



## Sedimentology and Morphology Study of Sistan River

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### ABSTRACT

Sistan River is located on the southeast Sistan and separated from the Hirmand River on the border between Iran and Afghanistan and it is considered as the main source of water supply and preventing its displacement seems necessary in terms of damaging the installation constructed on the river, channels, waterways, connecting roads, farmlands, houses and villages. On the Sistan River, Kahak, Zahak and Sistan diversion dams divert water for irrigation. One of the most important reason for the morphologic change in the river is continuous sedimentation in terms of geology. Intense fluctuations in the river flow and soil type of the area directly affect this issue. After sampling and investigating the sediments, following results were obtained. The amount of sand decreases from upstream to downstream areas of the river and the amounts of silt and clay increase and this represents a low slope and low energy flow in the downstream area. In studying the charts of changes in median, average and sorting, the slope of the line is positive. The most important sedimentary structures in the bed and channel walls of Sistan River are (Graded bedding), (cross-bedding), (Ripple mark), (Mud Cracks) (Concretions), (Grazing traces), (Rill mark), (Swash mark), Sand wave). The facieses identified in the Sistan River are fine-grained clastic facieses. 1- FL facieses (mud, silt and sand with lamination); 2- Fm facieses (silt, mud pile) and structural elements of FF, SB and LA were observed and according to sedimentary facieses and structural elements identified in the channel of Sistan River and the sedimentary models presented by Miall, two models were presented: 1- Meandering river with sand load at the beginning of the river, 2- Meandering river with suspended load at the end of the river, the morphology of the Sistan River was studied. In total, Sistan River is known as a meandering river.

**Keywords:** Sedimentology, Sistan River, morphology, sedimentary facieses, fine-grained clastic facieses

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### INTRODUCTION

Water is the source of life and energy and also one of the important and vital resources. The rivers have been always used in order to meet human needs, for example in agriculture, transportation, energy generation, flood and pollution control and management and/or as borders and territories (Walter, 1988). The rivers play essential role both in the transport of sedimentary particle and erosion of older deposits and sedimentation in different sedimentary basins and so, they are very important factors changing the Earth's crust (Thorndycraft, 2008). Sistan River is the main source of water needed for agriculture in Zahak, Posht aab and Shib aab regions, in Zabol City. The river plays a significant role in development of farmlands, especially the lands on its banks.

The present study aimed to investigate the sedimentology and morphology of Sistan River, from Kohak Dam to where it bifurcates and the results were presented as a sedimentation model for the river.

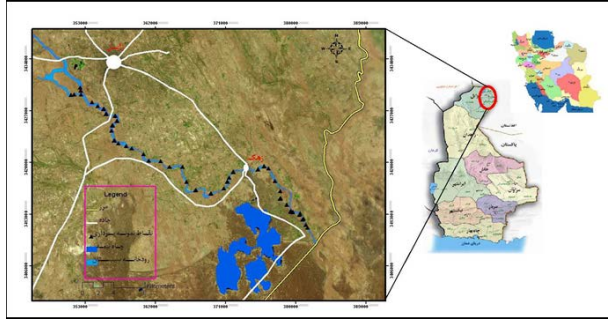
Case study is a part of Sistan area which is limited by international border between Iran and Afghanistan on the one

hand and Hirmand Plain on the other hand. It is located between 30°45' and 31°15' N and 61°15' and 61° 50' E.

In fact, the case study is the northern part and farthest end of Hirmand Delta located in the northern corner of Sistan and Baluchistan Province and, it was limited in the north and east, west and northwest by Afghanistan, Zahedan City, Birjand City and Loot Desert (Dasht-e Loot), respectively.

The area of Sistan sinkhole with east-west direction of about 500 km and a width of more than 300 m, is about 1814 hectares and just 737 hectares of it belongs to Iran and the remains belongs to Afghanistan (Consulting engineers, 2007).

