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Numerical Simulation of Flow and Sediment Transport of Karkheh River before the Reservoir Dam Construction Using MIKE 11 [A Case Study in Iran]

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ABSTRACT

Administration of the water resources engineering projects of rivers basin requires detailed knowledge and theoric simulation of various phenomena that are involved in the process. Using of computer models is an adequate tool for simulation of flow and sediment conditions in the rivers which can be the basis for planning and implementation of water engineering projects. Karkheh Basin is one of the most important watersheds of Iran that belongs to Karkheh River [the third biggest river of Iran]. Considering the wide and strategic position of Karkheh River basin and its impact on geographic and fundamental aspects of the environment, study on river flow, sedimentation and erosion especially before the construction of the Karkheh Reservoir Dam, when the river had its natural condition, is an inevitable project that should be performed. Accordingly, this would be impossible to discuss about the reservoir dam effects on the river basin changes without the results of this valuable study. In this survey, the Karkheh River condition before construction of the Reservoir Karkheh Dam and at the downstream of it was simulated and evaluated using the famous numeric model of MIKE 11. The river reach is about 200 Km, between Reservoir Karkheh Dam and its downstream regulatory dam of Hamidiyeh that has three hydrometric stations which their data were used for this investigation. The Manning coefficient of 0.024 estimated and selected to use on hydrodynamic model of MIKE 11 software and acceptable hydraulic and sediment results were obtained; the total sediment load transport methods of Ackers-White and Engelund-Hansen represent more desirable results for the different flow discharges.

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INTRODUCTION

The hydraulics of the fluvial sediments transport is discussing about the erosion and deposition of sediments in channels and rivers [1]. Since the fluvial sediments effects on the nature, agriculture or on the river's hydraulic structures [such as dams] are very wide, the accurate investigations are become the goal of hydraulic engineering. For this purpose, the three phenomenon of erosion, transport and deposition of the sediments should be well investigated [2].

When the soil particles are detached from their context and are moved to the other places by a transmitter agent, the erosion occurs [3]. Also, the sediment transport in alluvial rivers resulted from interactions between hydraulic conditions and the river bed characteristics. Sedimentation phenomenon leads to the significant changes in the creek appearance and formation or in the other characteristics of the river basin [2].

Alluvial rivers have the potential to adjust the shape and dimensions of all the streams that carry sediments [4]. Due to the importance of sediment transport phenomena, there is a need to understand and predict the volume of transported sediments, changes in river's bed and basin and etc.

Before building hydraulic structures, this is necessary to determine the amounts of sediment in the rivers [5]. Therefore, it can be calculated by the mathematical relations experimentally or through the numerical models that can simulate and predict the sediment transportation. In addition, this is necessary to compare the predictions of the sediment transport equations with the data of the field measurements [6]. Hence, a lot of

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mathematical relations and equations were proposed and used to simulate the sediment transport processes which happen naturally in the rivers [7].

Reservoir dams are the major hydraulic structures that are built on rivers. They have numerous effects on its downstream in terms of flow, sediment and morphology therefore, study on river flow and sediment conditions before the dam construction to compare with next situation of the river is inevitable [8].

Despite of great span and importance of the Karkheh River basin and its effectiveness on many environmental and geological aspects and also in the huge hydrological projects [Karkheh Dam is the largest dam in Iran], there are a very few information on Karkheh river before the reservoir dam construction which none of them are not well documented and has not been published in reputable journals thus are not accessible. Also, there is a very few reports [Published in Farsi] after the reservoir dam building which are the only references of Karkheh River before dam construction that bring as follows:

The survey that was performed at 1999 by Oveisi *et al*. may have been the first study on the Karkheh Dam and its effects on downstream of Karkheh River that investigates degradation process using HEC-6 model [Documented in Shahid Chamran University of Ahwaz as M.Sc. Thesis].

