.1	Erosion discharge
Farsiat	Karun	3451555.1	263017.2	Hydrograph and scale

In the section on sediment information, the model investigates the way of erosion transport in rivers using seven different erosion functions for transference of erosion and four methods of particle fall velocity of Robbie, Tofalty, Van Ryan, and Report 12. In this research, due to the lack of real and new information of Karun River for calibration of erosion model, based on previous studies, two Ikers-White and Tofalti models were chosen and results for these two models were analyzed.

Results and discussion

Analysis of changes in water profile

One of the purposes to remove steeped arches in rivers is to reform the path to increase the capacity of flood path. Increasing capacity of flood pass leads to decrease of water surface and consequently reduce the risk of river bank flood. In figure 4, the impact of Ganjieh meander removal on the water level profile on the upstream meander is represented. According to the hydrograph used in the hydraulic data section of model, for the hydraulic analysis of flow 3489, 2490, 1001 and 505 cubic meters have been used. This interval includes lower, average and full discharges of Karun River during the last decades. Here, it is important to note that, since the results of Ikers-White and Tofalti methods are near to each other, in this section only the results of Tofalti method are represented. In figure 4 (A) results show that along the way up to Kilometer 16, in the primary conditions before and after removing meander, the water surface is higher than profile in 12 and 24 years after modeling and continues from about 0.2 meters at the beginning up to about 2 meters in Kilometer 18 and up to this point, the water surface profile after 12 and 24 years, under the conditions after removing meander is slightly lower than water level profile before removing meander. Between 16 to 18 kilometers from the start of interval, water surface profile under primary conditions, either before removing meander or after it, suddenly decreases to about 2.5 meters, this phenomenon may indicate lowering of channel floor and the presence of supercritical flow in some parts of it (figures 5 and 6). In this interval, the profile under the condition of 12 and 24 years after modeling before and after removing meander slowly reduces and it indicates sedimentation and flattening the floor of water channel over time. After this interval and near Ganjieh meander, water level profile in primary condition and 12 and 24 years after modeling did not have significant change but the difference of water level profile between conditions before and after removing meander continues significantly from about 0.3 meters at the beginning to about 1.5 meters near the removed meander.