The river has permanent water and its regime is snow-rain. Hirmand River bifurcates on the border between Iran and Afghanistan which are called Sistan River and Parian River. Sistan River flows towards Zabol City and is finally connected to Hirmand Plain. The length of river is about 70 km and its altitude at its beginning point in Iran is 492 m and its altitude at the lowest point of it is 474 m. In the course of it, Kohak, Zahak and Sistan diversion dams divert the river water for irrigation (Consulting engineers, 2007). Figure1 shows the case study.



**Figure1.** Location and roads access to the case study

## METHOD

The methodology of the present study was based on library studies and data collection, field studies (field explanation, sampling river sediments) and laboratory studies with the use of two descriptive and analytical parameters.

### Library studies and data collection

- Collection of domestic and foreign articles and relevant books on the studied topic which published in the world, Iran and Sistan
- Collection of reports related to Hirmand Basin archived in Sistan Water and Soil Development Company and these reports were provided in the form of flood control studies on Sistan River.
- Use of geology and topography maps of the region and the reports provided by Regional Water Organization and Meteorology Organization of Sistan and Baluchistan Province in order to study lithologic, structural, stratigraphic, climatic characteristics.
- Preparation of satellite images and aerial photographs of the case study.

### Field studies

Given that the present study aimed to investigate the sedimentology and morphology of the Sistan River, firstly, the case study was identified using topography and geology maps and then, initial visit was performed, the sampling station were determined, field observations were recorded and the samples were taken from the marked stations and GPS was used to determine the locations of samples.

### Laboratory studies (granulometry test)

In this stage, in order to do the granulometry test, the samples were transferred to the laboratory of "Beh Azma" company in Zahedan City and each sample was separately tested and in the next stage, according to the size of sieve, percentage of sample passing through the sieve and hydrometry, cumulative chart of each sample was plotted and finally, mode, median, mean, sorting and skew were determined for each sample and the charts were compared and also, sediments were named according to the table developed by Folk (1974) and sedimentary structures along the river course were identified.

## RESULTS

### Granulometry of sediments of Sistan River

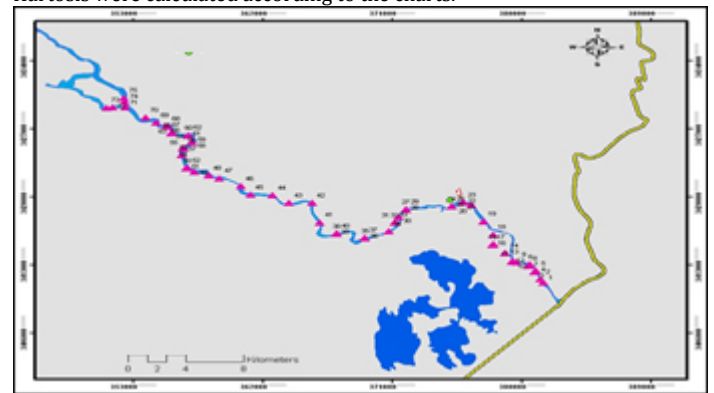
The particle is the best texture characteristic of the sediments and it is discussed in the analysis of clastic sediments (Nora, 2009).

In the present study, the wet sieving method and hydrometry were used to analyze the particle size. And in order to classify the particles of gravel, sand and mud and to calculate statistical parameters (median, mean, sorting, skew, etc.), the classification proposed by Folk (1974) was used.

In the present study with the objective of investigation of different parameters of sediments and analysis of them, after performing granulometry test in the laboratory in order to

determine the main features of sedimentology and texture parameters of particle size of river deposits sampled from the Sistan River and to identify the factors affecting sedimentation, particle size and their distribution in different point of the river were examined.

For this purpose, 75 samples were sampled along the river course and from the main channel and river bed and turns. Locations of the samples are shown in figure 2. The results of granulometry of the samples were plotted as cumulative curves and histograms. Then, different statistical parameters including average diameter of particles, median, sorting, skew and Kurtosis were calculated according to the charts.