Saghafian B. and his colleagues at 2009 reported a survey about flood warning of Karkheh by Water Research Institute. The Mahab Ghods Consulting Engineering also published two reports about optimization of large dams on Karkheh River Basin and construction of Karkheh reservoir dam by Ministry of Energy, 1986 and 2000, respectively.

Movahed E. *et al*. simulated the phenomenon of sediment transport and morphological changes of Karkheh River using MIKE 11 software. The river reach on downstream of Karkheh Dam to the Hamidiyeh regulatory diversion Dam was studied by them [Movahed E. *et al*. at 8th River Engineering Conference, 2010, Shahid Chamran University of Ahwaz].

Quantitative study on morphological changes of the Karkheh River was performed by Mohammad Pour *et al*. using transverse zonation and satellite images, at 2007. They represented that at the 211 cross-sections of Karkheh River [had been prepared by land mapping of the desired river reach] at the 80 cases transposition was occurred to the eastern of the river and at the 110 cases to the western side. The amount of displacement from zero to 477 meters in cross sections is varied [Documented as Ph.D. thesis in Shahid Chamran University of Ahwaz].

Bakhtiyari A. *et al*. applied different mathematical methods to calculate the total sediment load of Karkheh River at Hamidiyeh station at 2011[8th Hydrolic Conference of Iran, University of Gilan].

As mentioned, this survey is the only engineered evaluation of flow and sediment transport on Karkheh River before the reservoir dam construction. The goal of this study is to investigate the fluvial processes when the river had its natural flow on downstream of the river reach. Actually our experiment can be categorized to three main subjects of identification and careful examination of the circumstances of the river before the construction of the Karkheh Dam and also the powerful new hydroinformatic methods to simulate flow and sediment transport processes and finally identifying and selecting the best methods and equations to predict changes in various sectors. Hence, by comparing the river conditions before and after the dam construction [next paper is underway by the authors of this article] it would be possible to introduce new methods and equations for accurate simulating of the river processes.

MATERIAL AND METHODS

Karkheh Basin:

Karkheh River Basin is located in southwestern of Iran, and has an area of about 43 thousand square kilometers [Fig. 1A, B]. The average annual rainfall of the basin varies from 300 to 800 mm, so that the half of the total annual rainfall is in the winter and after that, autumn and spring have the highest annual precipitation. The geographical properties of Karkheh River cause heavy sediment transport of its basin that make various water management problems [9].

Karkheh River:

Karkheh River after "Karun" and "Dez" has the highest water level in Iran that originated of the West and Northwest regions of the Zagros Mountains which after passing a distance of 900 km along the north-south border of Iran and Iraq falls into Hoorolazim Lagoon [Fig. 1C].

The average of river flow and the sediment of Karkheh River before the dam construction were had been the 188 cubic meters per second and 1730 million tons per year, respectively [Report of the Karkheh Dams Optimization - Volume II - Technical Report 1986].

Karkheh Dam:

Karkheh Dam is located at 21 km north-west of the Andimeshk city in the Zagros mountain chain. The dam was built from 1991 to 2000.

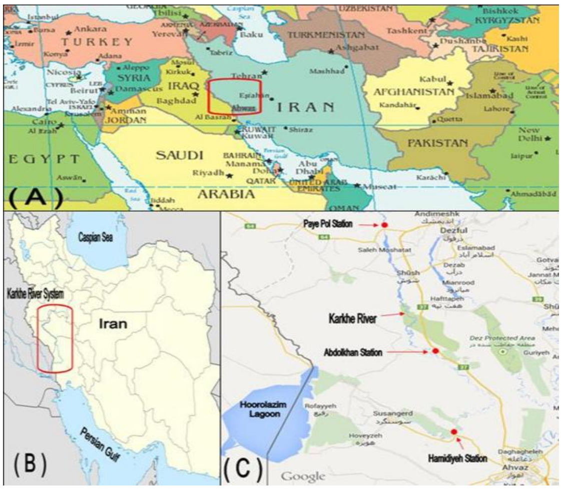

Fig. 1: [A] and [B]; Karkheh River basin located in west of Iran. [C]; Karkheh River and the location of the hydrometric stations.

