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Determining the Roughness Coefficient of Natural Channels and Flood Zone Focusing on the Vegetation Effect

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Abstract: *According to this fact that the subject matter of open channels hydraulic is investigating the rivers streams and one of the effective issues of streams in open channel is resistance against current; therefore, this resistance factor, in the hydraulics of open channels, is considered by applying the channel roughness coefficient. Of the important factors in line with determining this coefficient is the effect of vegetation that has been investigated in this research. By means of available formulas and field visits from the studied area (part of the Kashfrud River), also by means of soil gradation experiment, the exact values of roughness coefficients were determined. Then based on the obtained roughness coefficients, the values of the river flood zone were calculated and compared with the numerical values of the river flood zone which were obtained from Kavosh Pay Mashhad consulting engineers Company information. Different methods have been used to calculate the roughness that based on the obtained results, the area of the river flood zone is different about -29 and +21 percent with the designated values by the consultant. So this difference indicates the importance of this issue. In fact, the issue of scrutinizing the estimation of roughness caused by vegetation on a practical scale should be studied more prudently and with indigenous research on different plant species of each study area.*

Keywords: *Roughness Coefficient, Natural Channel, Vegetation, Flood Zone, Kashfrud River*

INTRODUCTION

The roughness coefficient is an important parameter in the natural channels that has been considered from different perspectives. This coefficient is a function of several factors such as the shape and form of a channel, the river bed material, road roughness, vegetation, etc. that determining the effect of vegetation factor has been selected as the main aim of the current research.

In order to determine the effect of vegetation roughness coefficient, one must consider several factors which are: 1. stream depth, 2. vegetation concentration, 3. vegetation height, and 4. vegetation element diameter, that each of which directly affects roughness coefficient caused by vegetation effect (Hosseini et al., 2008); therefore, exact determination of roughness coefficient can be achieved by means of calculating the above-mentioned factors and optimal formulas and effective numerical methods. For this end, in this research four methods of Jarvela, Velzen, Fathi-Moghadam and Cowan methods were used to calculate the vegetation roughness in an area with a range of about 1 km from the Kashfrud River, which consists of 8 cross sections. The main reason for selecting this area is the presence of studies which have been conducted by consulting company that makes it possible to compare the computational values with existing values. Then, based on these obtained values and the roughness resulting from the material of the river bed which were obtained from field surveys and visits, the total roughness for the study area is obtained, finally, with the calculated roughness values of the river depth and flood zone was determined and compared with the depths and flood zone of the consulting company (Kavosh Pay, 2013). The obtained results illustrate the effects of the obtained roughness coefficient on the river depth and flood zone.

Vegetation Roughness Coefficient Estimation Methods

These methods are as follows:

a) **Jarvela Method**: Jarvela by means of different studies reached the following empirical formula to calculate the vegetation roughness coefficient.

$$f = \frac{4dhC_d}{a_x a_y} \quad (1)$$

Where d is vegetation element diameter (m), h is the depth of water (m), a_y and a_x are longitudinal and longitudinal distances of vegetation elements (m), f is Darcy–Weisbach roughness coefficient, C_d is drag coefficient (that its value can be considered as 1.5).
The vegetation density (m) is related to a_y and a_x by means of the following relation:

$$m = \frac{1}{a_x a_y} \quad (2)$$

Therefore, the Jarvela method can be presented as follows:

$$f = 4dhmC_d \quad (3)$$

Manning's roughness coefficient (n) based on the following relation is related to f that the value of n can be calculated based on this relation:

$$f = 8g\left(\frac{n}{R_h^{\frac{1}{6}}}\right)^2 \quad (4)$$

Where g is earth gravitational acceleration and R_h is the hydraulic radius (Jarvela, 2004).

b) **Fathi-Moghadam Method:** Fathi-Moghadam by means of experimental researches achieved the formulas below in order to calculate the roughness coefficient of vegetation in the non-submerged state.

$$n = 0.36\left(\frac{V}{\sqrt{\frac{\psi E}{\rho}}}\right)^{-0.4}\left(D\ \frac{A}{a}\right)^{0.2}\left(\frac{Y}{H}\right)^{0.48} \times R_h^{\frac{1}{6}} \quad (5)$$

$$f = 10.2\left(\frac{V}{\sqrt{\frac{\psi E}{\rho}}}\right)^{-0.78}\left(D\ \frac{A}{a}\right)^{0.4}\left(\frac{Y}{H}\right)^{0.95} \quad (6)$$

Where n is the Manning's coefficient. H is vegetation height, Y is water depth, Y/H is submergence ratio, A is the cross-section of one side of the vegetation foliage, a is the cross-sectional of the pipe used in the Fathi-Moghadam experiment covered with vegetation, V is current rate, ρ is water density, D is vegetation density, *A/a* is the absorbed momentum level, ψE is the parameter for vegetation index that is a function of vegetation density and height. (Values of *A/a* and ψE by Fathi Moghadam are presented in Table 1) (Fathi-Moghaddam and Drikvand, 2012).

