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Determination of erodibility or sediment ability of river reaches using three methods of fortier, Mavis and Hjulstrom (Case Study: Sirvan Basin, Kurdestan - Iran)

Amir Khosrojerdi [1], Nooshin Mohammadzadeh [2], Amirpouya Sarraf *[3]

[1] *Department of Water Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran*

[2] *Department of Water Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran*

[3] *Department of Civil Engineering, Roudehen Branch, Islamic Azad University, Roudehen, Iran*

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Abstract

The human activities and natural factors cause changes in sediment supply rate in the rivers. The rivers naturally react to this change to balance themselves to the new imposed conditions. This transformation is continued until the river section is reached to dynamic equilibrium. In this study, Erodibility or sediment ability of Gheshlagh River reaches are determined based on the critical velocity by means of different methods (Fortier table, Mavis method and Hjulstrom diagram). At first, cross sections of studied river are provided using the basin's topographic maps and ArcGIS 9.3 software and later Gheshlagh River is modeled and simulated in steady flow state, aiding HEC-RAS software. Results obtained from simulation and performed computations indicate the differences in results obtained from morphologic variations determination methods in Gheshlagh River so that according to two methods Mavis and Hjulstrom, all sections of Gheshlagh River are exposed to scour whilst in Fortier method, some reaches are sedimentary.

***Corresponding Author:** Amirpouya Sarraf ✉ amirpooya@hotmail.com

Introduction

One of the most important phenomena in river is the erosion and sedimentation that is observed more and less in all rivers (Vanrijn, 1984). The water flow in rivers causes moving the sediments including solid materials of floor and side of rivers (Sampei *et al.*, 2012). Movement of sediments in rivers is along with three processes including erosion, transmission and sedimentation. These three processes in addition to changing the river flow process also affect the bed level, gradient and roughness factor (Ralston *et al.*, 2013.

In general, the erosion is referred to a process during which the soil particles are separated from their main bed and to be transported to another place aiding a transmitting factor. Erosion of flow channel sides incurs losses to the fertile farming lands, adjacent installations and widens the flow channels (Pritchard *et al.*, 2002).

On the other side, each particle that is transmitted by the fluid flow and ultimately deposited is called the sediment. Sedimentation is followed by a lot of problems including establishment of islands, delta at the river entrance to the sea and reduction of dam reservoirs capacity and water transmission canals (L. Graf *et al.*, 2010). For solving these problems in any country, it is required to execute an overall plan for conservation of soil based on the actual and exact data on intensity, erosion and sedimentation, because logical decision making for prioritization of soils conservational activates at any zone is dependent to exact information about erosion and sediment. In order to control the soil erosion, it is required at the first stage, to identify the nature and mechanism of sediment movement; at the second stage, factors effective on erosion to be identified and at end, the rate and value of transported sedimentary materials to be determined and calculated exactly, in order to prioritize the zones in terms of erosion intensity and sediment production (Arı Güner *et al.*, 2014; Grasso *et al.*, 2011).

It is notable that the hydraulic conditions that cause the first movement of bed are called critical conditions or primary scour. Critical conditions are determined based on three methods, critical velocity, shear stress equations and lifting force criterion. In this paper, critical conditions are determined using critical velocity method (Valyrakis *et al.*, 2013). In this method, based on the critical velocity equations therein liquid collision impact on the particles is considered, critical velocity is determined and later is compared to average velocity of section that obtained aiding HEC-RAS program running, and upon their comparison, existence or nonexistence of critical conditions is cleared. Fortier *et al.*, (1926) applied extensive studies on determination of maximum standard value of average velocity in the different channels and provided their results for different materials in a table.

Hjulstorm (1935) in his studies on analysis of uniform aggregates movement in the channels, instead of measuring the velocity at the channel floor used the average flow velocity and offered a diagram for showing the relationship between particles size and average flow velocity for three states of erosion, sediment transmission and sedimentation. Johnson *et al.*, (1999) applied HEC-RAS for prediction and determination of suitable lands area within 10km along Wyoming-Greybull River in USA.

Vojdani *et al.*, (2006) analyzed the erosion phenomenon and determined the critical shear stress of sticky sediments erosion in several channels. Summary of their studies indicated that erosion of sticky sediments randomly and according to erosion theory of Einstein and Hoonlee is occurred while accidental failure of slow sub layer and domination of driving hydraulic forces over the resistant forces.

