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Assessment of morphological mhanges of Taleghan river in upstream of Taleghan dam

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A B S T R A C T

River channels have been affected by climate changes and human interventions such as channelization, dam, gravel and sand mining and land use changes. Dam changes water and sediment transport in river systems. These changes are as one of the most important factors affecting upstream and downstream river morphology. The aim of this paper is to explain the effect of Taleghan dam (it was constructed from 2001-2006) on upstream of Taleghan River over the period 2000–2017. Taleghan River is very important river in the Central Alborz of Iran. For this reason, Taleghan River was divided 2 reaches as control reach and backwater reach. Channel morphology have been investigated using historical aerial photographs, remote sensing images and field observations. Also channel width, sinuosity index, and particle size distribution were calculated for two reaches pre and post-dam construction. Results showed that the channel width was increased in the post-dam period. Widening was dominated in the backwater and the control reaches but increasing in the channel width in the backwater reach is more than the control reach. the channel width has been increased due to the impact of the dam and flood events. Also the results of grain size distributions showed that dam affects the grain size distribution and leads to an increase in the fine particle size. Finally, the channel adjustment (aggradation and widening) in upstream of Taleghan River may cause floodplain inundation and damage to agriculture and residential area in floodplain.

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1. Introduction

Morphology of river channels constantly change in response to alterations in hydrological regime and sediment load. Channel changes are driven by natural processes and human interventions. Natural processes (e.g. topographic conditions, hydrological data, and climatic factors) can lead to change in water flow and sediment fluxes and thus changes in channel morphology. In the meantime, human intervention, (direct or indirect), can be crucial for channel adjustments. The role of humans directly and indirectly changes the amount of water and sediment and channel morphology in the rivers (Khaleghi et al., 2015). Dam is one of the most important structures in transmission systems and water resources.

Constructing of dam is for flow regime control, agricultural water supply and urban consumption through water storage and energy production. Dam construction disrupt the water and sediment, causes major changes in the river morphology and eventually in the entire drainage basin (Gordon and Meentemeyer, 2006; Takahashi and Nakamura, 2011; Ma et al., 2012; Smith et al., 2016). Effects of dam can be spatially divided into upstream and downstream sections of the dam. There are many researches that have studied the effect of dam construction on downstream of river planform, channel morphology (Kong et al., 2010; Sanyal, 2017; Słowik et al., 2018) and grain size (O'Flynn et al., 2013; Vázquez-Tarrío et al., 2019) but there are few studies about the effects of dam on upstream of river morphology.

pointed out that the changes of river channels upstream of dams was studied in only a few studies (Leopold and Bull, 1979; Xu, 1990; Alibert et al., 2011; Liro, 2015). Dams are the most important controlling factors in Iranian rivers so that have been caused channel narrowing and incision at downstream (Khaleghi and Surian, 2019). There is a lake of study about effects of dam on upstream of Iranian rivers. In this study, the temporal and spatial variations of the Taleghan River at the upstream of Taleghan Dam are discussed. Taleghan River is an important river in the city of Taleghan, which originates from the mountains of Kandovan and Kahar in the North of Karaj.

Taleghan Catchment is one of the important catchment of the Sefidrood River Basin. Taleghan Dam was built on Taleghan River from 2001 to 2006. The morphological changes caused by the construction of the Taleghan Dam may result in changes in the river pattern and morphological changes. These factors can affect residential areas and also contribute to flooding upstream of the dam.

2. Material and Methods

2.1. Study area

The study area is the upstream of Taleghan Dam (an approximate length of 18 km) with a catchment area about 940 km^2 (Fig. 1). Taleghan catchment is a mountainous and high area (between 1688 and 4402 m) located on the southern slopes of the Alborz Mountains and within the Savojbolagh County of Alborz Province. Taleghan Dam is a type of concrete (pebble-clay) dams that was built 9 kilometers northwest of Taleghan on the Taleghan River and was put into operation in 2006. Taleghan is geologically part of the Central Alborz Zone and includes Precambrian to Quaternary geological formations and has been affected by numerous tectonic movements. According to the data obtained from Taleghan Meteorological Station, the average annual temperature is about 11.4 C and the average annual rainfall in the Shahrak Taleqan is 471 mm. The highest slope of the catchment is >45%. The most land use type is rangeland and the villages usually are spread around the river and floodplain.

