Journal of Water Sciences Research,
ISSN: 2251-7405 eISSN: 2251-7413
Vol.7, No.2, Winter 2015, 1-9, JWSR

Sensitivity analysis of geometric and hydraulic parameters on water depth of flood plain in the Ab Nik River

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Received: 12 June 2015 Accepted: 17 November 2015

Abstract

Transfer of debris flow caused by floods in the river downstream of the mountains leads to several damages every year. Numerous researches have been carried out on the Mountain Rivers the results of which show the importance of performing more researches to control debris flows in the floodplain because of various effective hydraulic-geometric parameters.For this purpose, AbNik Mountain River located in Jajrood basin, northern Iran was selected to evaluate the effect of geometric and hydraulic parameters on moving and controlling the debris flows. Therefore, a length of 200 meters of the steep mountain river length was chosen for which velocity values were measured at different times and at different levels. In 28 selected sections, bed materials were sampled and mapped. Using the analytical methods for field data measurement and geometric properties of the composite trapezoidal channels and hydraulic equations such as Manning, sensitivity analysis of different geometric- hydraulic parameters was performed. In this analysis, using Manning equation in the composite trapezoidal channels, a multivariate equation was obtained by which the flow depth is obtained using trial and error analysis method (Newton-Raphson equation), i. e. variations of each parameter with respect to flow depth in the flood plain are obtained by keeping the other parameters constant at the minimum value. Changes of the geometric and hydraulic parameters were plotted versus flow depth. Results were obtained by investigating the resulted diagrams and equations. Analysis of the results showed that the longitudinal slope of the channel and width of the channel floorhad the greatest effects on the flow depth in the flood plain of the Mountain Rivers.

Keywords

Hydraulic geometry; Sensitivity analysis; Mountain rivers; Depth of flood

Introduction

Flood occurrence in mountain rivers will directly influence the human life and downstream systems of the river. 60% of the natural disasters in the mountainous areas are related to the earthquake and flood. Among the risks associated with mountain rivers is mainly flood occurrence and sediment transportation including debris flows (Ellen 2010). Flash flood is one of the floods usually with high peak

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values in a short time that last for less than an hour making it difficult to warn the flood occurrence. Such flood will cause numerous hazards and damages because of the rapid increase in water level and high flow velocities. As a result, these rapid and sudden floods in steep rivers usually will transport sediment and woody debris intensifying the induced damages (Jarrett, 1990; Borge et al., 2007).

Scheuren et al. (2008) and Gaume et al. (2009) performed studies and indicated that the flash flood due to rapid melting of snow and heavy rains in mountain areas is one of the most dangerous natural phenomena, which involves rapid transfer of sediment bearing runoff. Occurrence of such flash floods with high sediment transportation capacity may cause considerable loss of lives and property every year.

Montgomery and Buffington (1997) performed studies to establish a relation between the river morphology and activities performed in the rivers by human originated activities and natural factors. By classifying the steep mountain rivers, they indicated that such rivers usually have a Step-pool morphology limited to the narrow valleys with rocky bed sides.

Bowman (1977) concluded that in the morphology of the steep rivers, river bed causes frequent flow regime changes from the critical flow on the steps to the supercritical flow and then, to the subcritical flow in the pools. Then, Chin (1989) indicated the step-pool as the governing characteristic on the channel beds in steep mountain rivers that is the main water and sediment source for the downstream large basins. Therefore, they indicated the proper understanding of the step-pool as the necessary step to identify the hydraulic-geometric parameters effecting the river system changes. Grant et al. (1990) performed studies and estimated the step distances almost 1 to 4 times the river width in the step-pool rivers.

Researches on the stability of step-pools in Mountain Rivers show that though the step-pools are normally observed in stable beds, their stability is not absolute and depends on their size, scale and shape. Hydraulic analysis of the step-pool sequence stability in the intact reaches of Mountain Rivers of Santa Monica, California indicated them as active channels' features reconstructed during 5 to 100 years floods (Chin, 1998).