**Figure2.** Location of sampling from Sistan River for granulometry

### Statistical parameters

The phi scale ( $\phi$ ) presented by Krumbein was considered to measure the particle diameter.

$$(Eq.1) \quad \phi = -\log_2 \frac{d}{2}$$

Where d is particle diameter in millimeter.

### Median

Median is the middle part of particles distribution curve and half of the particles are coarser than it and half of them are finer than it. Chart1 shows the median variation along the course of the river. The slope of the line is positive in it and indicates reduction in the particle size from upstream to downstream parts of the river. Along the main course of the river, the maximum value of median at the upstream point of the river is  $\phi=3.20$  and increases to  $\phi=4.06$  towards the downstream point.

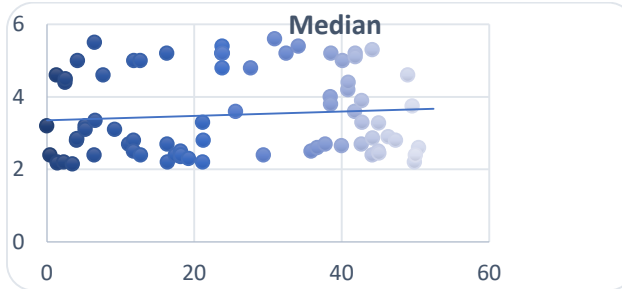


Chart 1. Median variation along the course of the Sistan River, the slope of the line is positive and indicates reduction in the particle size from upstream to downstream parts of the river.

Mean

Mean is the average size of the particles and represented by MZ and calculated by Eq.2.

$$(Eq.2) \quad MZ = \frac{\phi16+\phi50+\phi84}{3}$$

In the case study, variation trend of mean is increasing. The maximum value of mean at the upstream point of the river is  $\phi=3.33$  and increases to  $\phi=6.62$  towards the downstream point. So, the variation trend of median follows the variation trend of mean (Chart2).

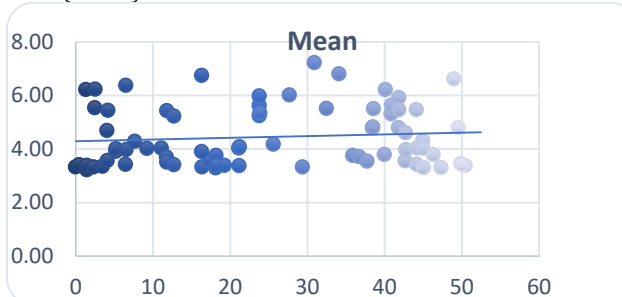


Chart 2. Mean variation along the course of the Sistan River, the slope of the line is positive and indicates reduction in the particle size from upstream to downstream parts of the river. Comprehensive standard deviation (sorting)

Comprehensive standard deviation is represented by  $\sigma I$  because it includes %90 of particles distribution and provides a more accurate sorting. It is calculated by Eq. 3.

$$(Eq.3) \quad \sigma I = \frac{\phi84-\phi16}{4} + \frac{\phi16-\phi5}{6/6}$$

As the value of  $\sigma I$  is close to zero, there is good sorting and vice versa. This means with the increase in the value of  $\sigma I$ , sorting decreases. Chart3 shows the variation of sorting along the course of the Sistan River, the slope of the line is almost positive and it indicates the bad sorting of sediments from the upstream to the downstream points of the river. The average sorting is  $\phi=1.64$  and it was descriptively bad sorting and this sorting is associated with the river flow type.

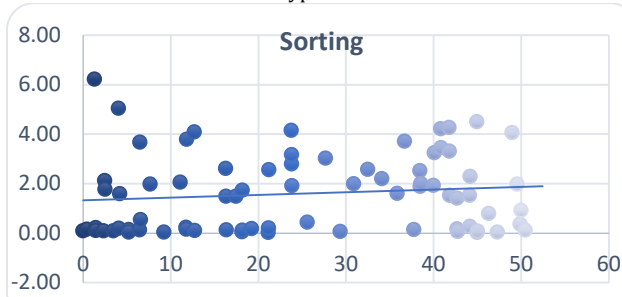


Chart3. Variation of sorting along the course of the Sistan River, the slope of the line is almost positive and indicates increase in sorting from upstream to downstream parts of the river.