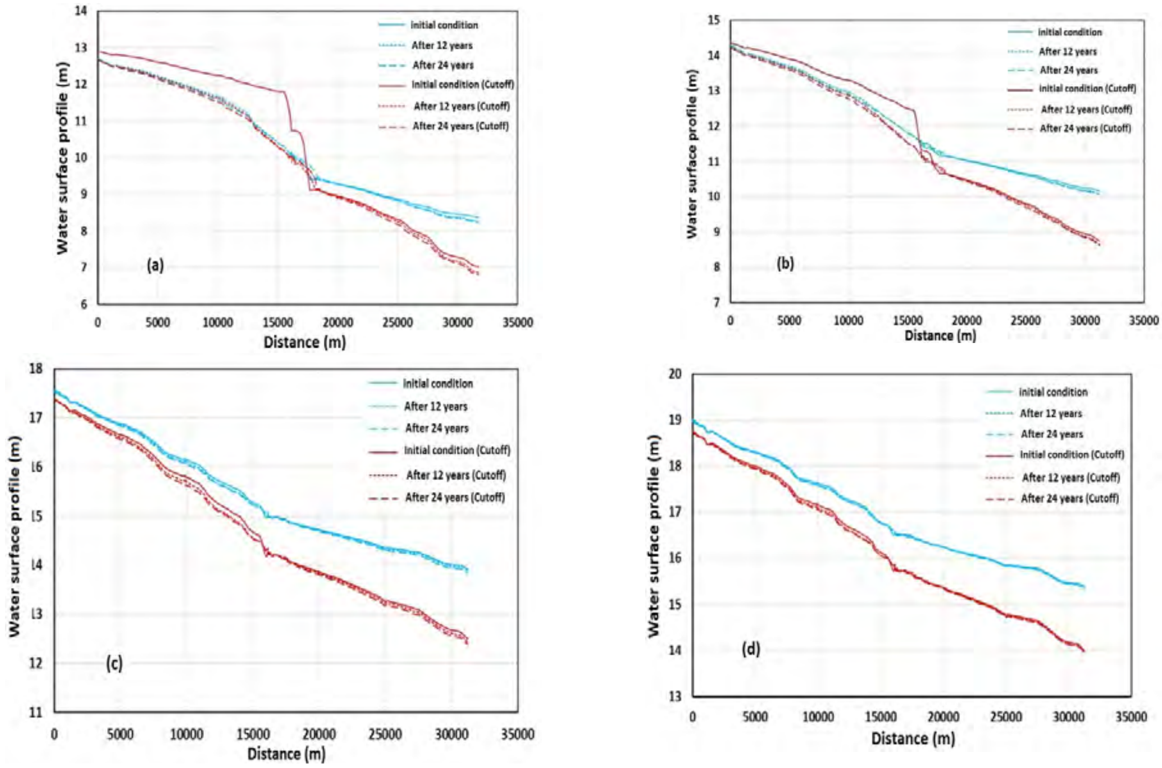

Figure 4: Display of water surface profile in the upstream meander in discharge A)505 B)1001 C)2490 D)3486 cubic meters per second

In figure 4 (B) which shows the water level profile at 1001 cubic meters per second, the trend of profile change is generally the same as water surface profile in 505 cubic meters per second discharge except at the first 16 kilometers of the interval. The difference between water surface profile at the primary condition with profile at 12 and 24 years after modeling which is high at 505 cubic meters discharge and at the 0.2 interval change is lower in this discharge and changes from about 0.05 at the beginning to about 1.2 before removing meander and 1.5 after removing meander.

In figures 4 (C) and 4 (D) that water surface profile in full discharges of Karun River is 2490 and 3486 cubic meters per second, in general water surface profile along the river after removing meander is lower than conditions before removing it. Meanwhile, the water balance difference changes from about 0.1 meters at the beginning to about 1.5 meters at the upstream of Ganjieh meander. Another point should mentioned here is that in 12 and 24 years modeling periods, there is no significant change between water surface profile compared to primary conditions both before and after removing meander.

The overall result of this part can be stated in the following figure, in which in low and medium discharges of Karun (1000≥) in this interval up to about half way in the upstream of Ganjieh meander (the first 16 kilometers), the water surface was up at first and over time by flattening of floor balance because of sedimentation in deep sections, the water surface decreases. In full discharges (≤1000) and in the first 16 kilometers, uneven floor slowly goes under water and the water surface considerably changes compared to before.

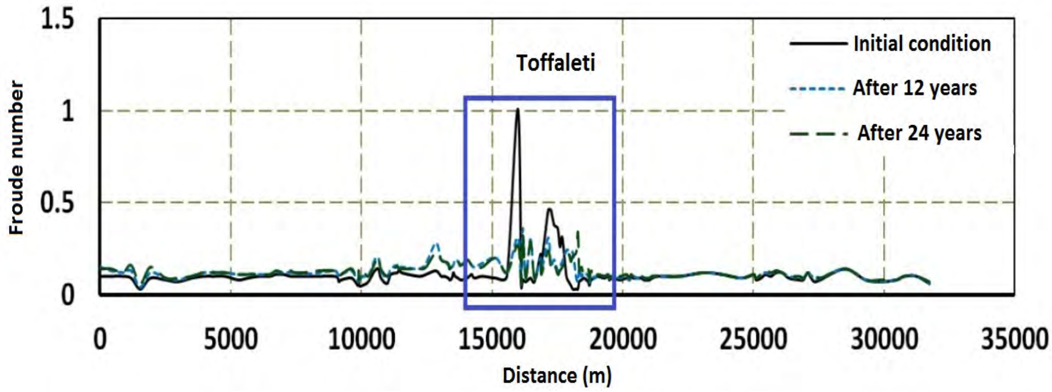

Figure 5: Changes in Froud numbers before removing meander in the upstream of Ganjieh Meander using Tofalti method