River Reach of Study:

This study focused on the downstream of Karkheh Dam; the interval distance is approximately 200 kilometers between the Paye-Pol hydrometric gauging station of the Karkheh Dam and Hamidiyeh hydrometric gauging station of Hamidiyeh regulatory diversion dam. Paye-Pol hydrometric gauging station is located at 13 km downstream of the Karkheh Reservior Dam. Moreover, the information of hydrometric station of "Abdolkhan" that is located at the 130 kilometers downstream of the Karkheh Dam near the Abdolkhan Village was also used at this simulation process [Fig. 1C].

MIKE 11 Software:

MIKE 11 software is a professional, one-dimensional and dynamic engineering program of the Danish Hydraulic Institute produced at 1992. This model is used to simulate flow, sediment transport and water quality in rivers and river basins, as well as the management of rivers and the irrigation and drainage networks.

This numerical model simulates the river flow and sediment in a transient and one-dimensional status. In addition to the technical properties, the MIKE 11 model has executive capabilities which make it a fully commercial model, now. The MIKE 11 engineering software of the river contains the three main sections including hydrodynamic modeling, hydrological rainfall-runoff modeling, water quality modeling and sediment transport modeling [10, 11].

The input data required by this model include the following:
- River hydraulic data
- River sediment data
- Physical characteristics of the river
- Boundary conditions of upstream and downstream of river reach

Steps of rivers flow simulation process:
- River network plan, including branches and sub-branches
- Providing the cross-sections information and locating them with the river plan
- Collecting the data of river flow and surface elevation measurements at consecutive stations on torrential and on-torrential conditions to calibrate the model
- Preparation of torrential discharges with different return periods
- Making input file from information and data
- Running the program
- Calibration of the model
- Observation the model outputs
- Interpretation of Results

MIKE 11 model uses of the equations of dynamic wave model to routing the flow. Equation of continuity and momentum in this method is known as Sant Venant equation, which includes:

$$\frac{\partial Q}{\partial t}+\frac{\partial(\alpha Q2/A)}{\delta x}+\left(gA\frac{\delta h}{\delta x}+\frac{gQ|Q|}{C2AR}\right)=0 \qquad \frac{\partial Q}{\partial x}+\frac{\partial A}{\delta t}=q$$

Where, the Q, A, C and R refer to discharge, cross section, Chezy coefficient and the hydraulic radius, respectively. The h, q and α define the water level, lateral discharge and the momentum correction factor, respectively. The MIKE 11 software uses nine models to calculate transportation of total non-cohesive sediments of the river. These methods include:

The equations of sediment simulation which were used in MIKE 11 model are:

Ackers and White, Ashida and Michiue, Ashida, Takahashi and Mizuyama, Engelund and Fredsoe, Lane and Kalinske, Meyer-Peter and Muller, Sato, Kikkawa and Ashida, Smart and Jaeggi, Van Rijn.

For example, equations of Engelund and Hansen method are as follows:

$$f'\phi = 0.1\,\theta^{\frac{5}{2}} \qquad \phi = q_t\left[\gamma_s\left(\frac{\gamma_s-\gamma}{\gamma}\right)gd^3\right]^{-0.5} \qquad \theta = \frac{\tau}{(\gamma_s-\gamma)d} = \frac{hs}{(s-1)d_{50}} = \frac{u_*^{\,2}}{(s-1)gd_{50}}$$

In this regard θ and Φ are dimensionless total bed shear stress and dimensionless sediment transport rate, respectively. The q_t, f' and τ stand for total bed material transport per unit width, roughness coefficient and shear stress, respectively. γ, γ_s are the specific gravity of water and sediment and u_* and d_{50} define shear velocity and median diameter, respectively [12].