Kurtosis or the sharpness of the peak of the distribution-frequency curves

Kurtosis is represented by Ku and it is the measurement of sharpness of the peak of the distribution-frequency curves and it is calculated by sorting of the curve tail to the sorting of the middle part of the curve ratio, as shown in eq.3.

$$(Eq.4) \quad KU = \frac{\phi95-\phi5}{2.44(\phi75-\phi25)}$$

Chart 4 shows the variation of Kurtosis along the course of the Sistan River, the slope of the line is constant and it indicates the very high kurtosis of the particles.

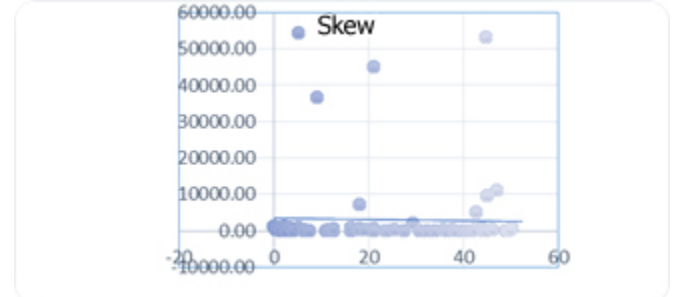


Chart4. Chart 4 shows the variation of Kurtosis along the course of the Sistan River, the slope of the line is constant and it indicates the very high kurtosis of the particle.

Skew

Skew shows the asymmetry of heterogeneity of the particle distribution curve which is determined by the tail of distribution curve (Mousavi Harami, 2010). In symmetric curves, the value of skew is zero but in the curves where the tail tends to right side or finer-grained sediments, skew value is positive and if the tail tends to left side of coarser-grained sediments, skew value is negative (Mousavi Harami, 2010). In order to calculate the skew, the equation proposed by Folk, is used.

$$(Eq.5) \quad SKI = \frac{\phi16+\phi84-2\phi50}{2(\phi84-\phi16)} + \frac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)}$$

Chart 5 shows the variation of skew along the course of the Sistan River, the slope of the line is negative and it indicates the reduction in skew due to the increase in muddy particles at the downstream point of the river.

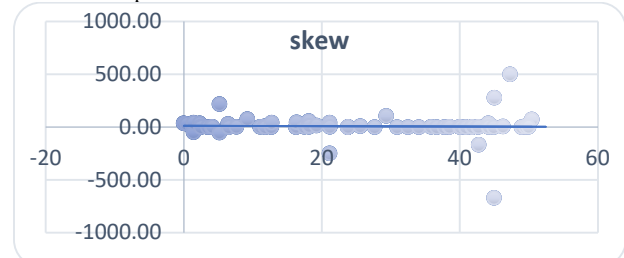


Chart5. The variation of skew along the course of the Sistan River, the slope of the line is negative and it indicates the reduction in skew due to the increase in muddy particles at the downstream point of the river.

Sedimentology of the Sistan River

Chart 6 shows the variation of weight percent of sand in the Sistan River. The variation trend is decreasing. In the river, weight percent of sand decreases from %90 at the upstream point to %57 at the downstream point which is due to the reduction in the river slope and reduction in the power of river flow in carrying coarse-grained particles.

Chart 7 shows the variation of weight percent of silt in the Sistan River. The variation trend is increasing. In the river, weight percent of silt increases from the upstream point to the downstream point which is due to the reduction in the river slope.

In total, according the charts of changes in the texture characteristics of the Sistan River, the variation trend for sand is decreasing, and for silt and clay, it is increasing.

The texture changes in the samples is from sand at the upstream point to sandy silt at the downstream point.

