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The role of soil engineering in producing bank erosion and morphological changes of Sistan River

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ABSTRACT

A river changes its cross section, longitudinal profile, flow period, and pattern for several times, by means of scouring, sediment transport and deposition processes. For stabilization of the cultural and economical development of the adjacent areas to the river, it is essential to understand these processes. The Sistan River has undergone many morphological changes since 1956 to this date; and these changes have tremendous economical, political, and social impacts. Every year, by loss of the lands around the river, numerous damages imposed on the farmers and the environment of the region. In this study, the relocation of the Sistan River's plan (since 1956 to this date) has been evaluated and analyzed. This was done using river edge sampling, sedimentological and geotechnical tests, and erodibility status of the edge along their reasons, by emphasis on soil engineering properties of the banks of the river in producing bank erosion. Evaluations show that incoherence, absence of drained shear strength, low aggregate levels, and weakness of the edge sediments (which are due to their newness, human interventions, natural harsh, and ignoring the measures necessary to prevent erosion of the river edge) have resulted in riverbank erosion and progression of the water current to the river concaves. Finally, to control river edge erosions and prevention of the river progression, possible solutions proposed based on local conditions.

Keywords: Sistan River, Bank erosion, Morphology, Soil

INTRODUCTION

In the past one hundred years or so, great progress has been made in river geomorphology. River morphology, focusing on meander and braided river, has been one of the most important parts in river geomorphology [1]. Rivers are considered the main arteries of human life, whose optimal use it is avoidable to make scientific planning for the preservation of these structures because of the importance that natural resources have long had to meet human needs and also because of agricultural lands near the river banks.

The phenomenon of bank erosion is one of the factors to which a special attention is paid both in morphology and life of this artery and in agriculture. Riverbank erosion has a significant role in producing river sediments and affecting the characteristics of river channels, development of flood zone and management of water resources. Riverbank erosion causes the loss of fertile agricultural lands and buildings adjacent to the river, and each year causes a lot of material damage in different parts of the world.

Due to climatic, hydrological, and geological conditions as well as the inappropriate use of land basins, rivers of Iran carry a higher sediment rate compared to those in the world [2]. The eroded sediments are transferred along with the flows of water in downstream areas; and finally after settling in reservoirs of dams, it causes a reduction in the

useful volume of dam reservoirs and damage to hydroelectric power plants. They may accumulate in the place of diversion dams and block the vents of irrigation networks. In addition, the accumulation of eroded sediments in the riverbed cause the creation of barrier islands, increase in water level of river, and changes in the geometry of river, and outflow of water in the floodplain region. After distribution of water flow and accumulation of sediment load on the floodplain, natural embankments are formed. In this case, river becomes wide and shallow, with a rapidly changing morphology; and some meanders in river will be created. So, we will be able to lessen the harmful effects of river systems with a proper understanding of the hydrological, hydraulic, geological and geomorphological changes in a river. Hence, many studies have been conducted in the various river basins in this regard, among which Yamani et. al. (2012), Comiti et al (2011), Nagy et al (2010), Mousavi et al (2010), Talaat et al (2009), Parker et al (2008), Shrestha and Tamrakar (2007), Ghobadian and Shafaei Bajestan (2007), Schumm et al (1984) and Simons (1971) can be noted [3-12]. The purpose of this study is to examine the role of mechanical properties of the soil in the creation of bank erosion and morphological changes of Sistan River located in Sistan Plain in two intervals since 1956 in 6 locations between Kohak dam and Hirmand's Hamoon Lake.

Location of the study area:

Sistan plain area is 15000 Km^2 and locates in north of Sistan and Baloochestan province of Iran and has 2 cities, 6 parts, 6 townships and 937 villages. Its population estimated about 420000 persons in 2008 which half of them work in agricultural and domesticated fields. 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 [13].

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 Paryan Moshtarek 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-Niatak flood barrier, 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 [14]. Figure 1 shows an overview of the position of Sistan and Sistan River.

Review of aerial photographs and satellite images of Sistan River plan in two intervals since 1956 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.