Ackers and White equations are as follows:

$$F_{gr} = \frac{u_*^n\left[\dfrac{V}{\sqrt{32}\log\left(\dfrac{\alpha D}{d}\right)}\right]}{\left[gd\left(\dfrac{\gamma_s}{\gamma}-1\right)\right]^{\frac{1}{2}}} \qquad \frac{Q_t}{Q} = C\frac{d}{R}\left(\frac{V}{u_*}\right)^n\left(\frac{F_{gr}}{A}-1\right)^m \qquad d_{gr} = d\sqrt[3]{\frac{g\left(\dfrac{\gamma_s}{\gamma}-1\right)}{\nu^2}} \qquad G_{gr} = f(F_{gr}, d_{gr})$$

In these regards, G_{gr} is general transport parameter. C, A and m are model parameters determined from the dimensionless grain diameter. d, u and s stand for grain size, kinematic viscosity and the specific gravity of the sediment, respectively. F_{gr} is general sediment mobility number. D, ν, u_* and d_{gr} define water depth, kinematic viscosity, shear velocity and dimensionless Variable of diameter grain, respectively and the n is for model constant determined from d_{gr} and ranges from 0 [coarse material] to 1 [fine material] [13].

Karkheh River Records:

The interval distance which this research has been done is located in downstream of Karkheh dam. This distance is approximately 200km starts from Paye-Pol hydrometric station up to the Hamidiyeh hydrometric station at regulatory diversion dam of Hamidiyeh. In this paper, the recorded data has been gathered from three different hydrometric stations, named Paye-Pol, Abdolkhan, and Hamidiyeh. The location of the stations on MIKE 11 software is showed at Fig. 2.

Hydrometric Station of Paye-Pol:

The most important station of Karkheh dam hydrometrics study is Paye-Pol station with Geographical Coordinates of 48˚09´ east longitude and 32˚25´ north latitude, 108m above sea level and was established at 1954 on Karkheh River. The Paye-Pol station is located in 13 Km downstream of Karkheh Reservoir Dam and has been facilitated by gauge, limnograph and cable way equipments. Since 1954-55 it has being gathered the hydrometric information of the river.

Hydrometric Station of Abdolkhan:

Abdolkhan hydrometric station is located in 120km downstream of reservoir Karkheh Reservoir Dam at 48˚21´ of east longitude and 31˚25´ of north latitude, 38.5m above the sea level. It has been equipped with gauge, limnograph and cable way and from 1965-66 up to now, it has being recorded hydrometric data.

Hydrometric Station of Hamidiyeh:

Hamidiyeh hydrometric station is located at downstream of Hamidiyeh regulatory diversion dam and 35km far from Ahwaz city. This station was funded in 1950 and up to now, it has being reported collected information. Gauge, limnograph and cable way are its significant machinery. Its geographic coordinate is 48˚26´ east longitude, 31˚30´ north latitude and 24.5m above the sea level.

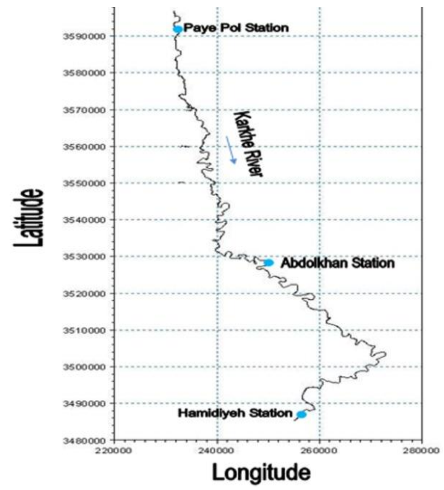

Fig. 2: Plan of Karkheh River at the interval distance of study on MIKE 11 software.

