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A study of the locus of the erosion and sedimentation in Sistan River using HEC-RAS model

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Abstract—Recognizing the flow and sediment situation as well as hydraulic parameters of the flow and sediments under different conditions is the basis for the analysis of the river behavior and decision making about the engineering measures affecting them. Accordingly, this study seeks to spot the areas exposed to sedimentation and erosion, and determine some of sedimentation parameters in Sistan River using HEC-RAS model, which is used to simulate the sedimentation. In this regard, an area of 47 km from Sistan River was studied. The model was first calibrated for the flow and sediment, and then it was used for the simulation the sediment. The transverse and longitudinal profile changes of the river, shear stress changes, sediment transport capacity and the mass of inflow and outflow sediment at different levels were examined. The results showed that of 88 sections, 42 were erodible and 46 were depositional. The maximum sedimentation was between Nyatak spillway and Zahak Dam, with the maximum erosion occurring in the flood gates of Zahak Dam. The erosion was especially significant in areas with large longitudinal slope and tight transverse sections, while sedimentation was more likely to happen in low longitudinal and wide transverse sections, particularly the structured parts.

Index Terms— Sistan River, Erosion, Sedimentation, HEC-RAS model

1. INTRODUCTION

A major problem in the management of rivers and streams is the issue of erosion and sedimentation. Each year, large amounts of sediment are deposited into the surface water transmission systems, which not only fill the dam reservoirs, but also impose stress to water resources management. A a normal behavior of the rivers, erosion and sedimentation destroy the fertile agricultural soil, posing irreparable damage to the water development projects. Variation in the relative balance between factors such as flow discharge, sediment load, slope and width of the river, which are the result of thousands of years of natural activity, lead to dynamic reaction of the river, inflicting significant damages on human settlements on the flood plains of these rivers[1].

Gibson et al (2010) tried to model COWLITZ River in HEC-RAS, taking into account the mobile riverbed. He did the modeling for the last 20 miles of river, because the flood risk caused by sedimentation was higher in that area. The aim of his study was to evaluate the long- term effects of sedimentation on flood risk [2].

Gill (1983) solved the expansive linear equation of the sedimentation and erosion process using Fourier series and error functions methods [3]. Lane (1987) proposed non-linear solutions for sedimentation and erosion, which were more adaptable with the experimental data [4] .

Chang et al (1996) presented the distribution and deposition mechanism in rivers and dam reservoirs using Fluviall2 the model [5]. Decsar al (2001) studied the effect of muddy water on the sedimentation process in reservoirs using an experimental model, along with the numerical solution of the stream by including thousand-year flood tank in Lausanne, Switzerland Alps[6]. Fox et al (2006) both explained the erosion mechanism caused by concentration changes in cross flow, and offered an empirical equation for sediment transport in unbalanced conditions [7]. Ravns (2007) compared the results of erosion and sedimentation data measured in a laboratory flume with the results of SEDFLUME8 model[8].

Hasan et al (2006) investigated the impact of the flood hydrograph on the river bed variation, concluding that the hydrograph shape had a significant impact on the river bed variation[9]. Siben (1999) studied the effects of sediment transport formulas and the thickness of the reference layer and critical stress on arming process of the riverbed in stable condition without any input sediment [10] .

Variation in the relative balance between factors such as flow discharge rate, sediment load, slope and width of the river, which were the result of thousands of years of natural activity, would undoubtedly lead to dynamic behavior of the river, causing damage to human settlements situated in river flood plains[1].

Goudarzi and Mousavi (1379) studied the erosion and sedimentation in the main branches of Zayande Roud using HEC-6 computer model, concluding that there was a significant correlation at the level of 95% between the degree of sedimentation estimated by HEC-6 program and the sampled values[11].

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Peyroo et al (2012) analyzed the river sediments in their study, finding that the inner edge of the river turns were a good place for extracting materials because the rivers were inclined toward the outer edge of the rivers at the turns, leaving their sediments in the inner edge. They also concluded that the extraction of sands and gravels would suspend the deposited material in the riverbed. This study drew on HEC-RAS mode[12].

Increased bed level due to improper exploitation of the Zahak Dam in its upstream during the years 1955 to 1991 added up to 2.5 m. If the mean geometrical section width was 130 meters, the volume of deposited sediments would be over 5.5 million cubic meters. The low riverbed gradient of Sistan River has made it susceptible to sedimentation; moreover, the detrimental effects of improper exploitation of Zahak Dam have aggravated this sedimentation in the upstream riverbed. The steady variations of bed profile from Zahak Dam to the point where the stream is branched at the end of upstream, shows that increased bed in the upstream of Kohak Dam has been influenced by the exploitation of the Zahak Dam[13].