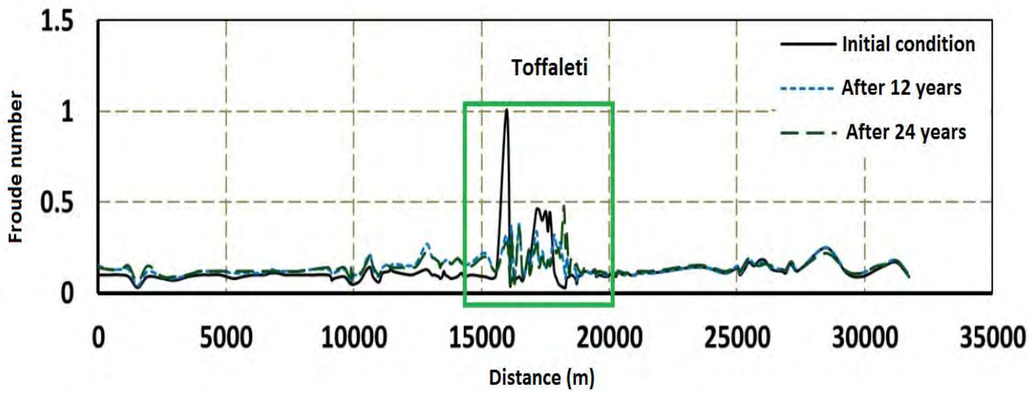

Figure 6: Changes in Froud numbers after removing meander in upstream Ganjieh meander using Tofalti method

At the end, an important and positive result taken from this discussion is a more considerable reduction of water surface balance especially in water-full condition resulted from removing downstream meander of Ahvaz around the city.

In figure 7 changes in water surface balance in downstream meander of Ganjieh before and after removing meander in middle to water-full discharges of Karun River is displayed. The important point here is that in these figures, water surface balance after removing meander compared to conditions before removing, is unlike conditions of upstream meander, and this balance decreases over time and increases along the river in all discharges. Also, according to the figures, water surface in all discharges over time and in 12 and 24 years modeling decreases compared to the primary condition. It should be noted that changes with high gradient of water surface profile at downstream is more affected by downstream boundary conditions.