RESULTS AND DISCUSSION

After dam establishment, inevitably, the sedimentation behavior of the river in downstream has been intensely changed. Proposing data showed that the years between 1994 and 1998 are the best informative for simulation and study the assessment of erosion and sedimentation of Karkheh River. In these years, not only the quality of recorded information is more coherent but the gradient of the river's bed changes profile also is available in mentioned hydrometric stations. Moreover, in this domain of years the dam operation was not started yet and therefore, the river sedimentation and flow were natural.

Hydrodynamic Model:

The hydrodynamic model of the MIKE 11 software is the basis of all this model equations including diffusion, transmit, water quality, sediment transportation, and etc. Accordingly, after performing a sensitivity analyzing on the hydrodynamics parameters, this model has been calibrated by the filed data of Karkheh River.

Cross-sectional Profiles:

Cross sections which were used for the model had been prepared by SazAb Pardazan Consultant Engineers Co. in terms of "Border Zone and Territory of the Karkheh River". In these mapping, approximately 250 cross-sections with an average distance of about 1 kilometer from each other along the Karkheh River [From Karkheh Dam to Hoofel- Neysan] were surveyed.

Boundary and Initial Conditions:

The numerical method was used at model MIKE 11, requires determination of the initial values of water depth [water level] and flow discharge at all computing spots to start the computations [trial and error]. For introducing the upstream and downstream boundary conditions to the hydrodynamic model, the time series of daily flow discharge of the river at Paye-Pol station, and the gauge water discharge curve of Hamidiyeh station were used, respectively; The maximum flow discharge rate of the Karkheh River was been around 4440 m^3/s which is well defined at the Figure 3.

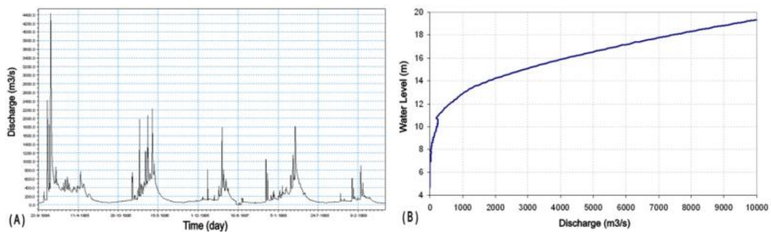

Fig. 3: [A]; shows the time series of daily discharge at Paye-Pol station [upstream of the studied river reach]. [B]; the gauge discharge curve of Hamidiyeh station [downstream of the studied river reach].

The sediment rating curves [discharge of water vs. discharge of sediment] of three hydrometric stations of Paye-Pol, Abdolkhan and Hamidiyeh are shown at the Figure 4.

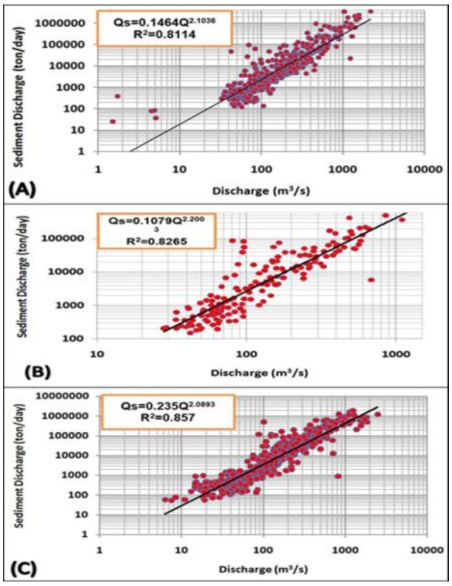

Fig. 4: Sediment rating Curves of [A] Paye-Pol, [B] Abdolkhan and [C] Hamidiyeh stations.

River Roughness Coefficient Estimation:

One of the parameters that should be calibrated in mathematical models of hydrodynamic simulations is the resistance coefficient of river's bed which defined as Manning roughness coefficient or Chezy coefficient [14].