Table 1: The values of ψE and A/a based on Fathi-Moghadam method

Vegetation type	ψE	*A/a*
Tamarisk	2.32	0.175
Very dense	2.02	0.150

c) **Velzen Method:** Velzen presented the Chézy's coefficient as a vegetation roughness coefficient in the submerged state. Based on the following relation, The Chézy's coefficient (c) is related to the Manning's coefficient (n) and value of *n* can be obtained from this relation (Velzen et al., 2002).

$$C=\frac{{R_h}^{1/6}}{n} \qquad (7)$$

d) **Cowan Method:** In the Cowan method, Manning's roughness coefficient (*n*) is calculated as a function of different factors, which is defined in the following formula.

$$n=(n_o + n_1+n_2+n_3+n_4)n_5 \qquad (8)$$

Where n_o is Manning's coefficient that is related to the aggregate of substrate (bed) materials, n_1 is Manning's coefficient related to the roughness degree at the river bed, n_2 is Manning's coefficient related to river cross-section changes, n_3 is Manning's coefficient related to obstacles in the river path, n_4 is Manning's coefficient related to vegetation and n_5 is Manning's coefficient related to the degree of curvature of the river path.

In this research, the coefficient n_4 has been considered and it has been used in calculations of roughness coefficient due to the effect of vegetation.

The values of the roughness coefficient because of the vegetation effect n_4 are presented in Table 2 for the main channel and in Table 3 for floodplain (George et al., 1989).

Table 2: Main Channel Vegetation Coefficient Values (n_4) based on the Cowan method

Description	n_4 coefficient range	Vegetation density
Vegetation is very dense and flexible that stream depth is at least 2 times the vegetation. Vegetation of trees such as Willow trees that their stream depth is at least 3 times more than vegetation height.	0.002-0.01	Low
Vegetation of grasslands that mean depth of stream is 1-2 times of vegetation, dense stalked grasslands and trees that depth of stream is 2-2 times of vegetation.	0.01-0.025	Moderate
Vegetation that stream height is almost equal to the vegetation, such as 10-8-year-old willow trees and its hydraulic radius is not more than 60 cm.	0.025-0.05	High
Vegetation of grasses that depth of stream is less than half the vegetation height.	0.05-0.1	Very high

Table 3: Floodplain vegetation coefficient values (n_4) based on Cowan method

Description	n_4 coefficient range	Vegetation density
Vegetation is very dense and flexible that stream depth mean is at least 2 times the vegetation. Vegetation of trees such as willow trees etc. that average depth of stream is at least 3 times the vegetation height.	0.002-0.01	Low
Vegetation of grasslands that average depth of stream is 1-2 times od vegetation, dense stalked grasslands and trees that stream depth 2-3 times of vegetation.	0.01-0.025	Moderate
Vegetation that its stream height is almost equal to the vegetation, such as 10-8-year-old willow trees and the hydraulic radius is not more than 60 cm.	0.025-0.05	High

Vegetation of grasses with a stream depth less than half of the vegetation height	0.05-0.1	Very high

Calculating The Roughness Coefficient (*n*)

In this section, the total roughness coefficients (n) value, in accordance with the Cowan and by means of the values obtained from the results of field visits and the parameters taken from the site to calculate the formulas can be calculated view as follows.

$$n = n_o + n_v \qquad (9)$$

Where n_o regardless of the effect of vegetation due to substrate materials is the basic roughness factor, and n_v is the coefficient of the roughness of vegetation.

A. **Calculating vegetation roughness coefficient (n_v):** Based on the formulas presented by field visits from the introduced region, the values of the roughness coefficient have been calculated based on the four studied methods that Table 4 indicates the roughness coefficients based on the desired methods. In the presented table, the main channel (M), right floodplain (R), the left floodplain (L) and the numbers 1-8 are the numbers of studies cross-sections. In this state and condition, the vegetation is in a submerged mode; consequently, the submerged methods (Jarvela, Velzen, and Cowen) have been used.

Table 4: Values of n_v by means of the introduced methods

Cross section	Jarvela	Velzen	Cowan
1-L	0.019035	0.020982	0.018
1-R	0.014899	0.02099	0.018
1-M	0.026887	0.049623	0.0175
2-L	0.028596	0.03259	0.018
2-R	0.031971	0.033793	0.018
2-M	0.033877	0.04746	0.0175
3-L	0.018899	0.034335	0.018
3-R	0.014941	0.028697	0.018
3-M	0.029177	0.034641	0.0175
4-L	0.014743	0.029469	0.018
4-R	0.014743	0.026027	0.018
4-M	0.034812	0.048301	0.0175
5-L	0.012946	0.037417	0.018
5-R	0.014181	0.040183	0.018
5-M	0.029339	0.044478	0.0175
6-L	0.014377	0.017274	0.018
6-R	0.013747	0.022909	0.018
6-M	0.030148	0.044394	0.0175
7-L	0.015528	0.024315	0.018
7-R	0.016772	0.02576	0.018
7-M	0.037876	0.034853	0.0175
8-L	0.013991	0.037684	0.018
8-R	0.012953	0.035641	0.018
8-M	0.03333	0.035414	0.0175

B. **Calculating the roughness coefficient (n_o):** In order to calculate $n_o$values, the d_{75} values were used which can be achieved from the results of the soil grading test which is shown in Table 5, and it is obtained based on formula 10 (Henderson's formula) (French, 1986).