Hosseini *et al.*, (2008) during studies on Abharroud River estimated the sediment and its local and temporal distribution within the different river sections. He estimated the average volume of sediment outputted from river and upon extracting the variations in the bed level of each one of river sections, the transited sediment during a 37-year simulated period, recommended the most suitable zones for survey of sediments along the river course. Sadeghifar (2012) estimated the sediment in Kharrood River and concluded that can utilize the sediment results and hydraulic parameters of HEC-RAS model in the cross sections excluding the sediment survey.

In this research, Erodibility or sediment ability of Gheshlagh river reaches are determined based on the critical velocity by means of different methods (Fortier table, Mavis method and Hjulstrom diagram) and studied river basin modeled and simulated in steady flow state using HEC-RAS software.

Material and methods

The studied reach is the basin of Gheshlagh River located in Kurdistan Province and within Sirvan basin.

Fig. 1. Situation of studied zone.

This river flows at the southwest of province and is originated from Rozab and Marivan in Kurdistan Province and after crossing through northwest of Uramanat, Doab and north of Herta, Zhavehrood, Gheshlaghrood, Leyleh, Loosheh, Zamkan, and Dasht-e-Hor Rivers joined thereto and then enters into Iraq and pours into Darbandkhan Dam lake.

Different branches of this river have similar flowing system and along their path cross through the deep valleys. The studied area of this research has been located within the geographical coordinates 35 degree and 8 min to 35 degree and 12min in northern width and 46 degree and 46min to 46 degree and 49min of eastern length.

Considering the objective of this project and studied zone, studies on Gheshlagh River organization plan have been applied in several stages and as follows:

a) Data Collection (Maps and Aerial Photos)

In order to provide the river model, it is required to produce an elevation model and provide the sections of river course. For this purpose, the available maps of zone were studied. The available maps include a series of maps with different scale and quality and differ in terms of application and surveyed terrains. These maps include the following groups:

First group - maps with scale 5000: these maps cover the zone upstream means from km 6500 (to zero point of downstream) to the beginning of reach i.e. km 14000. In addition, these maps only include the zone topography.

Second group- maps with scale 2500: these maps cover downstream of studied reaches means the interval between km 0 to 6500 as well as within Zhaveh Dam area.

Third group- maps with scale 1000: these maps cover the whole respective path and have been surveyed in spring 2002. These maps have no appropriate topographic quality and have various defects and problems.

Hence, it was necessary to extract the final map from combination of these three map groups.

b) Geometry of River and Cross Sections

After removing the map deficiencies, triangulated irregular network (TIN) was produced in GIS software environment. The said software creates the river sections and shape completely as geo reference. It is very suitable while using the software results and the flood zone may be implemented easily on the maps (Bhattacharya *et al.*, 2007).

For correct provision and execution of a model in HEC-RAS software, correct and enough sections are required in order to cover the river shape and its hydraulic conditions correctly. For this purpose, the sections have been provided with the average interval of 70m (this value has been extracted from averaging the whole intervals and is varied along the river depending on the need and situation). These sections after initial preparation are revised and modified as follows:

1) Suitable location for correct perception of river's morphologic conditions;
2) Adequate cover of riverbed area for hydraulic conductivity and correct exhibition of flood bed;
3) Sections with suitable intervals and correct direction before and after structures crisscrossed to river;
4) Perpendicularity of sections on water flow path;
5) Field visit and data collection.

c) Estimation of Manning Roughness Factors

According to the data on aggregation, visit and field surveys, analysis of sides vegetation, considering the other effective factors, manning factor of main channel, left and right shores in different sections of Gheshlagh Rivers have been computed by Cowan method. For estimation of manning factor by Cowan method, vegetation, meandering, bed disorganization, cross section size and shape have been analyzed (Hobbs *et al.*, 2013). After computation of manning roughness factor by Cowan method, the values obtained from presented photos by Chow were evaluated and amended and ultimately manning roughness factor was scrutinized.

Whereas for simulation of flow hydraulics, the sediment data collection is required, thus along the river, samples of bed sediment were collected. This sediment data collection was measured in 6 stages and each one within 1-month time interval. Fig. (2) shows the aggregation curve of riverbed sediment sample. In general, D_{50} has been assumed as 1mm.