Since researches performed on Mountain Rivers are not as much as less steep rivers, further researches on Mountain Rivers and data analysis and presenting the useful results are inevitable. further researches to evaluate the effect of different Hydraulic-Geometric parameters on the flood depth of the Mountain Rivers were performed in this study.

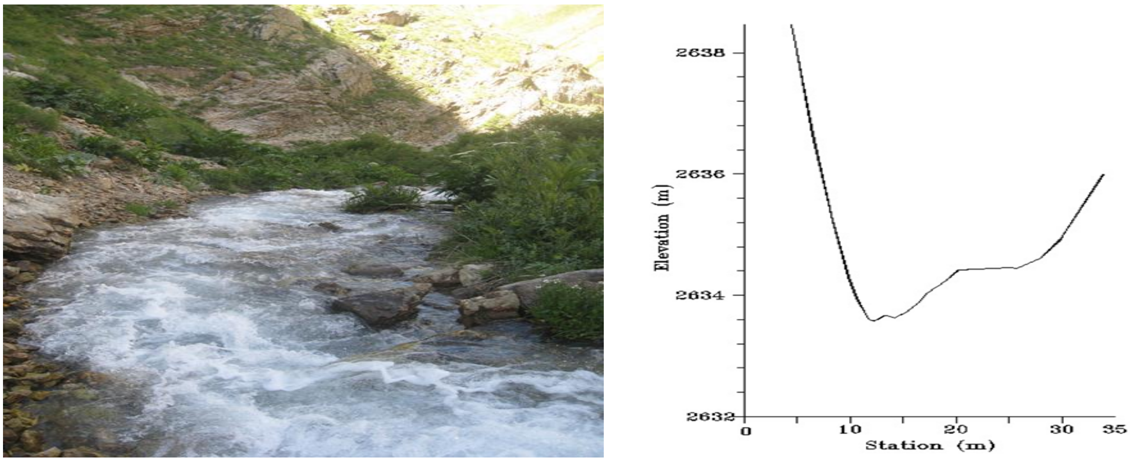
Field site and methods

Ab Nik River is one of the tributaries of the Jajroud River located in the northeast of Tehran, Iran with the geographical characteristics listed in Table 1. The river has no gauging station and is an ungauged river. Therefore, performing studies on the river is of utmost importance and has its unique problems.

Table 1.
Characteristics of the river reach.

River	Length (km)	Altitude (m)	Longitude	Latitude
Ab NIK	7	2500-2700	51° 37′ 15”	**36° 0′ 33”**

According to the recommendations by the researchers to study the flow in the Mountain Rivers and present the actual and natural results of these rivers, it was necessary to select an intact river reach. Therefore several field surveys were performed on Jajroud Basin located in North East of Tehran in order to select an intact and undisturbed river reach. As a result, after the field surveys and considering the recommendations by Montgomery and Buffington (1997), a river reach with a minimum length of 10 to 20 times the width of the river was selected to study the river morphology and surrounding environmental characteristics. Considering the average width of the river about 5 meters, a 200 meters long reach of the Ab Nikriver was selected in this study. In the selected river reach, mapping was performed exactly at 28 cross-sections with an approximate distance of 7 meters. . Figure 1 shows examples of the cross-sections.



(a) (b)

Figure 1. An example of the Ab Nik Mountain River cross-sections

Bed material sampling performed along with the mapping due to the wide range of bed particle size from silt and sand to very coarse particles. River bed reinforcement and high velocities of the flow will wash away fine particles and cause a turbulent bed during the sampling steps (Bunte and Abt, 2001). Despite the difficulties in sampling the coarse-grained mountain river beds, it is necessary in determination of the roughness coefficient at different river sections. Therefore, the roughness coefficient of different sections was determined as follows: for fine-grained particles sampling and weighting method was used, for coarser particles like cobblestones Wolman method was used, and for larger non-removable stones taking photographs and then Barnes (1967) method was used to estimate the roughness coefficient (Figure 2).