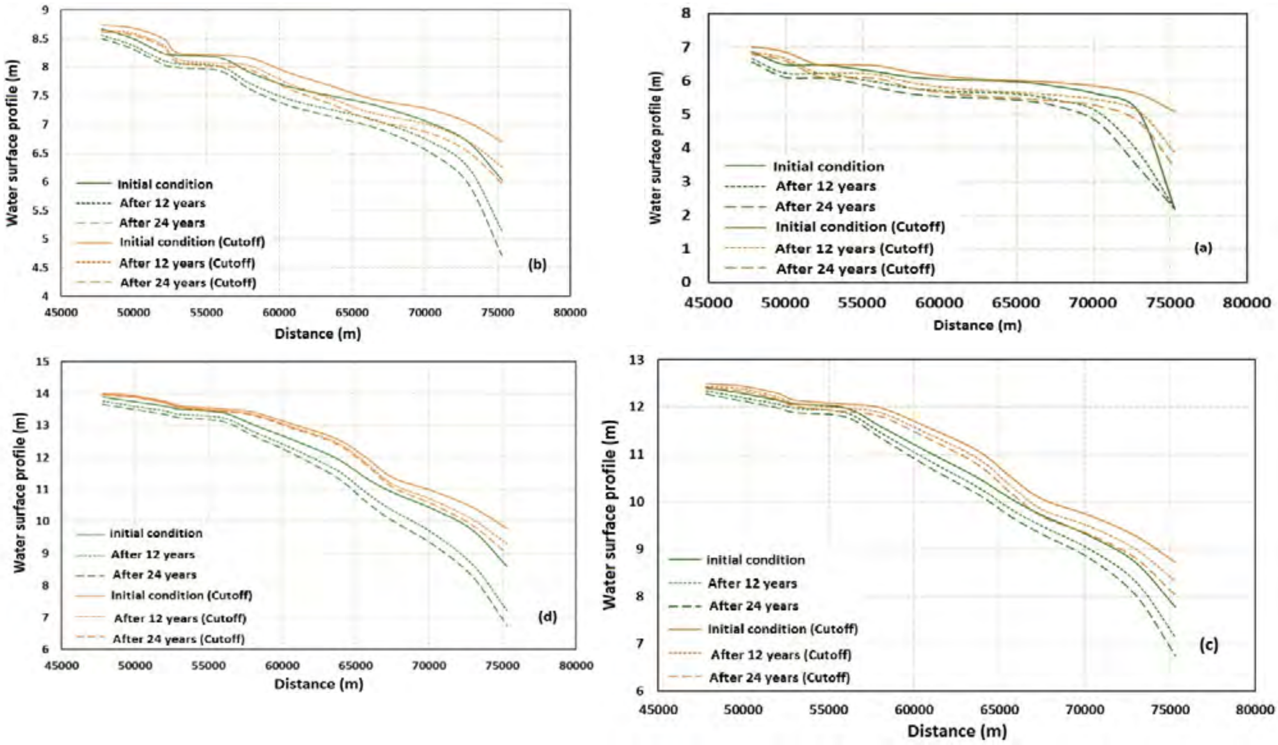

Figure 7: Display of water surface profile in downstream meander in discharges (A) 505 (B) 1001 C) 2490 D) 3486 cubic meters per second

Changes in river bed balance

In figures 7 and 8, changes in floor balance compared to primary conditions at 5, 10, 20 and 25 years periods is drawn, using both Ikers-White and Tofalti methods under conditions of before and after removing meander. According to these figures, apart from changes in floor profile on upstream and downstream boundary of the interval under study which is mainly derived from instability of boundary conditions, in the rest of the interval between 16 to 18 kilometers of the path that changes are considerable where floor profile changes occur, these changes are insignificant and less than 0.8 meters. In all models, in case of changing profile floor, this change occurs more during first 5 and or 10 years with more intensity and afterwards, changes are not significant. Analysis of figures shows that, during the modeling period from 5 to 25 years, the erosion or sedimentation trend at the sections or the sedimentation along the way is fixed over time. In figure 9, two sections with highest sedimentation are displayed.

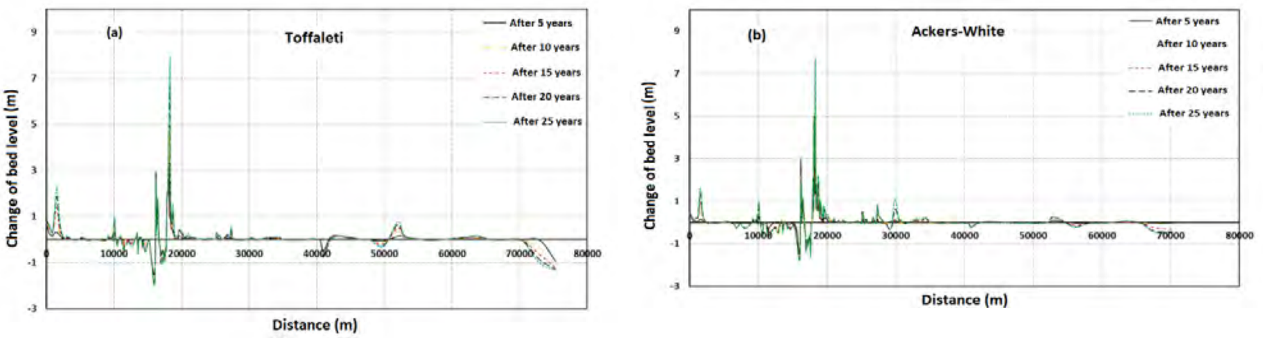

Figure 8: Changes in floor balance compared to primary conditions before removing meander using Tofalti and Ikerz-Whie method