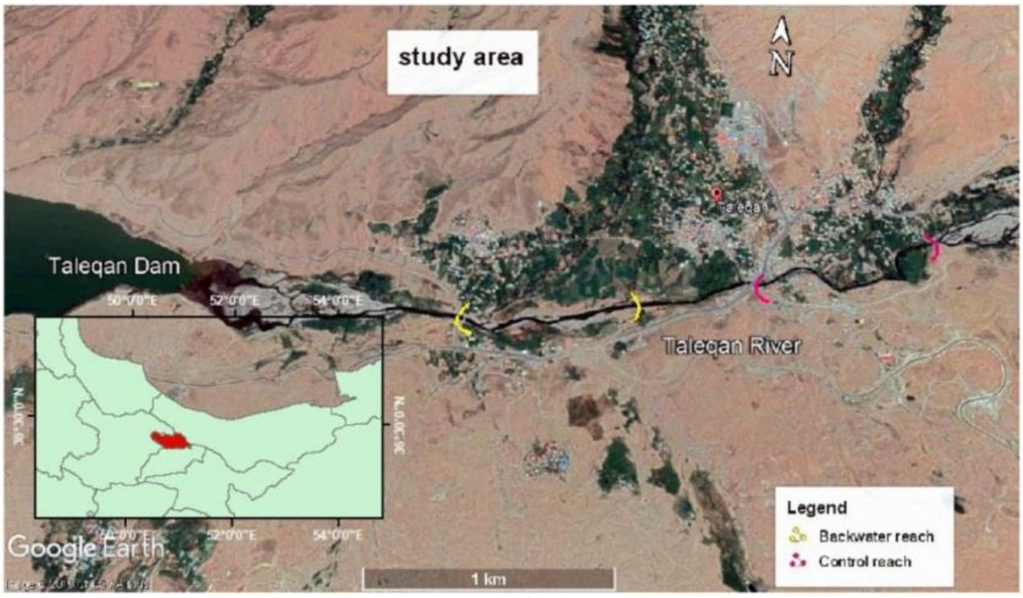

Fig. 1. Location of the study area

2.2. Material and Methods

2.2.1. Changes in discharge and sediment load

The data such as discharge, sediment and precipitation of Galinak station (this station is near the entrance of the dam) were obtained from Regional Water Organization of Tehran and Alborz Province then, the flow and sediment regime were analyzed. the annual sediment yield and discharge over the statistical period of 18 years (1992 to 2005 and 2007 to 2012) was used. Univariate linear regression model and least squares method were used to perform sedimentary calculations. Because the amount of sediment is affected by the discharge and precipitation parameters.

Using Excel software daily sediment yield data (ton / day) as dependent variable and daily discharge (cubic meter / s) as independent variable were entered and annual sediment yield (ton / year) was calculated. Also in order to compare the changes and to correlate between all parameters, sediment, discharge and precipitation diagrams are plotted and compared.

2.2.2. River morphology changes

Extracting of channel changes and river morphology can be detected by direct observations, historical records, sedimentary evidence, dating techniques, and inferential reasoning (Brierley and Fryirs, 2005). The GIS techniques and Auto-CAD were used to analyze channel changes in aerial photographs (2000) and SPOT images (2017). First, aerial photographs were scanned. Next, the photographs were georectified using topographic map and google earth images. In order to study the spatial effects of the dam, river path was divided into two reaches (backwater and control) with the same length (1km) and then the channel width and sinuosity index were measured on photographs and SPOT images. All of river path were digitized as polygons were saved in a vector file in the GIS software and then, active channel width and the centerline line of a major channel were extracted. The active channel width was defined as the sum of low-flow channels and bars not covered with vegetation (Ziliani and Surian, 2012; Liro, 2015). If a channel margin was hidden under tree canopies, the bank line was drawn through the middle of the clearly visible tree crowns closest to the channel (Liro, 2015). The active channel width and the sinuosity index was calculated in backwater reach and control reach at the pre and post dam periods. The sinuosity index is the ratio of the length of channel to length of valley axis. According to the Brice, rivers with a sinuosity index of 1 are straight and rivers with a sinuosity index between 1.05 and 1.3 are referred to as sinuous, whereas rivers with a sinuosity index 1.3 or greater are referred to as meandering (Brice, 1964).