(a) (b) (c)

Figure 2. the size of bed materials measurements in Ab Nik River

In the three river sections with channel form, flow velocities were measured during two high and low water level conditions. The first measurement was carried out in May 2014 after melting of snows, and the second measurement was carried out in July 2014 in the low water level period (Figure 3).

Figure 3. River discharge measurement during high water level conditions

In this study, considering the average bankfull discharge and the effects of geometric parameters including channel and flood plain widths, bank slope, channel flow depth, longitudinal slope and roughness coefficients of the channel and flood plain on the flood depth, the effect of each parameter was investigated by using analytical methods and assuming asymmetric composite trapezoidal cross sections (Fig. 5) using the Manning formula (as recommended by Howard. H. Chang, 1939) according to Eq. 1.

$$Q_{total}=((B_c+Z_c y)\times y)+((Bc+2Zcy)h_f+\frac{1}{2}Zc\, h_f^{2}))\times\frac{1}{n_c}\times\left[\frac{(B_c+Zc\, y)y+h_f\left[(B_c+2Zc\, y)+\frac{1}{2}Zh_f\right]}{B_c+2y\sqrt{1+Zc^2}+h_f\left(1+\sqrt{1+Zc^2}\right)}\right]^{\frac{2}{3}}\times S^{\frac{1}{2}}+ \quad [1]$$

$$h_f(B_f+\frac{1}{2}Zf\times h_f)\times\frac{1}{n_f}\times\left[\frac{h_f\left[B_f+\frac{1}{2}Zf\, h_f\right]}{B_f+h_f\sqrt{1+Zf^2}}\right]^{\frac{2}{3}}\times S^{\frac{1}{2}}$$

where,
nf=Manning coefficient for floodplains [s/m$^{1/3}$]
nc=Manning coefficient for channel [s/m$^{1/3]}$
Bf=width of floodplains [m]
Bc=width of channel [m]
y=water level in channel[m]
hf= Depth of flood [m]
Zc= the side slope of the channel
Zf= the side slope of the floodplain