The river roughness is the most effective parameter on the calibration process result of the hydrodynamic modeling software of MIKE 11. All the experimental procedures were used to determine the roughness of the river from which the results are shown in table 1 [15].

Table 1: Estimated values of the Manning roughness coefficient at the three stations.

Method	Formula	Paye Pol Station	Abdolkhan Station	Hamidiyeh Station
Strickler 1923	$0.019D_{50}^{(1/6)}$	0.011	0.02	0.01
Keulegan 1938	$0.039D_{50}^{(1/6)}$	0.01	0.01	0.01
Meyer,Peter,Muller 1948	$0.038D_{90}^{(1/6)}$	0.02	0.01	0.01
Carlson 1953	$0.026D_{75}^{(1/6)}$	0.02	0.012	0.012
Henderson 1966	$0.041D_{50}^{(1/6)}$	0.011	0.009	0.01
Raudkivi 1976	$0.042D_{50}^{(1/6)}$	0.011	0.01	0.01
Grade & Raju 1978	$0.039D_{50}^{(1/6)}$	0.013	0.011	0.011
Subramonya 1982	$0.47D_{50}^{(1/6)}$	0.013	0.01	0.011
Hager 1999	$0.048D_{50}^{(1/6)}$	0.013	0.011	0.011

As mentioned in the Table 1 different values were obtained for roughness coefficient of Manning. In addition, more values were obtained addressing to the previous researches on this field such as Shafaei Bajestan [2009] the value of 0.035, Razeghi [2009] the value range of 0.0263 to 0.0162, Eskafi [2009] the value of 0.025, Ghomshi [2011] the value of 0.0246, Kashefi Pour [2012] the value of 0.028.

Thus, on the basis of the carried out investigations, the constant roughness coefficient of 0.024 considered for the whole of the river afterwards, the hydrodynamic simulation was performed by MIKE 11 model. Also, the sensitivity analysis on the river roughness was determined using this parameter in different cross-sections of the river. Then, all of the deposition models with the roughness value of 0.024 were performed and their results were compared with the observed values from the field.

To run the sediment transport model, the average diameter of the sediment particles was considered constant on the all equations of sediment transport at all along the river. Considering to the grain size distribution curve of the sediment particles at the Paye-Pol, Abdolkhan and Hamidiyeh stations, the constant value of 0.23 mm was considered for the average diameter of sediments. Also, the specific weight of sediments based on measurements at hydrometric stations was assumed equal to 2.65 ton per cubic meter [Fig. 5].

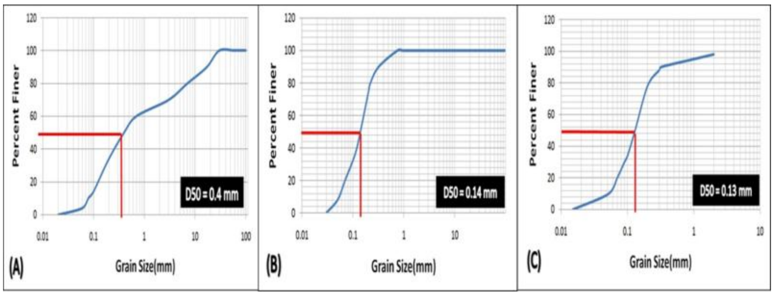

Fig. 5: Grain size distribution curves at three hydrometric stations of the interval distance of study; [A] Paye-Pol, [B] Abdolkhan and [C] Hamidiyeh.

Hydraulic Results of the River:

Table 2 indicates to hydraulic characteristics of the river at Paye-Pol and Abdolkhan and Hamidiyeh stations which calculated on the basis of different water discharges by hydrodynamic part of MIKE 11 software. The long term studies of river flow discharges data before the dam construction represent that the most flow discharges had been below 2000 m^3/s thus the maximum water discharge amount was considered 2000 m^3/s at MIKE 11 model.