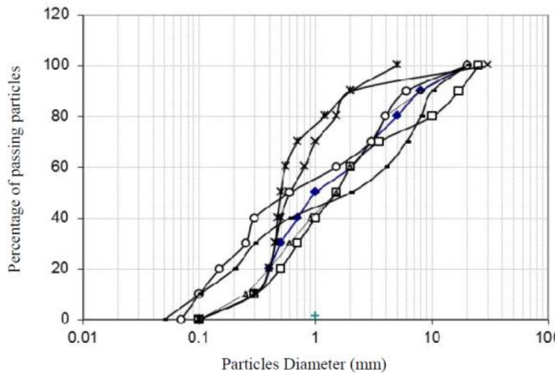


Fig. 2. Aggregation of riverbed sediments sample.

Result and discussion

At first, a brief of three studied methods was mentioned and then the extracted graphs are exhibited based on discharge with 25-year return period.

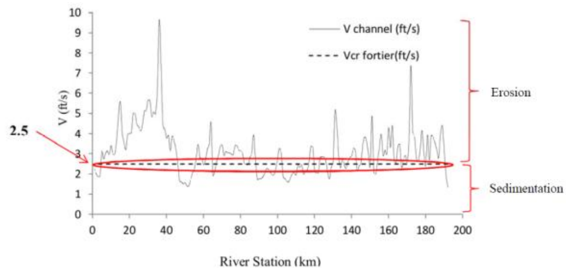


Fig. 3. Comparison of velocity by Fortier method for 25-year return period.

Critical Velocity Equation Based on Fortier Method

Fortier *et al.*, (1926) applied extensive studies for determination of maximum standard value of average velocity in different channels and presented their results for different materials in a table. According to aggregation test, bed materials type and sandy loam was determined. Accordingly, according to Fortier table, considering the conditions therein water contains suspended mud particles, the maximum standard velocity of channel is equal to 2.5 ft. /s.

Upon placing the data in diagram and considering the maximum standard velocity of channel, fig. 3 is created.

Critical Velocity Equation

Mavis *et al.*, (1937 and 1948) offered the following final equation based on analysis of 400 laboratory values for determination of critical velocity at the floor bed:

$$U_{b_{cr}} = 0.5d^{4/9}\left(\frac{\rho_s}{\rho} - 1\right)^{0.5} \quad (1)$$

In this equation, $U_{b_{cr}}$ is the critical velocity of channel floor based on ft. /s, d implies the diameter of sediment particles based on mm, ρ_s the specific mass of sediment particles and ρ the specific mass of water. Upon placing the D_{50}=1mm and ρ_s = 2.65, maximum standard velocity of channel equaled to 0.67. Upon placing the data in diagram and considering the maximum standard velocity of channel by Mavis method, fig. 4 is obtained.

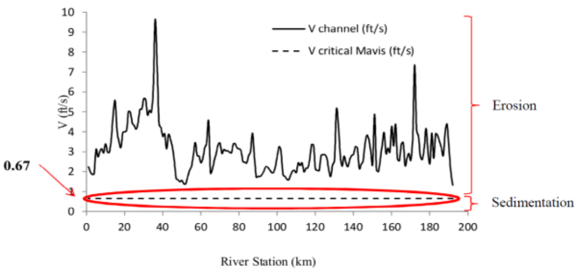


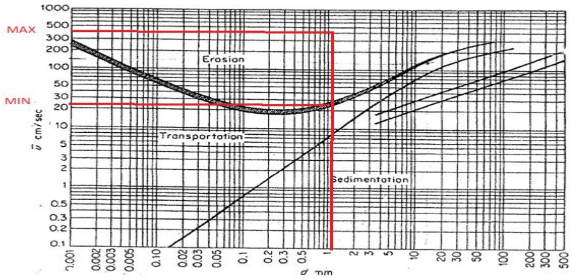
Fig. 4. Comparison of velocity by Mavis method for 25-year return period.

Critical Velocity Using Hjulstorm Diagram

Hjulstorm (1935) offered a diagram for determination of critical velocity. This diagram is formed on this basis that due to availability of section's average velocity to the bed velocity, average velocity of channel has been assumed 40% more than bed velocity for flow depths more than 1. Thus, this diagram based on the obtained average velocity and the line located between erosion and transportation areas may estimate the average velocity in critical conditions (movement threshold). In this diagram, in addition to movement threshold velocity, sedimentation velocities also may be calculated.

During analysis of sedimentation, erosion and equilibrium states of a river, various criteria have been presented that in this study Hjulstorm criterion has been used. In this criterion, the flow velocity is drawn in lieu for the particles size. In this curve, three areas of erosion, sedimentation and equilibrium have been distinguished from each other. Consequently, several sediment samples extracted along Gheshlagh River have been used for the present study.