2.2.2.1. Data and statistical analysis

Statistical analysis was conducted on the changes in channel width and sinuosity index in the per-dam (2000) and post-dam (2017) periods. In order to determine between which periods there existed statistically significant differences in the channel width changes analyzed during the study period (2000-2017), calculated values for 100٠-m-long channel reaches were analyzed using the paired-samples t test (a parametric test for normally distributed, dependent samples). The paired-samples t test (also called dependent-samples t test) is used to compare two means for situations in which every participant is in both samples. The paired-samples t test was chosen because the data obtained came from repeated measurements for the same channel reaches (dependent samples), with the channel width at a later date (2000) being dependent on its former state (2017), and the data were normally distributed. The tests used a significance level α= 0.05. The comparison over time aimed to determine whether there were differences in the channel width in the backwater reach and in the control reach during the pre- and post-dam periods. Also statistical analysis was conducted on the potential changes in channel width between control and backwater reaches in the same period of time). Comparisons over time and between locations used sample data collected for the backwater (n = 12) and in the control section (n = 12). The independent-samples t-test (or independent t-test) compares the means between two unrelated groups on the same continuous, dependent variable. The Independent t-test (a parametric test for normally distributed, independent samples) was used to analyze differences in channel width change between the backwater reach and the control reach for the same time periods. This test was chosen because data obtained came from different channel reaches (independent samples), and the data was normally distributed (Helsel and Hirsch, 2002). The tests used a significance level of α = 0.05. This comparison was made in order to determine whether the dam has a significant impact on changes in channel development.

2.2.3. Sampling and Particle Size Analysis

Two samples were collected from a depth of 0-30 cm reaches across to the backwater and control reaches of Taleghan River. To determine the particle size distribution, 200g of sample was washed and dried at the oven and then sieved to separate the sand fraction (>63µm). The sand fraction separated using a series of sieves. The mean grain size (Mz) (equation1), sorting ($Q1$) (equation 2), skewness (SKI) (equation 3)and kurtosis (K) were calculated. These parameters were calculated in accordance to the graphical measurement method with the following equations (Folk and Ward, 1957).

$$mz = \frac{\phi16+\phi50+\phi84}{3} \quad (1)$$

$$Q1 = \frac{\phi84-\phi16}{4} + \frac{\phi95-\phi5}{6.6} \quad (2)$$

$$SKI = \frac{\phi16+\phi84-2\phi50}{2(\phi84-\phi16)} + \frac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)} \quad (3)$$

3. Results and discussion

3.1. Changes in discharge and sediment load

The correlation coefficients of the discharge and sediment load data for the years 1991 to 2005 (before the dam construction) and 2007 to 2012 (the years after the dam construction) were plotted. Sedimentation rate curves are derived based on the relationship between the average sediment load and the average discharge (Fig. 2). Based on the Galink Hydrometric Station, the time period before and after the dam construction is plotted. Comparison of the graphs shows a decrease in the correlation between sediment and discharge data in the post-dam construction.

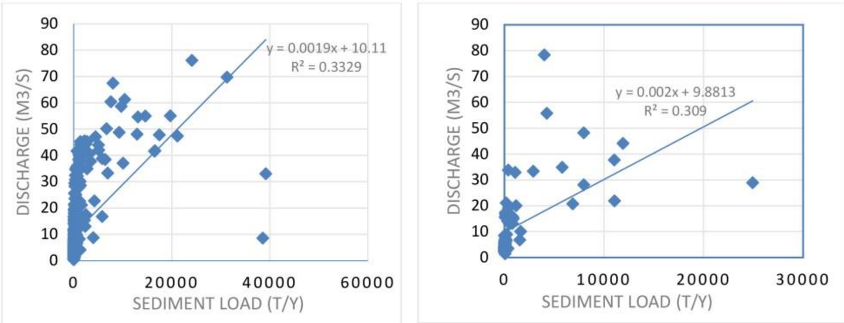

Fig. 2. sediment rating curve; right: pre-dam period, left: post-dam period

Investigation of changes in the mean discharge and average annual sediment indicate that these two parameters are relation to each other. According to the results, the average annual discharge has decreaded from 16.77 cubic meters per second in pre-dam to 11.483 cubic meters in the post dam period. The annual sediment load also decreased from 863880.05 to 18789.41 ton / year after dam construction (Fig. 3).