Table 2: Hydraulic characteristics of Paye-Pol, Abdolkhan and Hamidiyeh stations.

Station Name	Discharge (m^3/s)	Area (m^2)	Velocity (m/s)
Paye Pol	200	146	1.38
	500	252	1.98
	1000	422	2.37
	1500	682	2.2
	2000	918	2.18
Abdolkhan	200	410	0.49
	500	727	0.69
	1000	1359	0.74
	1500	1915	0.78
	2000	2494	0.8
Hamidiyeh	200	860	0.23
	500	1610	0.31
	1000	2550	0.39
	1500	3115	0.48
	2000	3490	0.57

Morphological Results of the River:

In the simulation process, all methods of MIKE 11 model that was mentioned at model introduction part were used and their results were compared. Refer to this software computation and compared results with the field observations, the methods of Ackers-White and Engelund-Hansen had the most correlation at the morphological model. This means that the transported sediment amount and the simulated value of it, was more closely associated in comparison with the existing data at this model.

Predicted changes at the shape of river cross-sections versus observed data values by the two methods of Ackers-White and Engelund-Hansen at the hydrometric stations are shown at Figure 6.

To indicate the longitudinal profile of the river bed assessments the Ackers-White method was used [Fig. 7].

The Figures 8 exhibited the Karkheh River bed elevation changes versus time at the Hydrometric stations which can be interpreted as follows:

From Figure 8A, which corresponds to the Paye-Pol station, this infers that the bed level changes during the simulation, is variable with increasing of bed level and scope of these changes is about four meters.

Figure 8B, which is related to Abdolkhan station, shows a sinusoidal trend is changing. In general, bed elevation value is increased due to the sedimentation with a variation range less than a meter.

Figure 8C also represents the variation of the bed elevation at Hamidiyeh station which this value is reduced and erosion occurred during the period of study. The extent of these changes is also estimated to be less than a meter.

Total Sediment Load Assessment:

The total sediment load of the river versus the different river flow discharges is obtained by the MIKE 11 model. By study of model out puts, it is recommended to use the Ackers-White and Engelund-Hansen methods to simulate the total sediment load of the river. Tables 3 exhibits total sediment load assessment using two mentioned methods and the results were compared with the observed values of the field at Paye-Pol, Abdolkhan and Hamidiyeh stations.

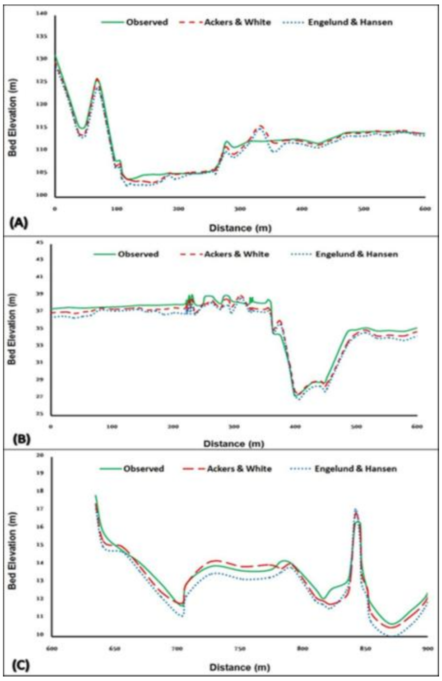

Fig. 6: The estimated changes of cross sections at the Paye-Pol [A], Abdolkhan [B] and Hamidiyeh [C] hydrometric stations using Ackers-White and Engelund-Hansen methods in comparison with observed data.