MATERIALS AND METHODS

Movement of rivers causes erosion of bed and banks. Since river is one of the components of water resources, it is essential to understand the behavior of rivers in different environments, optimum conservation and use of them, as well as protection of their bed and privacy. In this study, we prepared a morphological map of the river from 1956 to present, after information gathering and review of aerial photographs and satellite images of the region with the help of GIS. After field visits of the river's bends at different intervals, the soils of some river bends at all intervals (from Kohak dam to Hirmand's Hamoon Lake) was sampled; and Undrained soil shear strength was calculated as in situ with DCP (Dynamic Cone Penetration). Then, the role of mechanical properties of the soil in the process of creating bank erosion and morphological changes of Sistan River was examined on the basis of the field data and laboratory analyses.

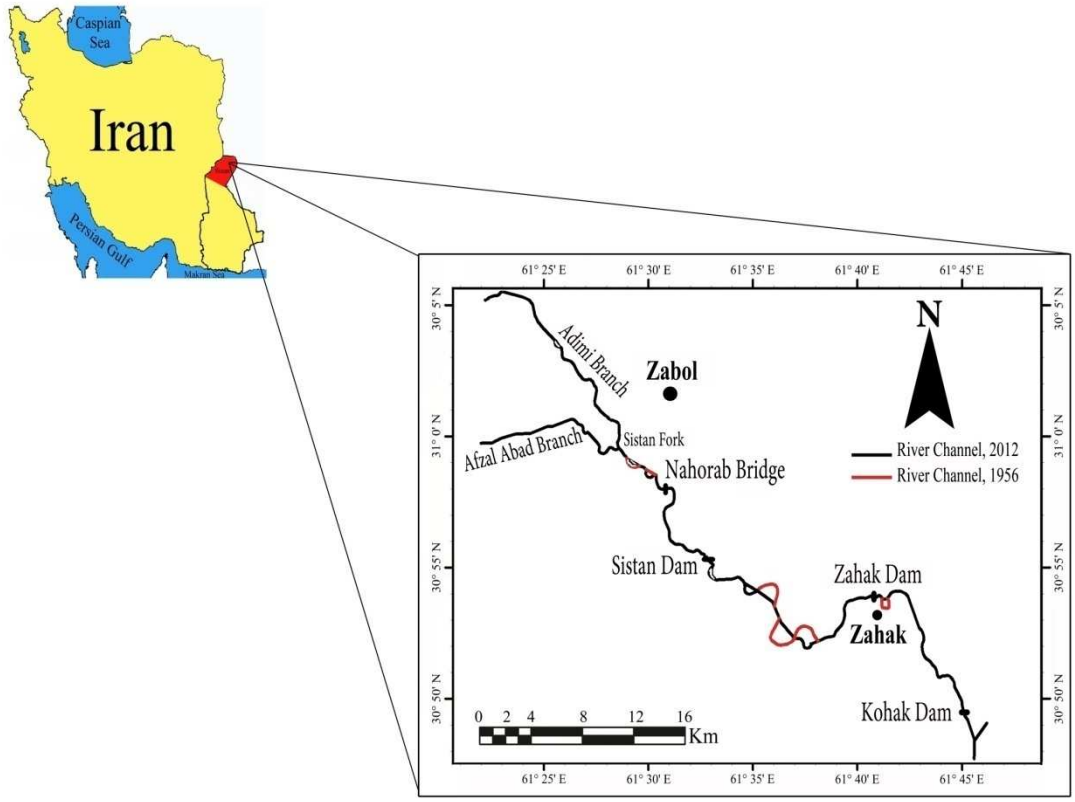

Fig 1: Position of Sistan region and plan of Sistan River

RESULTS AND DISCUSSION

Mechanism of riverbank erosion and the factors affecting it

In morphological studies, identifying the materials of the bed, riverbank and the bank along the course of river has a significant important role in predicting the future status of rivers [15].