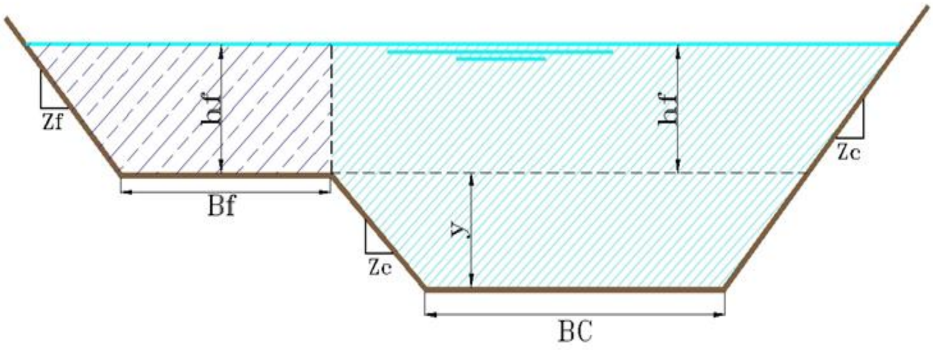


Figure 4. The asymmetric trapezoidal channel

Results and Discussions

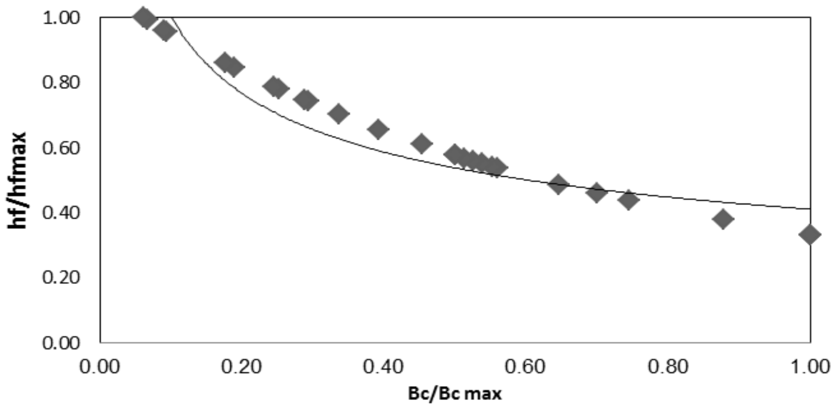
As mentioned in the previous section, to investigate the effect of different hydraulic-geometric parameters on flood depth of the Mountain Rivers, an Ab Nik River reach was selected. Using the Manning formula for the composite trapezoidal channels, a multivariate equation was obtained by which the flow depth was obtained using trial and error analysis method (Newton-Raphson equation), i. e. variations of each parameter with respect to flow depth in the flood plain were obtained by keeping the other parameters constant at the minimum value. To investigate the effect of each geometric and hydraulic parameter on the flood depth and performing the sensitivity analysis, corresponding dimensionless diagrams were presented. The dimensionless parameters include channel width ratio (Bc/Bcmax), longitudinal slope (S/Smax), floodplain width (Bf / Bfmax), channel depth (Y / Ymax), roughness coefficient of the channel (nc / ncmax), roughness coefficient of the flood plain (nf / nfmax), channel bank slope (Zc / Zcmax) and the slope of the flood plain (Zf / Zfmax). Dimensionless curves of the dimensionless parameters were plotted as shown in Figs. 5 and 6. By studying the linear and nonlinear equations, the best nonlinear exponential and linear equations were fitted to the curves in Figs. 5 and 6, respectively.

Considering Fig. 5 and the fitted exponential equation for each graph it follows that each of the dimensionless parameters have a decreasing trend so that the influence of these dimensionless parameters on the flood depth was more at the beginning of the curve with smaller values. By increasing the values of these dimensionless parameters, their influence gradually decreases. Adverse effect of the width and slope on the flood depth in a constant discharge is attributed to the fact that by decreasing the width, flow depth and thus, flood depth is increased. In addition, by increasing the longitudinal slope, flow velocity is increased and thus, flood depth is decreased. However, according to Fig. 6, despite the decreasing trend of Zc and Zf dimensionless parameters with respect to the flood depth, nc and nf dimensionless parameters representing the roughness coefficients of the channel and flood plain have an ascending trend. The reason is attributed to the fact that the roughness resistance against the flow directly influences the flood depth, i. e. by increasing the roughness coefficient, flow velocity is decreased and flow depth is increased.

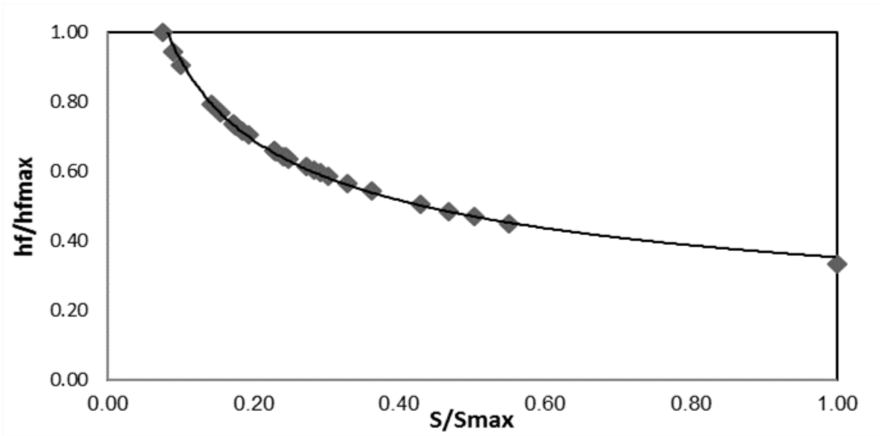
According to Figure 6, in the first part of the graph, steeper slopes have less effect on the flood depth, because steeper slopes will cause higher flood flow velocities and decrease the flood residence time and hence, flood depth.