Located on the tailwater of Helmand River basin, Sistan River receives huge amounts of sediments every year. The results of the frequency analysis of the data related to sedimentation measurement shows that the amount of sediments entering Sistan River is about 7 million tons per year. In flood with return cycles of 5, 10, 100 and 200 years, this figure is respectively 11.5, 14.5, 24 and 36 million tons. A large portion of these sediments are deposited across Sistan River, which results in the enlargement of bed level[14].

Zahak Dam has exposed an area of 5 km in the upstream to the sedimentation phenomenon, preventing the depth of erosion in the outer bends of the curve in this area. Moreover, the diversion dam of Zahak at the outset of the area has caused the outflow to expose the right bank of Sistan River to severe erosion, which is currently protected by a Gabiony wall. Sistan Dam has also intensified the sedimentation phenomenon in the upstream area, which is especially significant in the inner bends of the curves[15].

With variation in sediment transport capacity of the river, parameters such as slope and depth of the flow are also modified, including shear stress of the flow. Since the direct measurement of sediments deposited in reservoirs and rivers is practically difficult, not to mention the high cost and the lack of accuracy of experimental techniques, mathematical and computer-based models have gained popularity as useful instruments for this purpose.

HEC-RAS4.1 is one of such models developed by the U.S. Army Corps of Engineers, which in its latest version, can measure erosion and quality, besides its previous ability to analyze the deposition process.

Considering that this model is capable enough to hydraulically analyze the flow and sediments, this study draws on this model to simulate the river and analyze parameters such as shear stress, sediment transport capacity and the volume of inflow and outflow sediments along with determining the erodible and depositional areas.

2. Materials and Methods

2.1.Location of the study area

Sistan plain area is 15000 Km2 and locates in north of Sistan. Climate of region evaluated totally dry. Mean annual precipitation is 52.3 mm and in fully rain years this rate reaches to 120 mm rarely and in dry year there is no precipitation (such as 9 mm for water year 2001-2002). This little precipitation makes impossible any kind of dry farming. Even regional natural vegetations, seldom grow, if do not locate near ground water. In this condition only an external water resource could make alive region and Hirmand Trans Boundary River has such role. Totally could say environment of Sistan is very vulnerable and depends on Hirmand River [16]. Hirmand River is an evident example of a flow of Endorheism from an Endorheic region. After passing a distance of about 1100 km, The river is divided into two main branches of ParyanMoshtarek and Sistan at a place called Jarikeh bordering Iran and Afghanistan. As one of two main branches of the Hirmand River, Sistan River is the main source of water in Sistan which is responsible for 70 percent of irrigated farmland in Sistan plain. The general slope of the river is about 0.2- to 0.6-thousandt. Important structures such as channel feeder, Kohak dam, Zahak- Nyatak spillway, Zahak dam, Hedris canal, Sistan dam, Nohoorab Bridge and numerous irrigation channels, several villages and also the city of Zabol are located along the river, each of which has a significant impact on hydraulic process of the river. Sistan River is rare among the world's rivers because concentration of the suspended load of the river's flood flow varies mainly from 10 to 50 grams per liter. Low slope of the Sistan River's bed makes it prone to sedimentation; and on other hand, the negative effects of building Zahak and Kohak dams have sparked and increased the sedimentation. The particles forming the riverbed are very fine, and are mostly in the range of fine sand, clay and silt. The average diameter of particles forming the bed is about 0.02 mm [17]. Figure 1. shows an overview of the position of Sistan and Sistan River.

Review of aerial photographs and satellite images of Sistan River plan show that the meanders of Sistan River have a lot of changes due to the construction of longitudinal and transverse structures, erosion and other similar natural process, and have created several deltas in some cases. These changes also now continue with the relocation, increase or sometimes reduction of sandy islands. For the reasons mentioned above and therefore the reduction of water flow and increase of the amount of sedimentation in the riverbed, these natural and permanent changes have intensified the speed of these developments.

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2.2. HEC-RAS model

HEC-RAS program is the upgraded version of HEC-2, which is run by Windows. This integrated software package is one of the hydraulic analysis applications in which the user communicate with the system via a graphical user interface (GUI) . It has been designed to perform one-dimensional hydraulic calculations for a complete network of natural and synthetic channels. The sediment transport part of this model was introduced for one- dimensional simulation of sediments deposition, erosion and bed scouring as version 4 in 2006. It is able to analyze, calculate and distribute the water and sediment motions as well as other hydraulic parameters related the sediments in open channels. Another feature of this version