In the course of the river, from upstream to the downstream areas, the most abundant element is sand particles and this indicates the medium flow rate in the course of the Sistan River. So, since there are several dams constructed on the river, the increased percentage of mud is observed in the sediments at the downstream point of the river in spite of reduced slope of the main channel of the river. In the river, no large changes in the size and weight percent of sand are observed despite carrying fine-grained particles. Charts 1 and 2 show the changes in the parameters of mean and median in the course of the river. The trends of the changes are increasing. The maximum value of median at the upstream point of the river is  $\phi=3.20$  and increases to  $\phi=4.06$  towards the downstream point. The maximum value of mean at the upstream point of the river is  $\phi=3.33$  and increases to  $\phi=6.62$  towards the downstream point. Also, the variation trend of median follows the variation trend of mean.

In the Sistan River, the particle size of sediments is larger at the bottom of the channel and this is associated with the origin of the sediments and the slope of the main channel. The origin of the sediments in the Sistan River is soft sand. Reduction in the grain size along the course of the river can be due to the abrasion and collision of the grains and these result their fining. Also, reduction in flow rate which is discussed as hydraulic sorting and/or selective transport of particles, causes reduction in the grain size at the downstream point of the river (Noora, 2009). Along the course of the river, the average sorting is represented by  $\phi=1.64$  and it was descriptively bad sorting and this sorting is associated with the river flow type. The skew of the most samples is positive. in the most points of the river, the channel bed is covered by sand particles and this results in positive skew in sediments. The mean skew value for the samples of the Sistan River is  $\phi=38$  and this indicates that the tail of the curve tends to fine-grained particles. This can be associated with the type of flood flow so that the mud particles trapped in the sand particles cause the skew towards fine-grained particles.

According to the charts plotted for kurtosis, very thin (leptokurtic) to flat (platykurtic) curve can be observed. The kurtosis in relation with sorting is around the mean size of the particles on the curve. The mean value of the kurtosis was estimated according to the classification scale proposed by Folk (1974) which showed the curve with long tails.

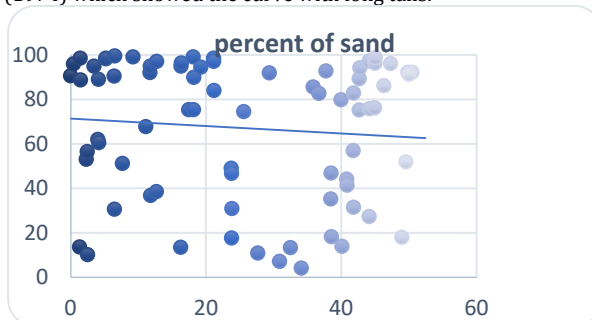


Chart 6. The variation of weight percent of sand along the course of the Sistan River, the slope of the line is negative and it indicates the reduction in the weight percent of sand from the upstream to the downstream points of the river.

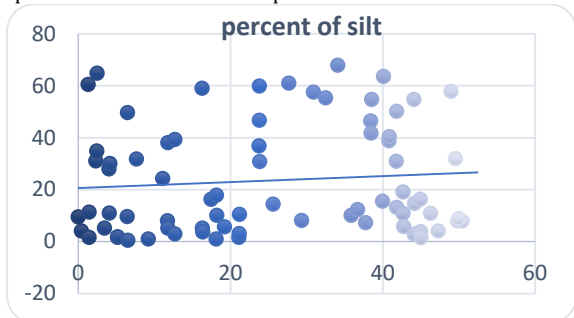


Chart 7. The variation of weight percent of silt along the course of the Sistan River, the slope of the line is positive and it indicates the increase in the weight percent of silt from the upstream to the downstream points of the river.

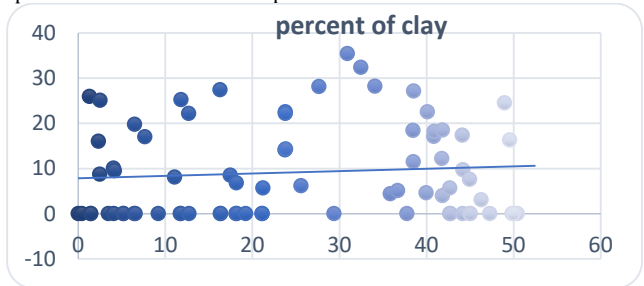


Chart 8. The variation of weight percent of clay along the course of the Sistan River, the slope of the line is positive and it indicates the increase in the weight percent of clay from the upstream to the downstream points of the river.