According to Montgomery and Buffington classification (1997), the considered river reach had a step-pool and cascade combined morphology and hence, a wide range of water surface slope exists that eventually causes an extensive water surface slope diagram in comparison to the flood depth one indicating the effect of this parameter in comparison to other parameters.

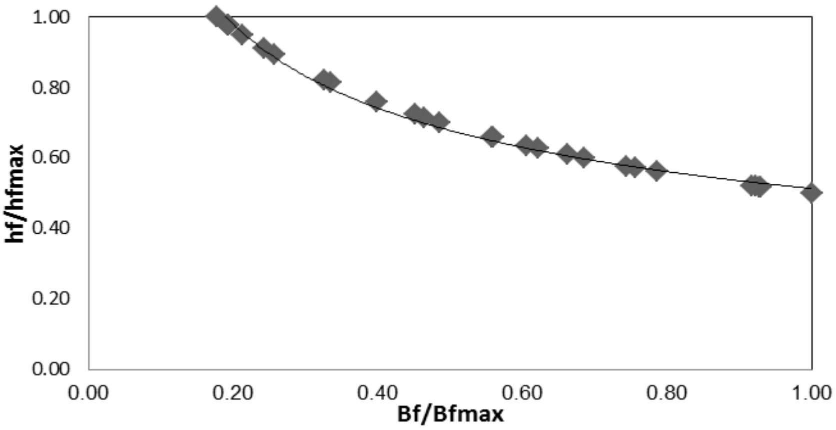
According to Table 2, it was concluded that the channel width and longitudinal slope were the effective parameters, respectively.



(a)