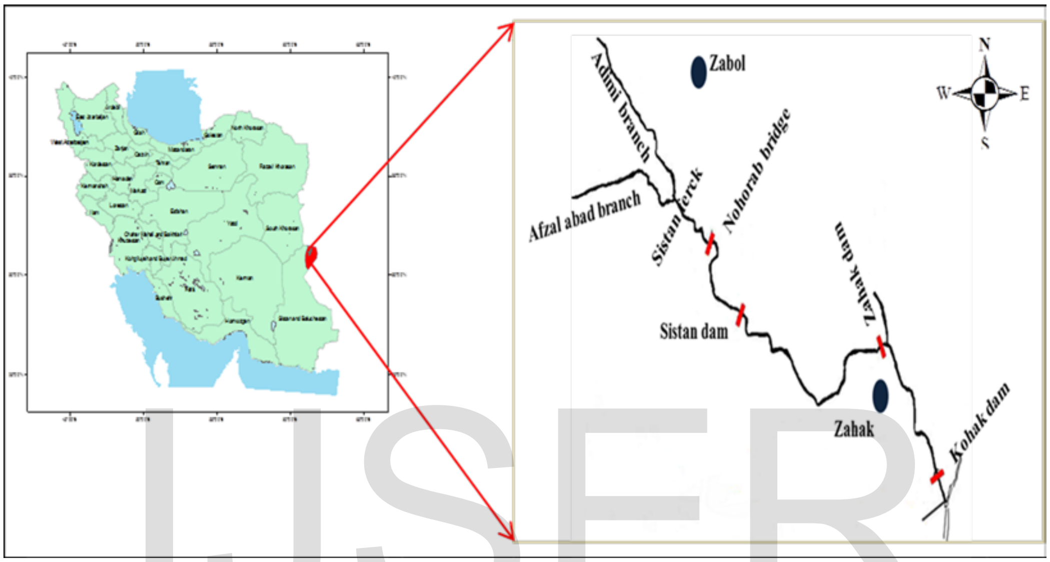

Fig.1.Position of sistan region and plan of sistan River

is the ability to separate sediment particles based on the bed load, suspended load and its related gradation in two classes, i.e. from tiny clay particles to boulders. The interface of this model has graphic design, in which the degradation and aggradation of the river is easily recognizable. [18].

2.3.Adding data to HEC-RAS model

The data are added to the model in three distinct stages:

2.3.1.Adding geometric data

The geometric data include connection information for waterway channel (schematic design of the channel system) transverse sections data as well as hydraulic structures data (dams, flood breakers and so on). The geometric data are generated by schematic design of Sistan River, an example of which has been shown in Fig. 2. In this paper, two branches of Hirmand River in Jarikeh along with two branches of Adimi-Afzalabad, which covers an area of 47 km, were studied and 88 transverse sections were added to the model.

2.3.2.Adding the flow data of the river to the model

After adding geometric data, the quasi unsteady flow data must be added to the model. The type of flow data depend on the kind of analysis desired. The current abilities of sedimentation in the HEC-RAS are based on quasi unsteady flow hydraulics. The quasi unsteady flow method estimates the flow hydrograph by a series of steady flow profiles corresponding to the flow time. To this purpose, flood hydrographs in the period between 2006 and 2007 were used in this study which has been shown in Fig. 3.

2.3.3.Adding sediment data to the model

To incorporate the data related to the grading of the river sediments, the results of sample riverbed experiments and the values of riverbed grading, which were carried out by the researcher, were used and the grading of riverbed

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for each transverse section was defined. Moreover, the coordinates of the mobile bed and the width of erosion area in all sections were defined for the model. The mobile bed is a part of the river in which there is a chance of erosion and sedimentation. Additionally, the depth of the riverbed sediments according to which the thickness of the erodible layers of a river are measured, was added to the model based on the field study. For the boundary conditions in this area, the sediment gauging curves of Kohak Hydrometric Stations, which is located at the outset of the area, was sued.

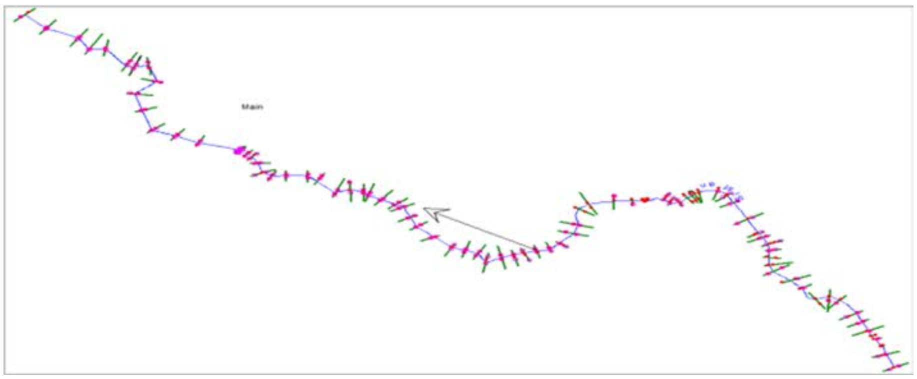

Fig.2. schematic design of Sistan River

2.4.Model calibration

2.4.1.Calibrating HEC-RAS hydraulic model

For the purpose of calibration, the water level calculated by the HEC-RAS model and the water level measured in Kohak Hydrometric Station 1989 was used. Finally, after trial and error, the manning coefficients were chosen in a way that the level difference in the simulated mode and current conditions was insignificant in the area.