Mechanical and physical properties and materials of bank, biological factors and human interference, chemical factors and hydraulic factors are among the main causes of erosion of riverbanks.

Darby (1988) divided the mechanisms of failure of the riverbank into three cases: rotary failure, planar failure and cantilever failure [16]. Due to the difference between the mechanisms of bank failure, a separate analysis is required for each of these mechanisms. Mechanisms of planar failure, rotary failure, and cantilever failure are shown In Figure 2.

Failure mechanisms in the walls not only depend on the type and severity of erosion, but they also are dependent on the wall size, shape and structure as well as the mechanical properties of its ingredients. A glance at the field observations made by different researchers in most rivers indicates high rates of bank erosion as a result of erosion in the form of planar failure [17]. Any type of mass erosion causes rapid widening of the channel and the arrival of large volumes of sediments into channel; and on this basis, it is considered an important factor in the management of water resources. After passing the flood, the mass erosion of the riverbank of planar type generally occurs during the fall of the water level as the result of the following factors [18]:

1- Removing the hydrostatic force resulting from the depth of flood water in the channel
2- Time delay between the fall of water level of the channel and underground water level and generation of substantial uplift force
3- Reduction of the suction force or negative pore water pressure and apparent cohesion as a result of penetration of rainwater or groundwater seepage.

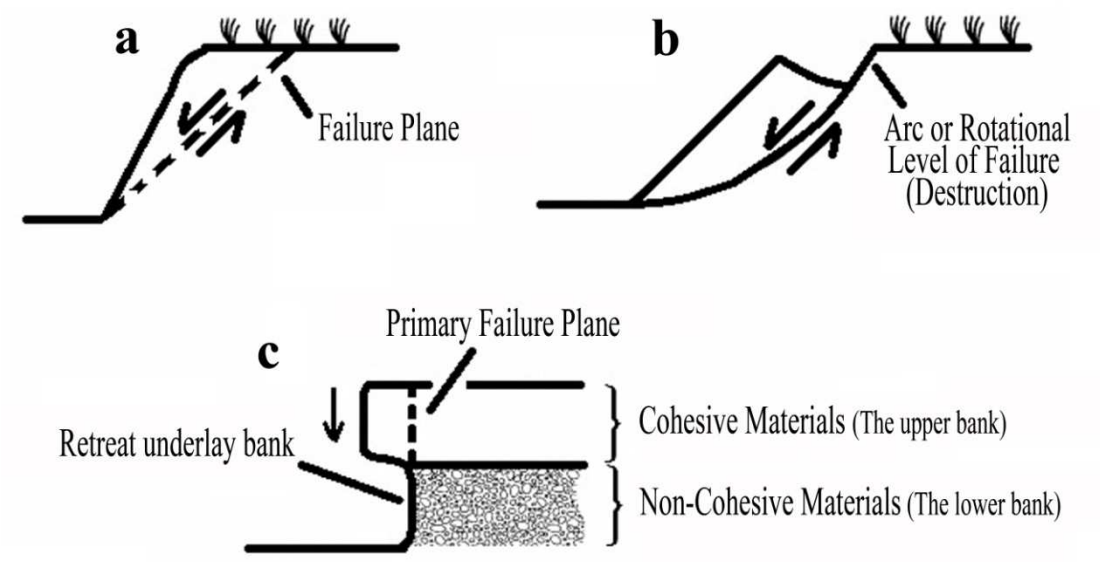

Fig 2: Mechanisms of bank failure: (a) planar failure (b) rotary failure (c) cantilever failure [16]

Under conditions that the height and slope angle of the bank reach a critical level due to erosion of material from the channel floor and bank walls, failure occurs along a nearly planar level. In addition to the role of river flow on bank erosion, failure fragmentation may be created on the bank as a result of changes in geotechnical characteristics of the materials forming the bank. For example, loss of adhesion between soil particles resulting from the formation of dew and/or the occurrence of positive pore pressures, which is followed by a sudden drop in water level of the river, can accelerate the failure of the bank. Development of tensile cracks is also important in speeding the failure of banks as above [19].