Whereas for using Hjulstorm curve, the average velocity of flow within the respective sections are required to be estimated, HEC-RAS model has been implemented using the 25-year discharge. Fig. 5 shows the comparison of velocity according to Hjulstorm method for the 25-year return period. Considering this figure, it is observed that approximately 80% of flow sections have a state that expose the river to the erosion.



Determination of critical velocity in terms of scouring and sedimentation based on particles size (Hjulstrom, 1935)

Fig. 5. Comparison of velocity by Hjulstorm method for 25-year return period.

As observed, after performing the computations required for each method, upon comparing the average flow velocity to critical velocity, erodible and sedimentary zones were specified and the results were exhibited as diagram for 25-year return period. In addition, in order to show the results of all three methods, summary of computations has been provided in table 1 for some reaches.

Table 1. Results related to some reaches obtained from 3 methods for 25-year return period.

Station	Profile	Q (m^3/s)	Fortier		Mavis		Hjulstrom
			Vcr (ft/s)	Result	Vcr (ft/s)	Result	Result
192	Yr = 25	369	2.5	Sedimentation	0.67	Erosion	Erosion
191	Yr = 25	369	2.5	Sedimentation	0.67	Erosion	Erosion
190	Yr = 25	369	2.5	Sedimentation	0.67	Erosion	Erosion
189	Yr = 25	369	2.5	Erosion	0.67	Erosion	Erosion
188	Yr = 25	369	2.5	Erosion	0.67	Erosion	Erosion
187	Yr = 25	369	2.5	Erosion	0.67	Erosion	Erosion
186	Yr = 25	369	2.5	Sedimentation	0.67	Erosion	Erosion
184	Yr = 25	369	2.5	Erosion	0.67	Erosion	Erosion
183	Yr = 25	369	2.5	Erosion	0.67	Erosion	Erosion
182	Yr = 25	369	2.5	Sedimentation	0.67	Erosion	Erosion

According to table 1 and presented diagram, Fortier method determines some reaches as sedimentary ones, but because the only intervening parameter in Fortier method includes particles diameter and fluid quality, moreover no theoretical study has been applied so far for determination of accuracy and non-accuracy of these values, thus this method has lower accuracy than two other methods. It is notable that Hjulstorm diagram is only applied for channels with water depth 1m at least and if required this procedure to be used in other depths, then it is necessary to suppose a correction factor for it. But, in Gheshlagh River, even in the flood discharges with 5-year return period, the river depth has not been reached to lower than 1m. Therefore, Hjulstrom is reliable for the said river and on the other side, results of this method are completely consistent to Mavis equation that in addition to sediment particles diameter, considers the specific weight of water and sediment. Furthermore, the results show that upon increasing the sediment transportation rate in the channel, the width and depth variations rate over time will be accelerated comparing to the state without sediment; in other word, the response of Gheshlagh Riverbed to sediment supply variation rate has been provided by dependence to flow rate, distribution of particles size and sediments transmission rate. These parameters within the short time have a high tendency to variation in order that ultimately balance their channel, gradient and geometry to the new conditions. The steady section may have a role as invariable section in sediment transport. At the end of reaches and after stability time, this subject was observed in all reaches so that in steady section state, the side is balanced and has no sedimentary transmission, but in the riverbed, the sediment transmission is observed. These observations demonstrate the field observations and laboratory results that formerly had been offered by other researches in relation to steady channels and sediment transmission mechanism.

Conclusion

In this research that erodibility or sediment ability of river reaches using has been determined three methods of Fortier, Mavis and Hjulstrom, the accuracy and efficiency of HEC-RAS model has been analyzed by means of actual and observed results and following results were obtained.

According to analysis of Fortier, Mavis and Hjulstrom methods, it is concluded that erodibility and sedimentation in the different river reaches has been occurred based on the different criteria.

Analysis of three above methods within the beginning, middle and end reaches indicates that the river is eroded within the most times and this erosion is increased from upstream to downstream. As the comparison shows averagely, the erosion in the middle and end reach has been increased 23.8 and 64.2% to beginning reach. It may be related to the increase of river slope. Moreover, analysis of longitudinal profile of riverbed indicates that the river slope is more than 3.2.

The performed computations and offered diagrams show that Gheshlagh River within the studied reach has critical conditions due to erosion and approximately in more than half of studied area, it has an erodible bed. Hence, it is necessary to take the conservational measures for prevention and reduction of probable losses in the said river.

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