2.4.2.Calibrating HEC-RAS sediment model

HEC-RAS software is able to model the flow containing sediment load through seven sediment transport equations and four methods of calculating the fall velocity. Thus, there are 28 different combinations that should be examined. Each of these sediment transport equations were compared with the natural conditions, and finally the equations that had most overlapping with the natural conditions of the area were chosen as best depositional equation.

3. Results and Discussion

In this study, a sample area of 47 km from Sistan River was studied. To do so, the geometric data, sedimentation and discharge rate of flow in 2006-2007 were studied. Accordingly, the geometric data related to 88 transverse sections were gathered and introduced to the model. Moreover, the grading curve related to 4 sections of the river, which has been carried out by the researcher, were also collected and incorporated into the model.

To calibrate the model, the flow discharge data of the intended station were collected, and the model was used in different discharge rates by changing the manning roughness coefficient. The output data related to the calculated water level were compared to the natural situation. Finally, the best manning roughness coefficient achieved for the main channel and flood plains were respectively 0.02 and 0.035. RMSE error was also equal to 13.24 cm, which indicates the high accuracy of calibration.

To calibrate the sedimentation model, 28 different combinations of sediment transport and fall velocity equations were analyzed in the software. The results showed that among sediment transport and fall velocity equations, Tofalti equation was most consistent with the natural conditions of the area.

After calibration of flow and sediment, the model was used to simulate the flow sedimentation. Then, the transverse and longitudinal profile variation of the river, shear stress variation, sediment transport capacity and the volume of outflow sediment were studied at different levels. The results have been shown in the following Figures and

Tables.

The longitudinal profile of Sistan River before and after the flood in 2006-2007 is shown in Fig.4.It shows significant changes in the longitudinal profile of the Sistan River after the flood, where of 88 sections, 42 sections were eroded and 46 sections were deposited by the sediments. The most sedimentation took place in the section 33659.83 of the river and maximum erosion occurred in the section 31728.27, as shown in Fig. 5 and Fig.6.