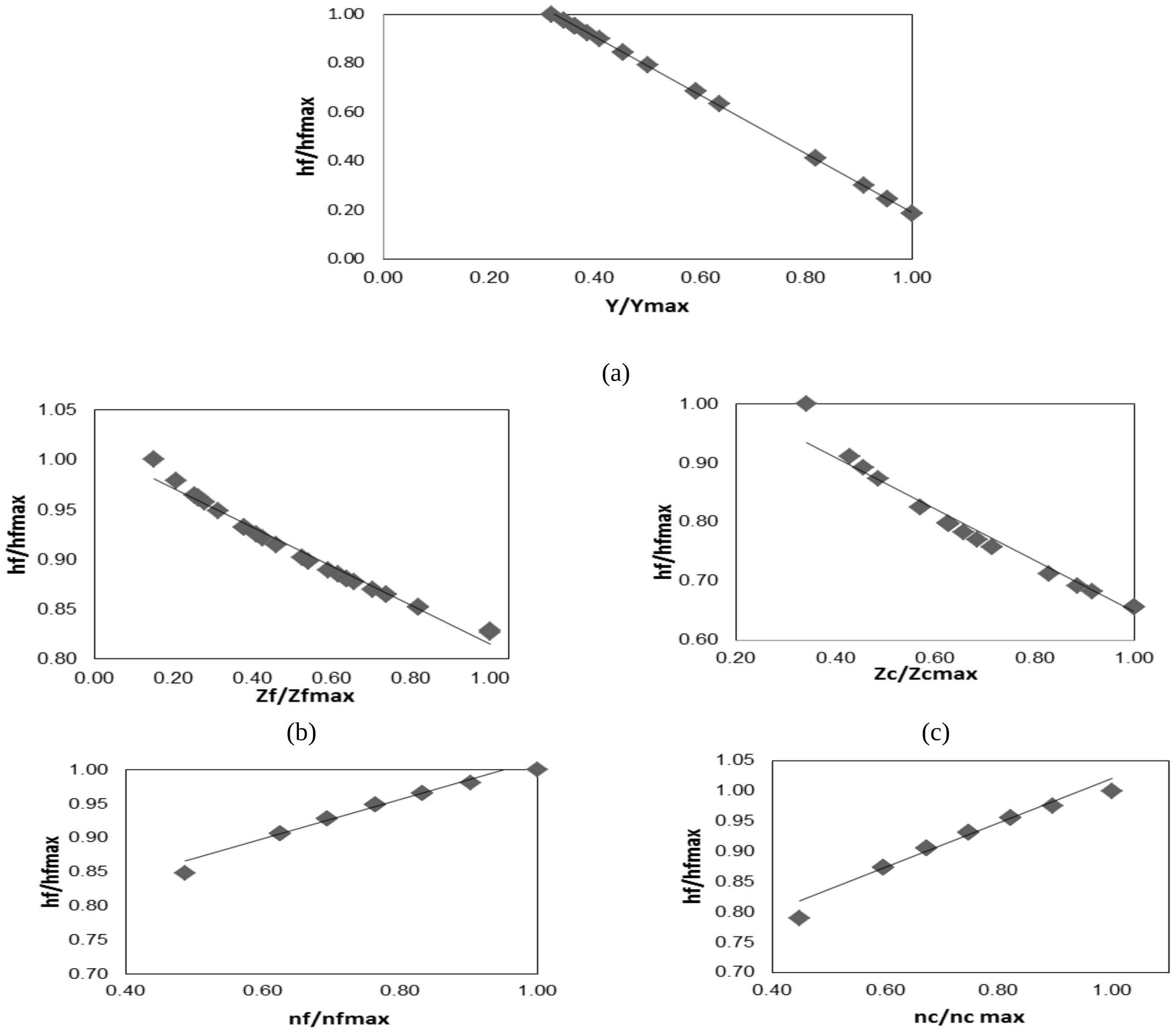


(b)



(c)

Figure5. Dimensionlesscurve of the effect of channel width, flood plain width and longitudinal slope on the flooddepth



(a)

(b) (c)

(d) (e)

Figure6.Dimensionlesscurve of the effect of channel width, channel and flood plain wall slopes, channelandfloodplainroughnesscoefficientonthe flood depth.

Table2.
Sensitivityanalysis results of the effective parameters on theflood depth

Figure	Dimensionless Parameter	Fitting Equation	R^2
5-a	Bc/Bc_{max}	$y = 0.41x^{-0.388}$	0.88
5-b	S/S_{max}	$y = 0.35x^{-0.417}$	0.99
5-c	Bf/Bf_{max}	$y = 0.51x^{-0.401}$	0.99
6-a	Y/Y_{max}	y = -1.19x + 1.3863	0.99
6-b	Zf/Zf_{max}	y = -0.19x + 1.0096	0.98
6-c	Zc/Zc_{max}	y = -0.44x + 1.0843	0.96
6-d	nf/nf_{max}	y = 0.29x + 0.7248	0.98
6-e	nc/nc_{max}	y = 0.37x + 0.6536v	0.97

CONCLUSIONS

- Adverse effect of the width on the flood depth in a constant discharge is attributed to the fact that by decreasing the width, flow depth and thus, flood depth is increased.
- By increasing the longitudinal slope, flow velocity is increased and hence, flood depth is decreased
- Flood plain width has an exponential descending relation with the flow depth in the Mountain Rivers
- Channel depth showed a descending trend with respect to the flow depth.
- Zc and Zfshowed a descending trend with respect to the flood depth.
- nc and nf dimensionless parameters representing the roughness coefficients of the channel and flood plain, respectively showed an ascending trend with respect to the flood depth
- Channel width and longitudinal slope were the most effective hydraulic and geometric parameters on the flood depth in the Mountain Rivers.
- By identification of the effective parameters on the flood depth inungauged Mountain Rivers, an estimation of the flood can be obtained.

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