Role of mechanical properties of the soil in the process of bank erosion of Sistan River

Soil is an important natural source and perhaps the most important foundation of civilization in any country. Progress or regression in each society is determined by the ways to use the soil; and according to some, the value of soil becomes apparent when it is put at risk as freedom [20]. Sistan region's soils, which are mostly as fine-textured sediments and in which the phenomenon of salinity is more or less visible, owe their lives to Hirmand River and Hamoon Lake.

Most sand layers and layers of hard and impervious clay, which have been alternately on each other, form the subterraneous soil of the region. The main soils of region consists mainly of Loam clays, Silt loam soils, sandy loam soils, sandy soils, and loam soils. A part of the soils of the area is covered by wind sands in which aeolian sediments are located below young surface soils. In terms of depth, soils permeability in Sistan region is estimated to be very low (approximately 1 x 10^{-5} cm per second). Thus, the entire study area is covered by fine-grained silt and clay sediments of the origin of the lake with a thickness of more than 2000m [21].

The permeability of soils in the Sistan region is reduced from the South East (Hirmand River as the source of inflow) to the North West of Sistan region; and the soil texture is heavy and dense. Hence, heavy textured soils, impenetrable layer over the surface of the alluvial plain of Sistan (at a depth of 1 to 5 meters) and poorly drained soils are among the characteristics of the region’s soil. Also, due to poor soil drainage, the intense heat and the severity of the evaporation occurring on the soil surface and its lower layers, soil salinity and its alkaline property increase, so that this situation may cause a region with salty and swampy soil, which creates many problems because of the increasing spread of the soil.

Sistan river morphology is in the way that bank erosion and meander occur frequently in its course, causing damage to adjacent farms. As Figure 3 shows, as a result of internal erosion of heel materials in the bank of river, the pores and deep furrows created by the flow, seepage of water from the adjacent irrigated agricultural lands, the upper bank has become as suspended and unstable arch, and tensile crack extending to the floor of the has separated several blocks from the soil of adjacent farms.

Fig 3: failure of farms adjacent to river as a result of erosion

planar failure along with tensile cracks in the materials of Sistan River's bank is the main causes of failure and retreat of the riverbank (Figure 4). In sediments of Sistan River's bank, water can easily erode the sediments after cracks and fissures are created. Figure 5 also shows the piping erosion and the fractured block adjacent to Sistan River.

Fig 4: planar failure along with tensile cracks in the materials of Sistan River's bank

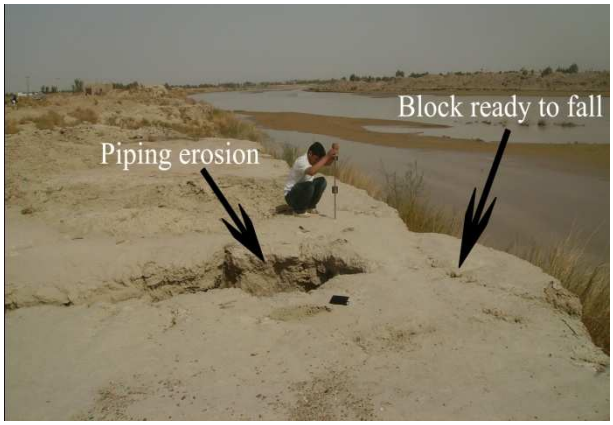

Fig 5. Piping erosion and fractured block ready to fall

Sediments of the failure of Sistan River's bank, most of which are fine, are transported in a suspended form in the flow of water downstream. These sediments are accumulated in the basin mouth of hydraulic structures, and cause obstruction of valves, damage to irrigation network pumps, and so on. Field and laboratory studies show that morphological changes of Sistan River - more than any other factor - are affected by bank erosion of the wall materials and continuous sedimentation of river. The river wall erosion has created many problems, such as destroying the farmlands, increasing the river width, threatening the villages adjacent to the river and water pumping systems. Thus, a large volume of lands adjacent to Sistan River annually enters the river flow as a result of bank

erosion, and is carried along with the flow downstream. The above sediments are deposited along the path, and reduce the volume of water entering the river, the efficiency of hydraulic structures, the feed of Hamoon Lake, and so on.