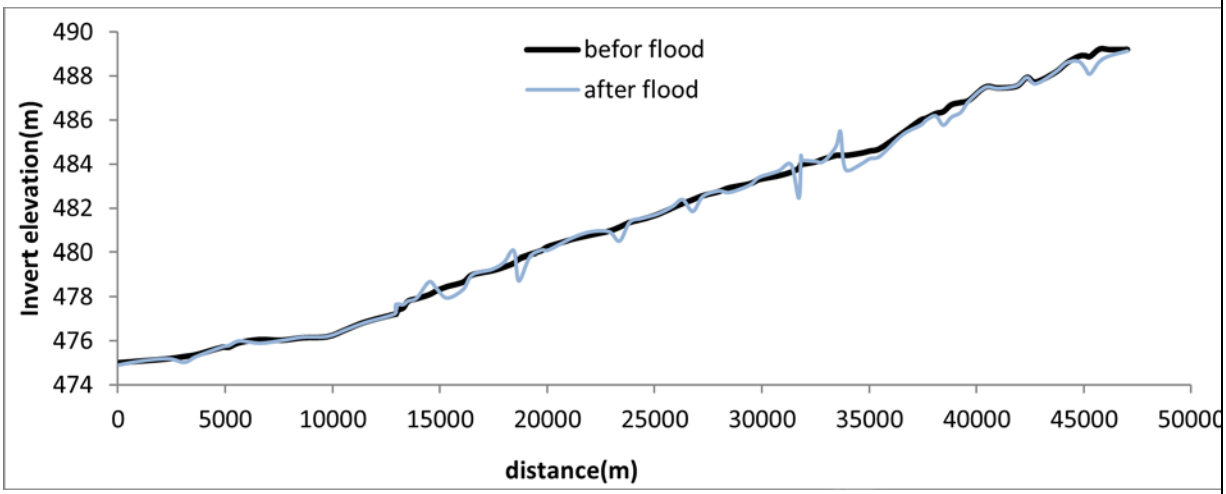

Fig.4. profile of Sistan River before and after the flood in 2006-2007

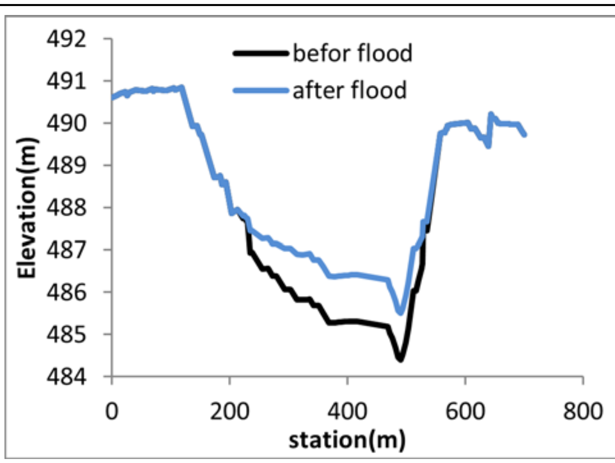

Fig.5.The most sedimentation took place in the section 33659.83

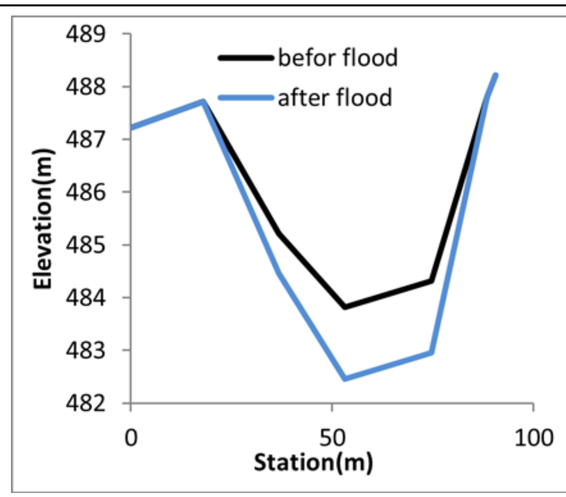

Fig.6. maximum erosion occurred in the section 31728.27

The erosion area, the mean slope of the area and maximum depth of the corrosion have been shown in Table 1. The results show that erosion was especially significant in the area with steep slope (0.00028-0.0008). The maximum depth of erosion in the studied area (31822.5 -31364.13) was observed at the section 31728.27 with a depth of 134 cm, which may be due to the steep slope (s =0.00079) and positioning of the area after the gates of Zahak Dam. In the area between 44208.7 and 47030.55, which has a mild slope, the erosion can be explained in terms of its positioning at the outset of the area, which gets steeper gradually. Furthermore, in the area between 5663.124 and8588.576, which despite its slight slope has been exposed to erosion, the reason could be its positioning after the bridge at the far end of the area, which prepare the grounds erosion.

The deposition areas, mean slope of the area and the maximum sediment height have been shown in Table 2. It indicates that the sedimentation has been especially significant in area with slight slope (0.00028 to 0.0015). The maximum sedimentation height in the area between (33113. 603 .33786. 52) at the section 33659 .8was 109 cm, which can be explained in terms of the slight slope of the river in this area (s =0.00015) and the existence of Zahak Dam. In the areas between (10627. 48 - 8588. 576) and (14845. 34 -12930. 51), which have steep slope, the sedimentation can be explained in terms of the structures built in the riverbed. Also, in the area (26309 –23845.24), which has steep slope, the deposition is due to the gentle slope at the end and a left-turning curve on the river path.

TABLE1. THE EROSION AREA THE MEAN SLOPE OF THE AREA AND MAXIMUM DEPTH OF THE CORROSION

EROSION AREA	MEAN SLOPE	MAXIMUM DEPTH OF THE CORROSION (CM)
4703055 - 42762.45	0.00035	80
40404.98 - 33786.52	0.00047	70
31822.5 - 31364.13	0.00079	134
29441.02 - 27994.98	0.00029	29
27256.13 - 26309	0.00038	54
23845.24 - 22891.75	0.00041	63
21223.63 - 18449.78	0.00039	95
16512.04 - 14845.34	0.00043	51

TABLE2. THE EROSION AREA THE MEAN SLOPE OF THE AREA AND MAXIMUM DEPTH OF THE CORROSION

DEPOSITION AREAS	MEAN SLOPE	THE MAXIMUM SEDIMENT HEIGHT(CM)
33786.52 - 31822.5	0.00015	109
31364.13 - 29441.02	0.00023	34
27994.98 - 27256.13	0.00025	3
26309 - 23845.24	0.00035	20
22891.75 - 21223.63	0.00022	16
18449.78 - 16512.04	0.00027	47
14845.34 - 12930.51	0.00056	57

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Despite the relatively high gradient in upstream of Sistan Dam, the sedimentation has occurred in an area of 2 km with the maximum height of 57 cm, which is due to the effects of the dam construction. Fig. 7. shows deposition in Sistan Dam upstream.
In an area of 2 km in the upstream of Zahak Dam, the slight slope of the area and the construction of dam have resulted in 109-cm high sedimentation, as shown in Fig. 8.