#### Sedimentary structures

Sedimentary structures are visible features within sedimentary rocks and in terms of size, they are larger than the components of the rock. The most important sedimentary structures existing in the bed and channel of the Sistan River are (Graded bedding), (cross-bedding), (Ripple mark), (Mud Cracks) (Concretions), (Grazing traces), (Rill mark), (Swash mark), (Sand wave).

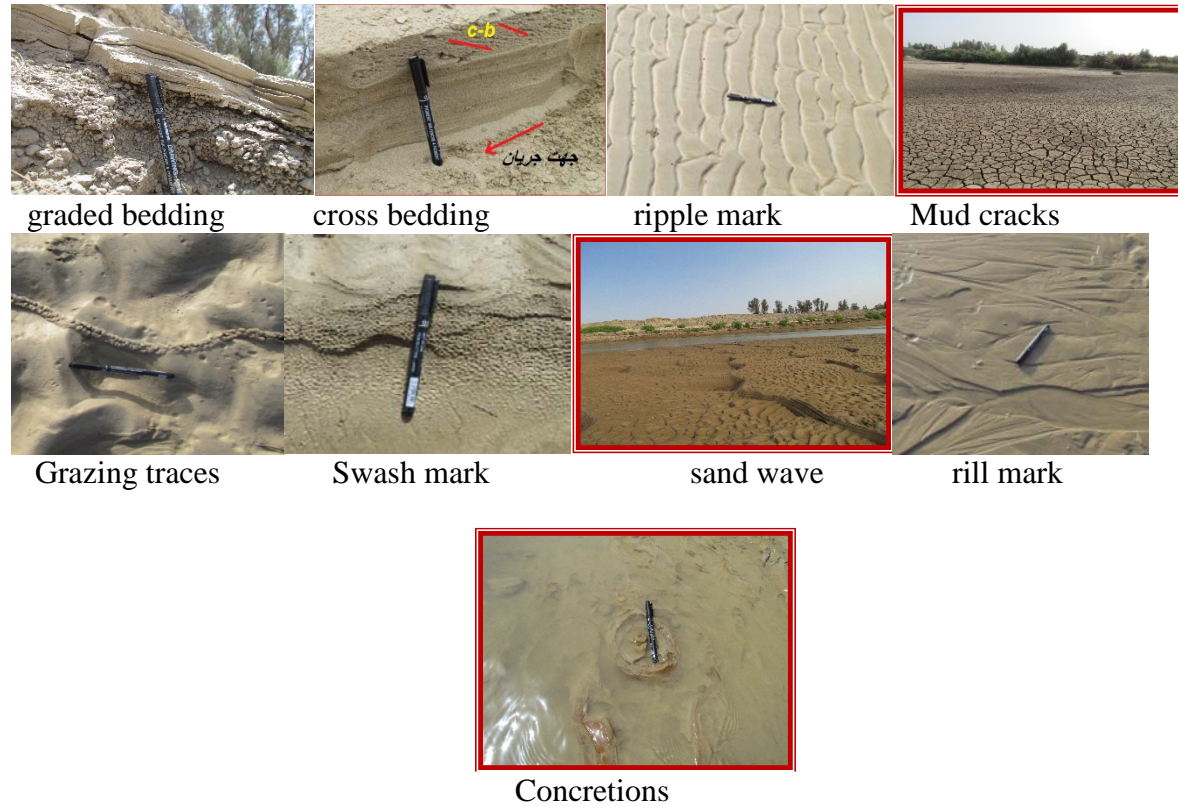


Figure3. Sedimentary structures existing in the bed and channel of the Sistan River

Rock facieses in the Sistan River

A rock facies is defines according to the distinguished lithological characteristics such as composition, particle size and sedimentary structures. The rock facieses identifies in the Sistan River are often muddy. Sandy facieses are observed sporadically. The fine-grained facieses identified in the Sistan River are as follows:

Sandy facieses

Sm facieses (sand with mass bedding)

It is formed by sand-size particles and without layering and sedimentary structure and in mass mode.