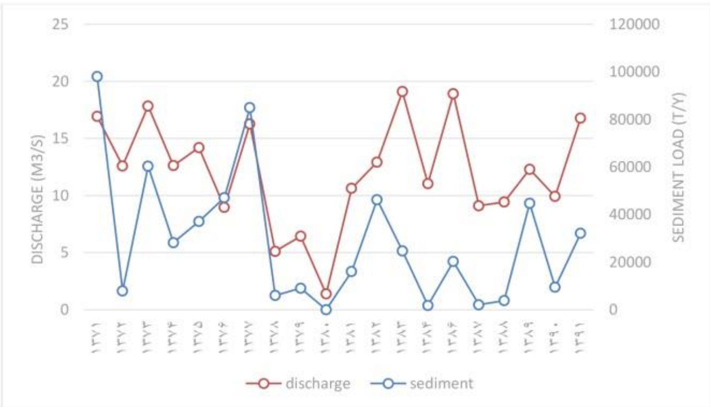

Fig. 3. Changes in the mean annual discharge and sediment load

Also, maximum peak discharge decreased after dam construction. Floods have declined in the years following the construction of the Taleghan Dam. Only one large flood (higher than average peak discharge) occurred in the post-dam period at 2010 (Fig. 4).

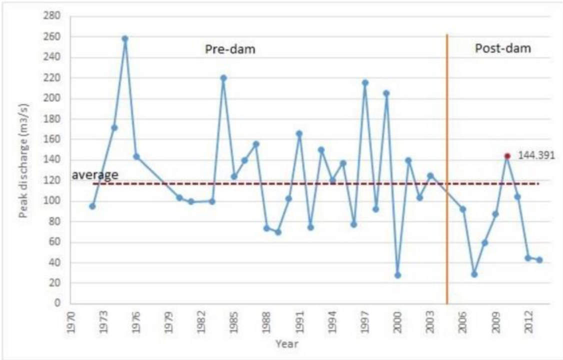

Fig. 4. Maximum peak discharge pre and post dam periods

3.2. Channel width changes

To investigate the effect of dam on river morphology, the width of channel was measured in backwater and control reaches (Fig. 5). Channel widening dominated after the post-dam period in the backwater and control sections (Table 1).

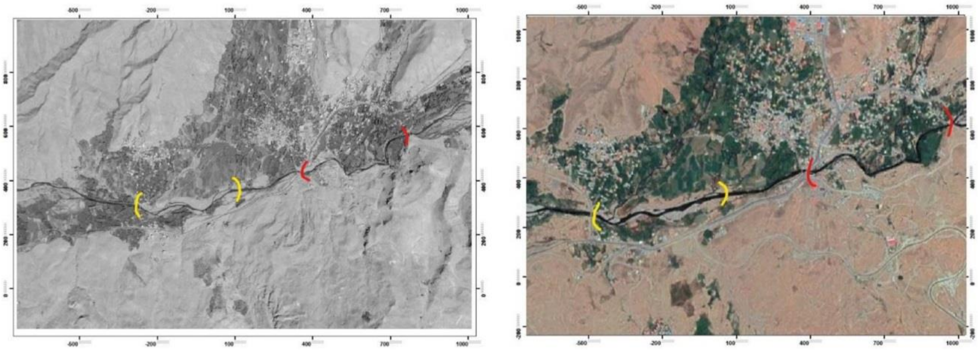

Fig. 5. The backwater and control reaches between 2000 and 2017

Table 1. Channel width changes in the backwater and control reaches

	Width (m)	
Year	**2000**	**2017**
Backwater reach	13.87	15.95
Control reach	9.27	12.17

Kolmogorov-Smirnov test was used to determine the normality of width in two reaches in backwater and control reaches as well as width changes pre and post dam construction. The results showed that, p value was greater than 0.05 and the test was significant and normal, so parametric test should be used. Results of an independent-samples t-test for the significance of difference in channel width change between the backwater and control sections of the Taleghan River. there is significant differences in channel width change ($p = 0.049$) were noted between the backwater reach and the control reach (Table 2).

Table 2. independent-samples T-test for the significance of difference in channel width change between the backwater and control reaches

	Levine's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Equal variances assumed	4.351	.049	-.331	22	.743	-.56417	1.70216	-4.09422	2.96589
Equal variances not assumed			-.331	16.694	.744	-.56417	1.70216	-4.16043	3.03209

Also, according to the normality of the data, paired sample T-test was used to compare the width changes pre and post dam periods in the backwater reach and control reach (Table 3). The results showed that there was a significant difference between the width of the channel pre and post dam periods in the backwater reach (sig. = 0.004) and control reach (sig. = 0.042). These results are consistent with those of Liro (2015). He concluded by studying upstream of a dam in southern Poland that floods and dam construction led to an increase in channel width. Also the depth of the channel post-dam has been reduced by indicating the deposition of the channel.

Table 3. Comparison of annual channel width changes in the backwater and control reaches between 2000 and 2017.