The cumulative weight of the sediments in the end of floodwaters has been shown in Fig. 9, which is in form of positive and negative values, where positive numbers show the weight of deposited sediments and negative numbers display the weight of transported or eroded sediments. The maximum mass of deposited sediment at the section 45740. 84was2956481.25tones.

The accumulative weight of inflow and outflow sediments in various sections at the end of floodwater have been shown in Fig. 10, which reveal the extent of erosion and sedimentation in different sections. The total outflow sediment of the river in the entire simulation was less than total outflow sedimentation at the end of simulation, with the difference adding up to10339558.53 tons, which shows the erodiblity of river.

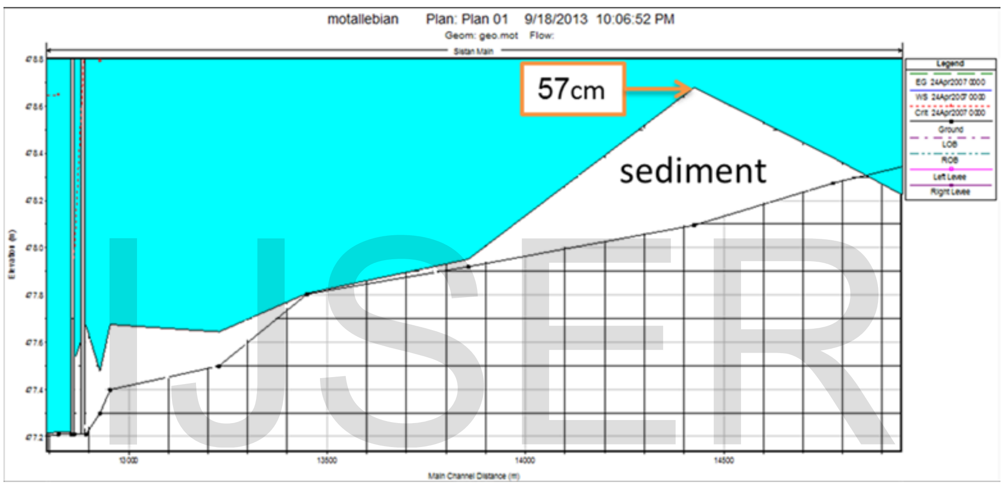

Fig.7. deposition in Sistan Dam upstream

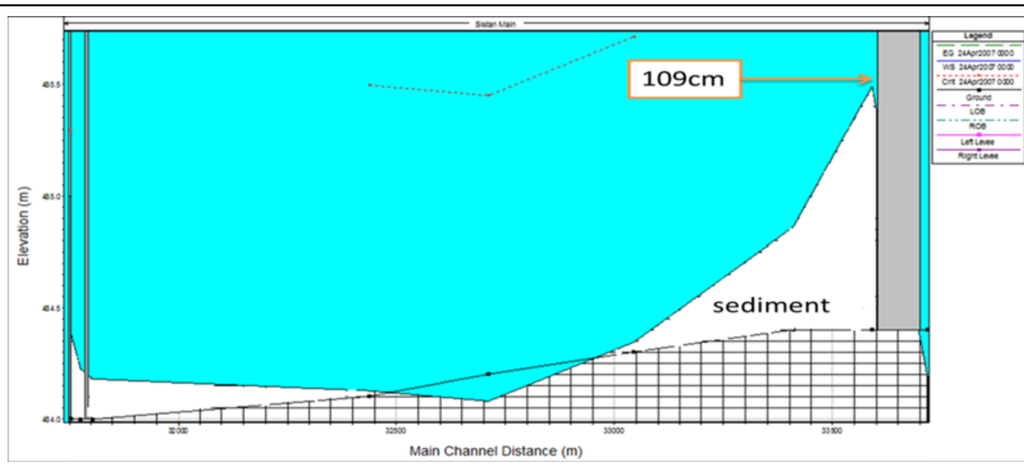

Fig.8. deposition in zahak Dam upstream

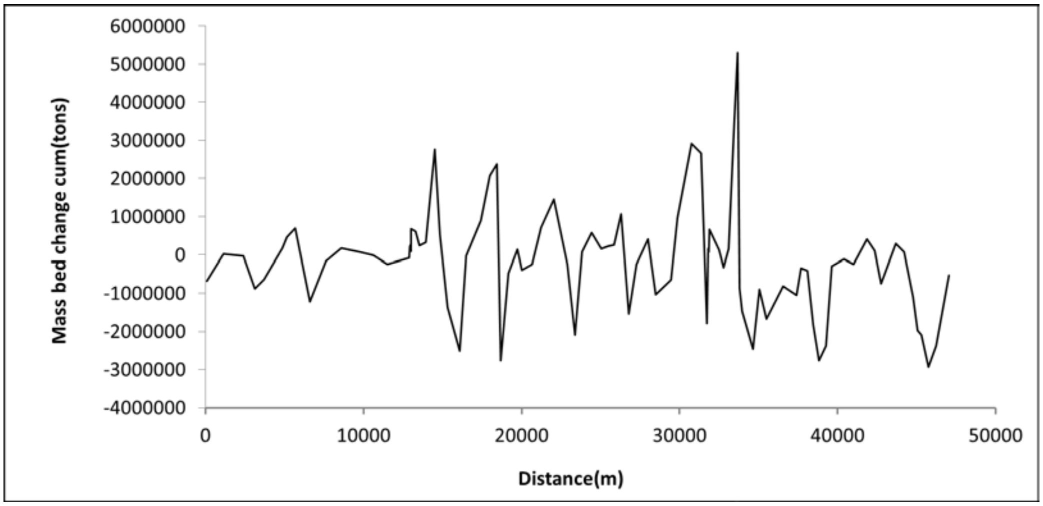

Fig.9. cumulative weight of the sediments in the end of floodwaters