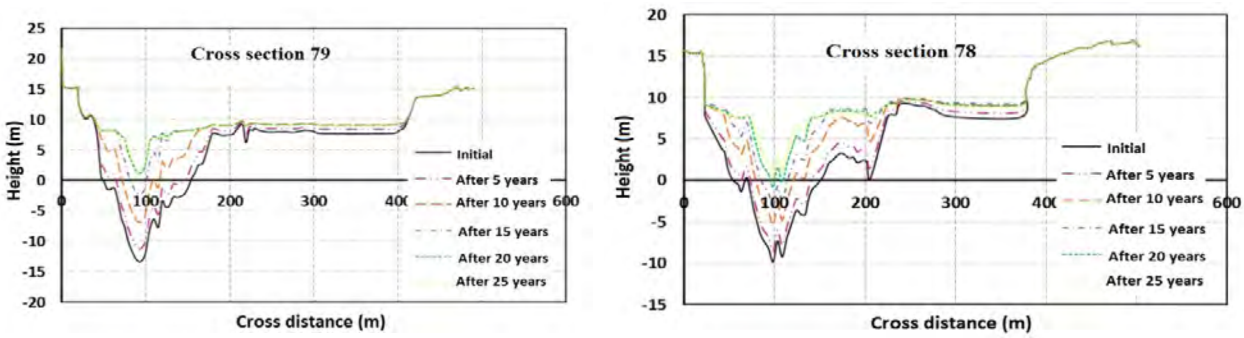

Figure 9: Display of two sections with highest sedimentation in the interval under study

Cumulative weight of sedimentation and erosion

In figure 10 and 11, the amount of sedimentation and erosion along the interval under study before and after removing meander after 5, 10, 20 and 25 years of modeling is displayed. The trend of capacity calculation (or weight) of sediments as the river length is divided between each section with distance and then the capacity or the weight of washed or unwashed sediments in the interval between the two sections is calculated. According to this figure, along the interval under study before and after removing meander, between 16 to 18 kilometers and also 35 to 40 kilometers the cumulative weight of erosion or sedimentation has the highest value. The amount of erosion or sedimentation in some intervals is high and their intensity increases over the time.

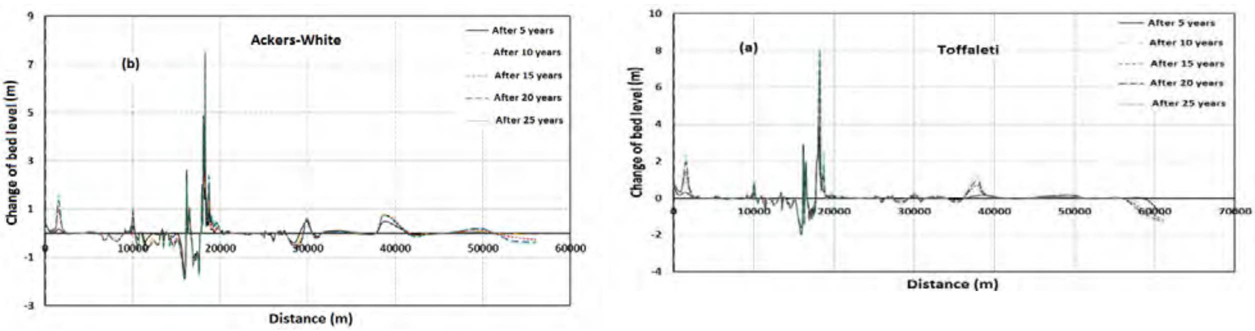

Figure 10: **Changes in cumulative weight of erosion or water wash before removing meander using Tofalti and Ikers-White method**