St facieses (sand with trough cross bedding)

It is formed by single or grouped trough cross bedding of fine to coarse sand and it is often formed as the result of migration or sedimentation of ripple mark and 3-D mega ripple with sinusoidal ridge (Therrien, 2006 and Ghosh, 2006).

Sp facieses (sand with flat cross bedding)

It is formed as the result of 2D movement of Mega ripple with direct ridge (Therrien, 2006 and Ghosh, 2006). The grain size changes from fine to coarse sand. The minimum thickness of such a facies is about 5 cm and average thickness changes from 0.5 to 1.5 cm.

Mud facieses

Fl rock facieses (mud and laminated silt)

In term of texture characteristics, the silt and clay-sized particles form this type of facieses and the amount of silt is relatively more abundant. Flat and cross laminations and ripple mark are the most important sedimentary structures of these facieses and they are often silt-sized particles in mud-rock facieses.

Structural elements

After identifying rock facieses, the structural elements are determined. Given the identified rock facieses, the structural

elements formed in the main channel of the Sistan River are examined as follows:

The element of channel (CH)

The geometry of the channel is determined by depth, width to depth ratio and sinuosity of the channel. Its upper and lower parts are erosional. Along the Sistan River, the river channel is wide and its sedimentary load is sand, and the percentage of silt and mud increase at the downstream point (Figure4). CH element geometry in the Sistan River is plate-shaped and its rock facieses are Fm and FL.

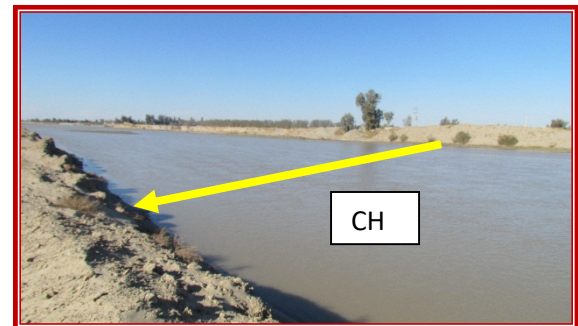


Figure4. A view of the main channel of the Sistan River Structural element of sediments with lateral growth

It is the most important structural element in the meandering rivers (Figure 5). Lateral channel movement causes erosion in the concave part and sedimentation in the convex part at the point of turns in the river (Roberts, 2007). Migration of sediments occurs in a way in which coarser sediments are

placed on finer-grained sediments and the move downstream (Mial, 1996). Its rock facieses are St and S m facieses.

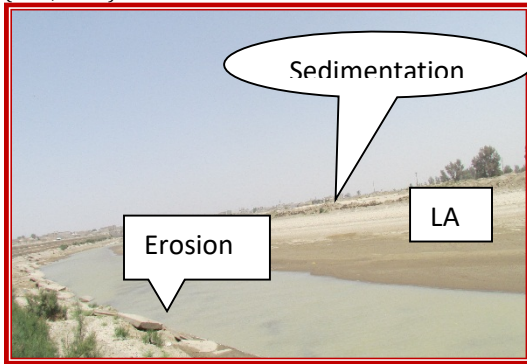


Figure5. structural element of sediments with lateral growth LA along the river

Structural element of sand with layered forms (SB)  
 Structural element of SB is observed in a layered and wide form and it mainly composed of sand facieses. This element is of the specific feature of deeper area of the channels where the sand is more abundant. Sp and Sm can be referred as its rock facieses.  
 Structural elements of fine-grained sediments (FF)  
 This element is deposited in a relatively stable and low-energy environments such as flood plains and abandoned channels and in a sheeted form and it can have vegetation on its surface (Mial, 1996; Coltortia et al., 2008). FL and Fm can be noted as its facieses.