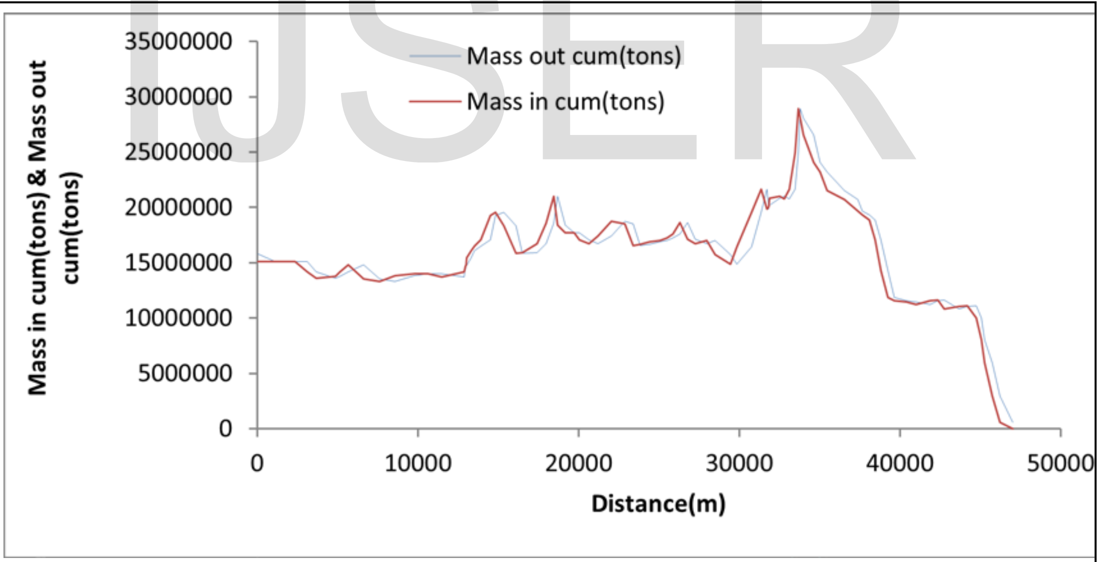

Fig.10. The accumulative weight of inflow and outflow sediments in various sections at the end of floodwater

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The shear stress variation in the peak discharge of flood hydrographic across the river in various sections has been shown in Fig. 11, in which the highest value of shear stress is equal to 8.36 Pa in the section 33975. 29.

In general, Sistan River can be divided into four areas in terms of the sedimentation:

1. erodible (from the beginning of the river to Nyatak spillway)
2. depositional (from Niatak flood breaker to Zahak Dam)
3. depositional and erodible (from Zahak Dam to Sistan Dam)
4. regime state (From Sistan Dam to the end of the area)

The mean longitudinal slope of these four sections were respectively 0.00036 , 0.00015 , 0.00035 and 0.00017.The longitudinal profiles of Sistan River along with the existing structures as well as sedimentation and erosion in different areas and above four areas have been shown in Fig. 12.