Figure 6. Sediment accumulation in the middle of the river channel

Figure 7. The accumulation of sediment on the site of hydraulic structures

It is worth noting that less comprehensive studies have been made particularly on the phenomenon of bank erosion as a major source of sediment load and how to protect them in Iran [17].
To examine characteristics of soil engineering and its role in morphological changes of river in different intervals, the bend of the river was sampled, and at each bend, Undrained shear strength (CU) of the soil was also calculated as in situ by the Dynamic Cone Penetrometer (DCP).
Thus, a few bends were sampled from the following intervals:

- 5 bends from the interval between Kohak dam and Zahak dam,
- 3 bends from the interval between Zahak Dam and Sistan Dam,
- 3 bends from the interval between Sistan Dam and Nahorab Bridge,
- 4 bends from the interval between Nahorab Bridge and the place where Sistan River is divided into two branches,
- 2 bends from the interval between Afzal Abad branch and Hirmand's Hamoon Lake, and
- 1 bend from the interval between Adimi branch and Hirmand’s Hamoon Lake

Laboratory results of these samples are listed in Table 1. After performing the tests and determining the mechanical properties of the soil, all the textures were determined and then were drawn on the classification triangle of agricultural soils which it has been presented by United States Department of Agriculture (USDA).

Results of field and laboratory observations show that there is a relationship between the engineering properties of materials forming the banks and the amount of tensile cracks in walls of the river’s bank. Due to the lack of clay in their combinations, most of these samples lack the have non-plastic behavior, low cohesion and low shear strength.

Thus, according to the texture classification of agricultural soils (USDA), it can be concluded that in fine soil, potential for tension cracks will exist depending on e conditions of soil moisture if cohesion of clay particles forms

less than 10 to 20 percent by weight of particles forming the bank's soil, because the increase in silt and sand particles between particles forming the soil of the bank reduces the force of cohesion between soil particles of the bank, decreases plasticity, causes the soil to be subjected to tensile cracks, and increases erodible soils as a result of water, wind and human erosion. Basically, this type of soil will face with failure due to lack of high plasticity, when the soil moisture changes during deformation. So, slight decrease in soil moisture of bank and increase in tensile force between soil particles create tensile cracks between soil particles, and cause river walls to be eroded as a result of the cracks and discontinuities. Therefore, the water flow continues to advance, failure of walls and side farms, and ultimately change in the course of the river.

Table 1. laboratory and field characteristics of the bends' soils in different intervals of Sistan River

Position	USDA textural class	Plastic Limit	Liquid Limit	Undrained shear strength or S_U (KPa)
Kohak dam to Zahak dam	Sandy loam	N.P	N.P	-
	Sandy loam	N.P	N.P	-
	Loam	N.P	N.P	23.12
	Sandy loam	N.P	N.P	-
	Sandy clay loam	31	12	27.37
Zahak Dam to Sistan Dam	Sandy loam	N.P	N.P	-
	Silt	N.P	N.P	21.3
	Silt	N.P	N.P	23
Sistan Dam to Nahorab Bridge	Silt	N.P	N.P	22.5
	Loam	N.P	N.P	22.87
	Sandy loam	N.P	N.P	-
Nahorab Bridge to the place where Sistan River is divided into two branches	Silt	N.P	N.P	22.75
	Silt	N.P	N.P	22
	Silt	N.P	N.P	21
	Silt	N.P	N.P	21.5
Afzal Abad branch to Hirmand's Hamoon Lake	Silt	N.P	N.P	24.62
	Silt loam	N.P	N.P	23.13
Adimi branch and Hirmand's Hamoon Lake	Silt	N.P	N.P	21.75
NP = not determinable				