Paired Samples Test

		Paired Differences				
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference	
					Lower	Upper
Pair 1	before1 - after1	-2.89833	2.75380	.79495	-4.64801	-1.14865
Pair 2	before2 - after2	-3.46250	5.21389	1.50512	-6.77525	-.14975

Paired Samples Test

		t	df	Sig. (2-tailed)
Pair 1	before1 - after1	-3.646	11	.004
Pair 2	before2 - after2	-2.300	11	.042

3.3. Changes in sinuosity index

A slight variation of the sinuosity index was indicated for the backwater reach and control reach between 2000 and 2017.

3.4. Grain size distribution

Spatial variations of grain size distribution of sediments provide insights to the sedimentary environments and processes. Grain size distribution is used to determine sediment genetics, sedimentation process and flow type. The following diagram is plotted on the basis of particle diameter (ɸ) and cumulative percent of grains weight (g) (Fig. 6).

Table 4. Sinuosity index between 2000 and 2017 in the backwater and control reach.

	Sinuosity index	
Year	**2000**	**2017**
Backwater reach	1.77	1.80
Control reach	1.50	1.64

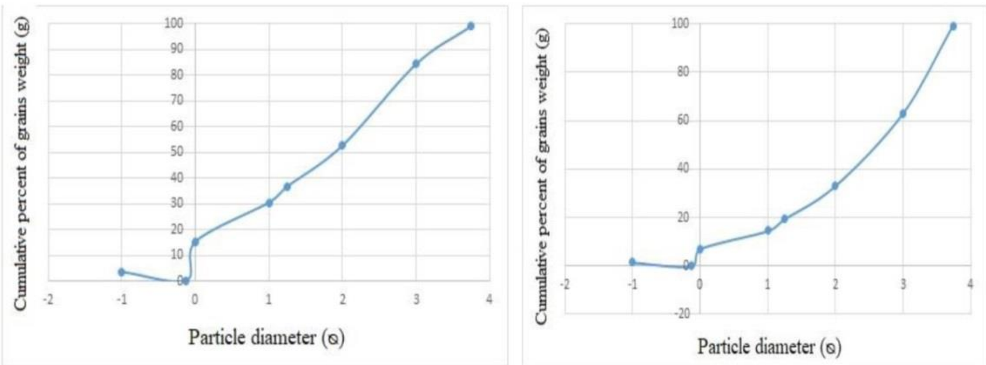

Fig. 6. accumulative grain size plot; left: sample of control reach, right: sample of backwater reach

In the first sample (the control reach), the median value is 1.8, and the mean grain size value is 1.6 which is considered to be medium sand grain size. In the second sample (from the backwater reach and near the inlet to the dam), the median value is 2.5 and the mean grain size is 2.2 which is the size of fine sand grain size. According to Folk classification, the sorting ($Q1$) value is 1 in the first and second samples which are the medium sorting rank. The skewness (SKI) value obtained for the first sample indicates a positive skewness and the curve tile oriented to the right so that is shows more fine grain particles. The skewness (SKI) value for the second sample is 0.6 and indicates a positive skewness and the curve tile oriented to the right and it shows more fine grain particles. Therefore, sedimentation takes place in a low energy environment. The dam has also led to sedimentation in the bed near Taleghan Dam, which has resulted in the formation of new non-vegetation terraces that are submerged during high discharge (Fig. 7). The results of grain size distributions are consistent with the results of O, Flynm et al. (2013). In this way, dam affects the grain size distribution in the upstream of dam and leads to an increase in the fine particle size.

Fig. 7. New terrace formed in the backwater reach

4. Conclusion

This study was conducted upstream of Taleghan Dam. One of the most important issues in Taleghan river is the morphological changes due to dam construction. In order to study of morphological changes of the river after the dam construction, first, the changes of sediment and discharge values were investigated. The correlation coefficient has decreased between sediment load and the corresponding discharge after the dam construction. The average annual discharge and the annual sediment load have increased after the dam construction. Thus, with increasing precipitation, discharge and sedimentation have decreased, which may be due to the increased use of river water for agricultural purposes and so on. The frequency of maximum flood discharges at the Galinak Station has decreased, but one large flood occurred after dam construction. For investigating of the channel width changes, two reaches of 1000 m length were selected as control reach and backwater reach. The results showed that there was a significant difference between the width of the backwater and the control reaches but the width of the channel has been more increased in the backwater reach compared to the control reach. So the increasing of the channel width in this area can be attributed to the impact of the dam and flood. According to the grain size analysis, grain size in the backwater reach is finer than the control reach so the Taleghan dam affects the grain size distribution in the upstream of dam and caused to an increase in the fine particle size.

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