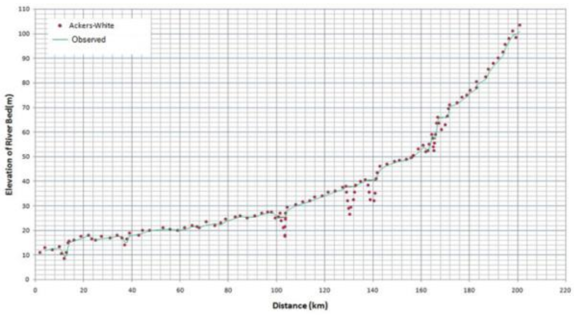

Fig. 7: Longitudinal profile of Karkheh River bed by Ackers-White method compared to observed values.

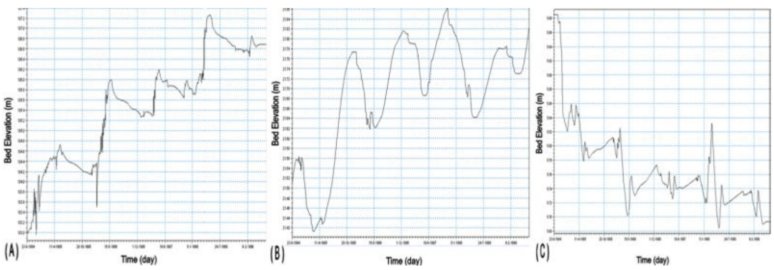

Fig. 8: Changes of bed elevation by passing the time at the stations: Paye-Pol [A], Abdolkhan [B], Hamidiyeh [C].

The Ackers-White values are always predicted to be more than Engelund-Hansen values which almost are less than observed values while, The Ackers-White values frequently are more than observed data especially about the discharges of less than 500 m^3/s.

As it was mentioned from the reports at the introduction; Movahed E. *et al*. represented that Engelund-Hansen sediment transport formula is the correct choice for the interval distance of the study and also the

Bakhtiyari A. *et al* introduced Ackers-White method as the most compatible equation to estimate the total sediment load of the Hamidiyeh station which both confirm our results for estimating the total sediment load of the Karkheh River.

Table 3: Total sediment load assessment of Paye-Pol, Abdolkhan and Hamidiyeh stations using Ackers-White and Engelund-Hunsen methods and compared with the observed values of the field at the stations.

Station Name	Discharge (m^3/s)	Total Sediment (Observed) (ton/day)	Total Sediment (Engelund & Hansen)(ton/day)	Total Sediment (Ackers & White) (ton/day)
Paye Pol	50	576	427	654
	100	2477	2145	2537
	200	10646	7931	12132
	500	73162	57854	69541
	1000	314435	255102	285743
Abdolkhan	50	620	533	771
	100	2850	1997	3474
	200	13097	9126	15325
	500	98345	79874	92874
	1000	451971	394753	418187
Hamidiyeh	50	875	602	1015
	100	3723	2945	4574
	200	15842	10282	19197
	500	107452	82954	99874
	1000	457254	403571	426902

As reported the average water discharge of the river is about the 188 m^3/s. Therefore, according to our results at the Table 3, the Ackers-White equation was selected to calculate the annual sediment value of the Karkheh River. The annual sediment value of the scope of Paye-Pol station is estimated about 4.4 million tons per year and approximately 5.5 and 7 million tons per year for Abdolkhan and Hamidiyeh stations, respectively.

The next part of the research in this area could include the assessment of flow and sediment conditions of the Karkheh River after the dam construction which is being developed by the authors of this research and its results will soon be published. Comparison of the Karkheh River flow and sediment conditions in the interval distance of this study with regard to the conditions before and after construction of the dam would also be a good topic for the following researches.

Conclusion:

Our study investigates the hydraulic and sedimentary conditions of the Karkheh River before the Karkheh Dam construction when the river has been had its natural flow. The MIKE 11 model software was used for hydrodynamic and sedimentary simulations of the river. Processing the out puts of this model suggests that the Ackers-White and Engelund-Hansen methods are the most compatible equations with data of field observations. Our results may provide a proper basis in flow and sediment of Karkheh River researches which would be used for technical designs and planning of water resources.

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