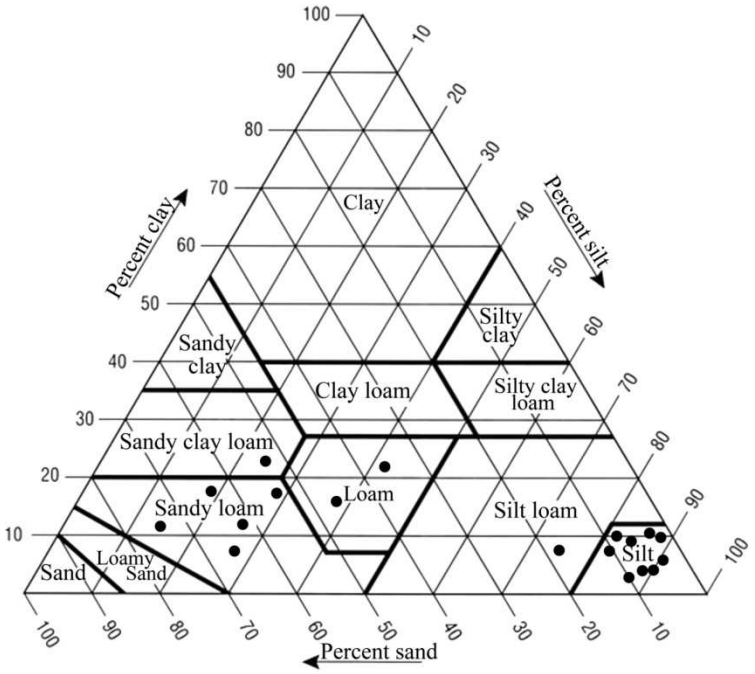

Fig 8: Distribution of soil texture in the bank of Sistan River on classification triangle of soil texture (USDA)

Therefore, to control erosion of Sistan River's walls, it is recommended that we avoid the failure of the walls, destroying of farms and villages, and change in direction of the river through the protection of the river's banks with vegetation, sand bag, rubber coating, layout of longitudinal or transverse walls and/or channelization of the river.

CONCLUSION

Due to low river slope and construction of longitudinal and transverse structures, morphology of Sistan River has faced with many changes in recent years; and meanders of the river have transverse and longitudinal movements that have caused changes in the course of river, bank erosion, land degradation, and so on. In the interval between upstream of Zahak Dam to Sistan Dam, meanders of the river have the highest longitudinal and transverse changes, which currently continue with the relocation, increase or decrease of sand islands. Bank erosion in Sistan River has caused great damage to agricultural ecosystems adjacent to the river, and threatens many agricultural lands and villages. Among the most important sedimentary deposits of Sistan River, flood deposits and fine-grained sediments (such as silt) can be noted. Fine-grained sediments, which cover most of the bank of Sistan River, mostly comprise silty loam and silt. Due to lack of clay, these fine sediments have low cohesion against erosion and do not show much strength. When the river floods, they will be subject to the erosion and degradation, and create diversion in the course of river and wideness of its bed. Studies of sediments and soil texture of Sistan River's wall show that most of the arches with high erosion and advance rates have composed of sandy loam, loam, loam sandy and silt loam. According to tests conducted on samples of Sistan River's wall in place of the bends, field observations and laboratory results showed that most samples have non-plastic behavior, low cohesion and low shear strength - the characteristics which cause the tensile cracks in walls of the river. The soils of Sistan River's bank primarily are fractured with changes in soil moisture during deformation because they have no high plasticity; and river walls are eroded as the result of the cracks and discontinuities.

Therefore, the water flow continues to advance, failure of walls and side farms, and ultimately change in the course of the river. Considering the importance of Sistan River as the main source of drinking and agriculture water supply in Sistan region, it is suggested that according to the results of geomorphology studies on the river, the basic guidelines are considered to implement engineering projects and organization of the river. Combination of studies on the geomorphology and river engineering help us to make correct and optimal use of the lands with minimal stress and social problems in addition to protecting the privacy of the river and maintaining the stability of banks. If this is not fulfilled, any executive operation such as river engineering and modification of the banks will be faced with serious problems.

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