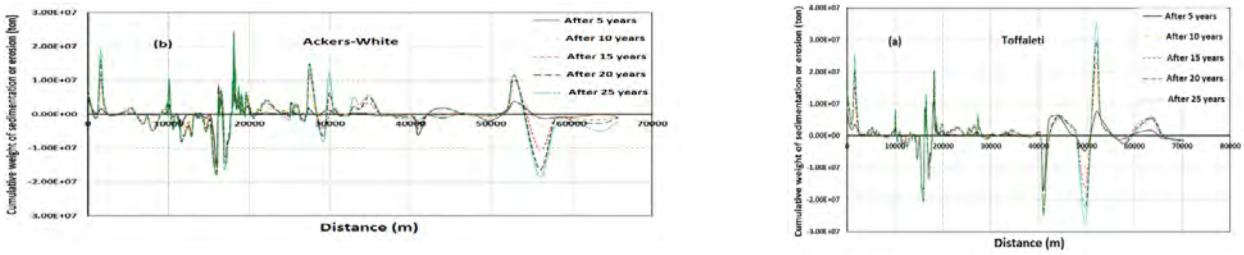

Figure 11: Changes in cumulative weight of erosion or water wash after removing meander using Tofalti and Ikers – White methods

In table 2, the cumulative weight of erosion or sedimentation along the interval during different years both Ikers – White and Tofalti methods before and after removing meander is represented. The results show that, generally, tofalti model before removing meander has the highest sedimentation and Ikers-White model after removing meander has the highest erosion and in these models, erosion or sedimentation increases.

Table 2: Cumulative weight of erosion or sedimentation along the interval after n years (*10^7)

n years after modelling						
Method	Conditions	5	10	15	20	25
Tofalti	Before removing meander	4.88	9.21	12.70	15.30	17
	After removing meander	4.43	8.09	11	13.30	14.80
Ikerz-White	Before removing meander	1.44	1.91	-1.83	-4.37	-5.96
	After removing meander	0.80	-1.71	-10.20	-15.60	-19

Changes of energy line boundary

Overall, in works of river engineering, since studies, plans and possible changes of river system in a small interval of the river is done, or in other words, the river is not managed in an integrated way, and in every research project energy line slope should not be changed. Because changes in energy line is the reason for erosion and beginning of river instability in another interval and we encounter a new problem. Thus, in this research, amounts of energy line slope of flow in both states before and after meander removal in figures 12 and 13 are respectively 505 and 3486 cubic meters per second using Tofalti relation for the sedimentation section are displayed.

Results show that for conditions before meander removal, energy line balance in the first 16 kilometer of the interval in the primary condition is higher than the energy line slope after a 12 and 24 years from modeling which is probably due to the rough floor balance in this interval.

Additionally, in downstream interval and near the downstream boundary between primary conditions and 12 and 24 modeling, there is a subtle difference which can be derived from boundary and subtle conditions in that part.

In figure 13, energy line balance of the interval under study after removing Ganjieh meander is displayed. According to these figures, the trend of energy balance line changes is the same as the trend before removing meander. In these figures also, except in low discharges that between energy line balance in primary condition and secondary condition in the first 16 kilometer is significantly different, in other conditions no significance can be seen in energy balance line.

Under these conditions, it can be said that energy line slope by removing Ganjieh meander in downstream Ahvaz does not change significantly and in case of conducting Karun River improvement, in the future will not have much effect on the morphology of the river.