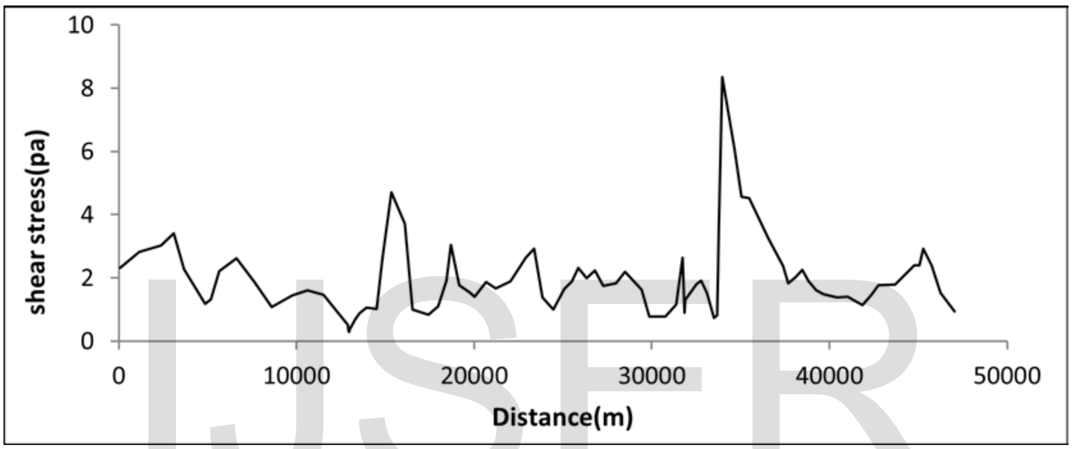

Fig.11. The shear stress variation in the peak discharge of flood hydrographic across the river in various sections

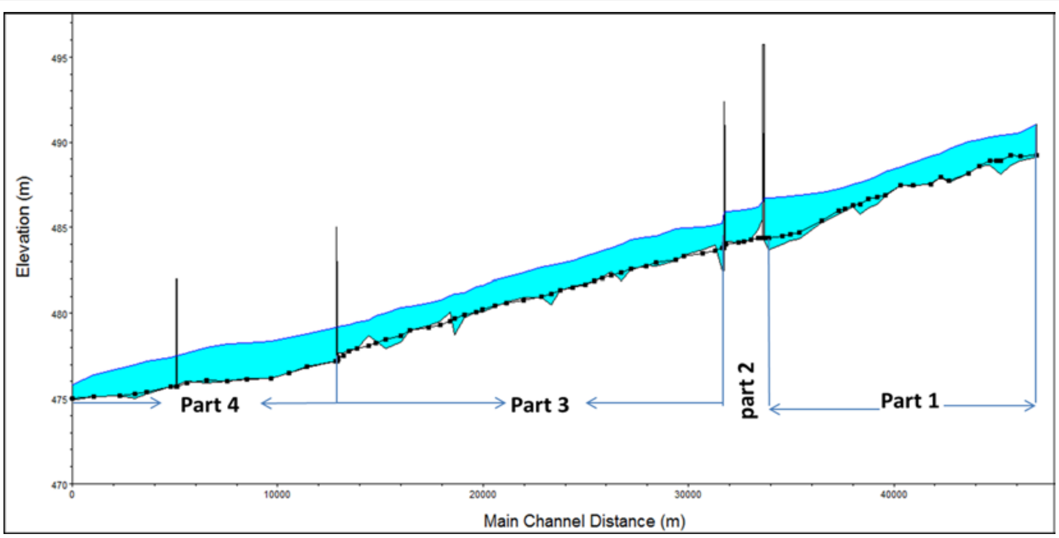

Fig.12.The longitudinal profiles of Sistan River along with the existing structures as well as sedimentation and erosion in different areas

4. Conclusion

In this study, an area of 47 km from the Sistan River was studied using geometric data and flow discharge rate in in years 2006 - 2007. The model was first calibrated for the flow and sediment, and then it was used for simulating flow sediment. The results showed that of 88 sections, 46 were erodible and 42 were depositional, with the highest sedimentation occurring in the area between Niatak Nyatak spillway and Zahak Dam at the section 83.33659 of the river, which was 109 cm. in height. The reason was the existence of Zahak Dam and the 0.00015 slope, which was the minimum gradient of the river.

The findings of this study regarding the effect of Zahak Dam on upstream deposition are in line with the results of Hassanpour (2008) and the report of Absaran Consulting Engineers Inc. (2008). The maximum erosion took place in the area next to the gates of Zahak Dam at the section 27.31728, which was 134 cm in depth. It could be explained in terms of the gates and 0.0008 slope, which was the maximum gradient of the river. In the upstream of Sistan Dam, despite the relatively steep slope, an area of 2 km has been exposed to deposition, which is due to the construction of the dam.

The findings of this study concerning the impact of Sistan Dam on sedimentation and erosion at the downstream of the Zahak Dam are compatible with the report of Absaran Consulting Engineers Inc. (2008). The results also suggest that erosion has been more significant in the areas with large longitudinal slope and tight transverse sections, while the sedimentation was more noticeable in the area with slight longitudinal slope and wide transverse section as well as structured parts.The total inflow of the sediments in the entire simulation was less than the total outflow sediment at the end of simulation, showing the erodibility of the river.

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