Table1. A summary of types of rock facieses identified in the Sistan River based on the classification proposed by Mial (1996)

Facies group	Code of rock facieses	Sedimentary structure	Description
Sandy	St	Trough cross bedding	3D mega ripple with complex and lunate ridge
	Sh	Horizontal lamination	Intermediate flow
	Sp	Flat cross bedding	2D mega ripple with transverse and lunate ridge
	Sm	Mass bedding	Flow deposits
muddy	FL	Very thin lamination along with small ripple	Sediments outside the channel
	Fm	Mass bedding containing plant roots and biological chaos	Channel sediments

Sedimentary model

Based on sedimentary facieses and structural elements identified in the main channel of the Sistan River, the

sedimentary model of the Sistan River which is the main waterway, was studied according to the models presented by Mial (1996) and it is as follows (figure6).

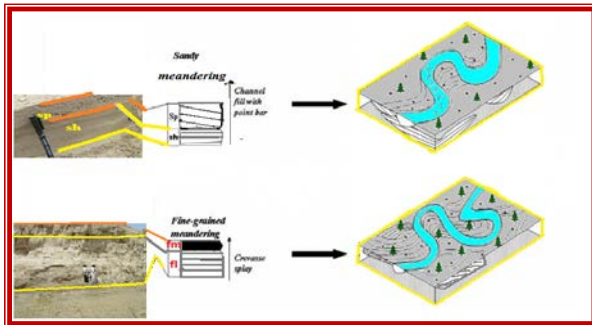


Figure6. Sedimentary model of the Sistan River according to the models presented by Mial (1996)

Meandering river with sand load  
 The larger part of the Sistan River length is related to this type of river. The sediments filling the channel are often sand and this type of river has many turns and it is considered as the rivers low energy (Mial, 1996). Sm and sp can be mentioned as its sedimentary facieses. LA and SB can be referred as the structural elements forming these rivers.  
 Meandering river with suspended load

In the Sistan River, this type of river is formed at the downstream area and end of the basin. It has sand and mud-sized sedimentary load. It has relatively high sinuosity and its lower contact is eroded. Downstream fining of the particles can be studies in this part of the river and this suggests the high suspended load of the river and it the specific feature of low-energy environment. Sm, FL and Fm can be mentioned as its facieses (Mial, 1996) and LA and FF can be mentioned as its structural elements.

Table2. A summary of different sedimentary models identified in the Sistan Rive according to the classification proposed by Mial (1996)

Type of river	sinuosity	Amount of energy carrying the sediments	Type of sediments	Type of facies	Structural elements
Meandering river with sand load	High	Low	Sand and small amount of fine-grained sediments	Sp·sm	LA·SB
Meandering river with suspended load	high	Low	Fine-grained sand, silt and mud	Sp·FL·FF	Ff·LA

### CONCLUSION

Sistan River with a length of 70 km is the main waterway in the Sistan hydrological unit and it is considered as the most important river in the region and it is the main source of water supply in Sistan. According to the results, it is concluded that the amount of sand decreased and the amounts of silt and clay increased from the upstream to the downstream areas. This suggests the low slope and low energy at the downstream points.

The results show that erosion and sedimentation, more than other factors, geologically affect the morphology of the different parts of the Sistan River. Because soft fine-grained sediments which have no adhesion and are eroded between fine-grained layers of silt and clay, help the erosion of river bed. The hydraulic structures constructed on the river affect its morphology and increase the erosion in a part and increase accumulation of sediments in the other part of the river. Due to the morphology of the Sistan River, side erosion and meanders phenomenon frequently occurs along the river when annual inundations take place. In order to prevent the change in the morphology of the Sistan River, the control of soft sediments and barchans of the regions is very effective. Also, the erosion can be minimized by creating green belt in the region as live windbreaks and the barriers perpendicular to wind direction. Establishing such wind breaks along the installations and in the limitation of water channels can be effective and also it is needed to take the measures in order to prevent flooding and to stop it regularly by building appropriate reservoir structures.

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