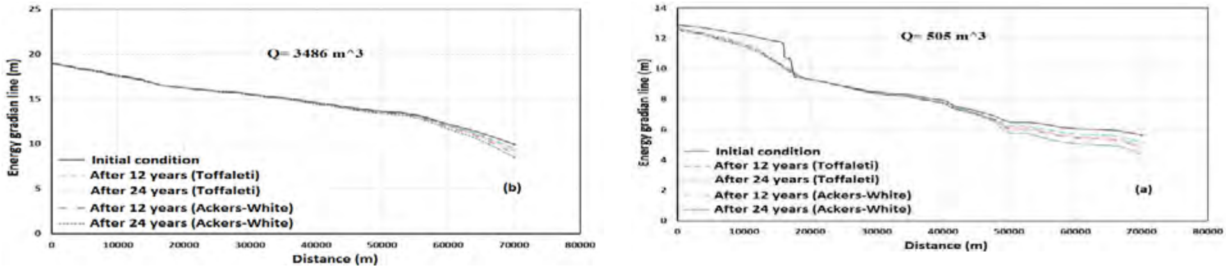

Figure 12: Changes in energy balance line before removing meander in low water and high water discharges

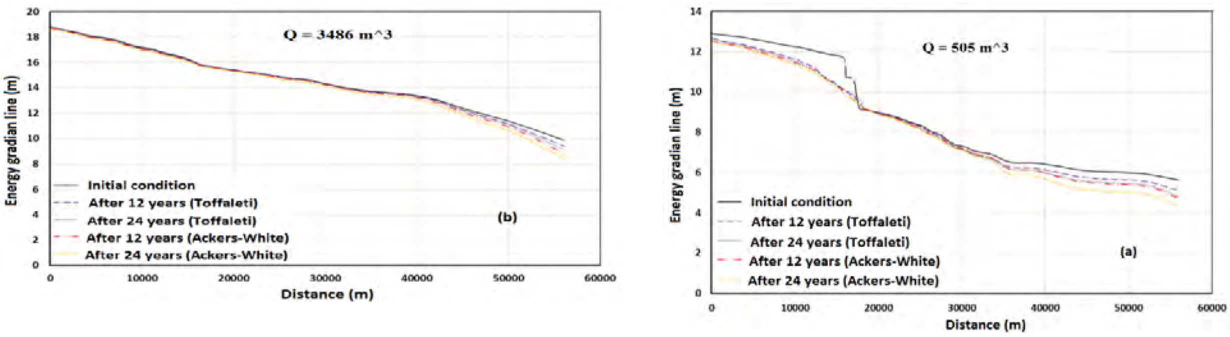

Figure 13: Changes in energy balance line after removing meander in low water and high water discharges

Conclusion

The present research was aimed at modeling the impact of removing meander of Ahvaz downstream Ganjieh on changes of erosion and sedimentation rate in Zargan-Farsiat interval (the range of upstream to downstream Ahvaz). The results of water surface profile shows that considerable decline of water surface balance especially in high water condition can be observed as a result of removing downstream Ahvaz meander around city which may be an efficient way to reduce flood balance. Changes in floor profile compared to primary conditions apart from changes in floor profile in upstream and downstream profile of the interval under study that is mostly derived from instability of boundary conditions, in the rest of interval except between 16 to 18 kilometers of the path with significant changes, where floor profile occurs, these changes is trivial and less than 0.8 meters. In all models, in case of floor profile change, this change mostly occurs in the first 5 and or 10 years more severely, so these changes are not significant. Also, during modeling period, from

5 to 25 years, the erosion or sedimentation trend in erosion or eroded sections over the path is almost stable over the time. Over all, along the interval under study before and after removing meander, between 16 to 18 kilometers and also 35 to 40 kilometers the cumulative weight of erosion or sedimentation have the highest value. The amount of erosion and sedimentation in some intervals are severe and their intensity increases over the modeling time. Findings also indicates that, generally, Tofalti, before removing meander, has the most sedimentation and Ikerz-White model after removing meander has the most erosion and over time erosion or sedimentation increases in these models. Also, change in energy line slope with Ganjieh meander remove in Ahvaz downstream does not experience considerable changes and in case of conducting Karun River improvement project, in future it will not significantly impact the river morphology.

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