Table 5: Values of d_{75} and n_o

Cross section	d_{75}	n_0
Main Channel (1)	0.01740	0.01934
Main Channel (2)	0.01760	0.01938
Main channel (3)	0.01790	0.01943
Right floodplain (1)	0.00714	0.01660
Left floodplain (1)	0.00634	0.01630
Right floodplain (2)	0.00714	0.01660
Left floodplain (2)	0.00714	0.01660
Right floodplain (3)	0.00873	0.01710
Left floodplain (3)	0.00634	0.01245

$$n_o = 0.038 d_{75}^{1/6} \quad \text{(Henderson's method)} \qquad (10)$$

Where d_{75} is the maximum diameter of a particle of soil that is 75% of the soil weight is finer than that participle.

C. **Calculating total roughness:** As it was mentioned, by adding n_o and n_v values which were obtained in previous sections, the value of *n* can be easily calculated. The values of n for the introduced methods in the studied region are presented in Table 6.

Table 6: Values of ***n*** by using the introduced methods

Cross section	Jarvela	Velzen	Cowan
1-L	0.035335	0.037282	0.0343
1-R	0.031499	0.03759	0.0346
1-M	0.046227	0.068963	0.03684
2-L	0.044896	0.04889	0.0343
2-R	0.048571	0.050393	0.0346
2-M	0.053217	0.0668	0.03684
3-L	0.035199	0.050635	0.0343
3-R	0.031541	0.045297	0.0346
3-M	0.048517	0.053981	0.03684
4-L	0.031343	0.046069	0.0346
4-R	0.031343	0.042627	0.0346
4-M	0.054192	0.067681	0.03688
5-L	0.029546	0.054017	0.0346
5-R	0.030781	0.056783	0.0346
5-M	0.048719	0.063858	0.03688
6-L	0.030977	0.033874	0.0346
6-R	0.030347	0.039509	0.0346
6-M	0.049528	0.063774	0.03688
7-L	0.032128	0.040915	0.0346
7-R	0.033372	0.04236	0.0346
7-M	0.057256	0.054233	0.03688
8-L	0.030291	0.053984	0.0343
8-R	0.030053	0.052741	0.0351
8-M	0.05276	0.054844	0.03693

The effects of roughness on the computational depth and flood zone and its comparison with the existing flood depth and zone

The obtained *n* values were entered into the HEC-RAS software and new outputs were determined. By changing the values of n, the values of the flood zone in the river will be changed.

It should be noted that design discharge current flow and the intended value of n for all studied cross-sections are considered by the consulting company are as follows.

$$Q{=}309.6\frac{m^3}{s} \qquad n_C{=}0.045 n_L = n_R = 0.042 \quad \text{(For the whole range)} \tag{11}$$

Where n_C is the roughness coefficient of the main channel, $n_L$is the roughness coefficient of the left floodplain, $n_R$is the roughness coefficient of the right floodplain and Q is the design discharge flow rate.
The values for depth and water level are presented in Table 7 in Jarvela, Velzen, Cowan and Consulting Company methods.

Table 7: Depth and level of water level in Jarvela, Velzen, Cowan and Consulting Company methods

Cross-section number	Bed level (m)	Water level (m)				Water depth (m)			
		Consultant	Jarvela	Velzen	Cowan	Consultant	Jarvela	Velzen	Cowan
31955.31	943	946.7	946.52	946.84	945.46	3.7	3.52	3.84	2.46
31856.29	942	946.5	946.26	946.58	945.76	4.5	4.26	4.58	3.76
31749.8	942	946	945.91	946.25	945.81	4	3.91	4.25	3.81
31638.96	942	945.79	945.63	945.92	945.24	3.79	3.63	3.92	3.24
31565.92	942	945.65	945.51	945.74	945.57	3.65	3.51	3.74	3.57
31502.94	942	945.5	945.21	945.63	945.11	3.5	3.21	3.63	3.11
31359.96	941	944.68	944.56	944.98	944.23	3.68	3.56	3.98	3.23
31301.42	941	944.47	944.41	944.71	944.27	3.47	3.41	3.71	3.27

In tables 8 and 9, the obtained flood zone was presented based on the studied methods (based on m^2) and it was compared with the flood zone of the consulting company.

Table 8: Flood zone values based on the introduce methods

Investigated methods	Flood zone (m^2)
Jarvela	108411
Velzen	135403
Cowan	90075
counsulting company	119923

Table 9: Difference in the computational flood zone of different methods with the values of computational flood zone of the consultant (%)

Investigated methods	Percentage difference of flood zone area
Jarvela	-9.59
Velzen	12.91
Cowan	-24.88

Figure 1 indicates a comparison of the computational zone values with the introduced methods with the flood zone of the consulting company. As it is clear from this figure, the obtained values are significantly different from the consulting company flood zone.

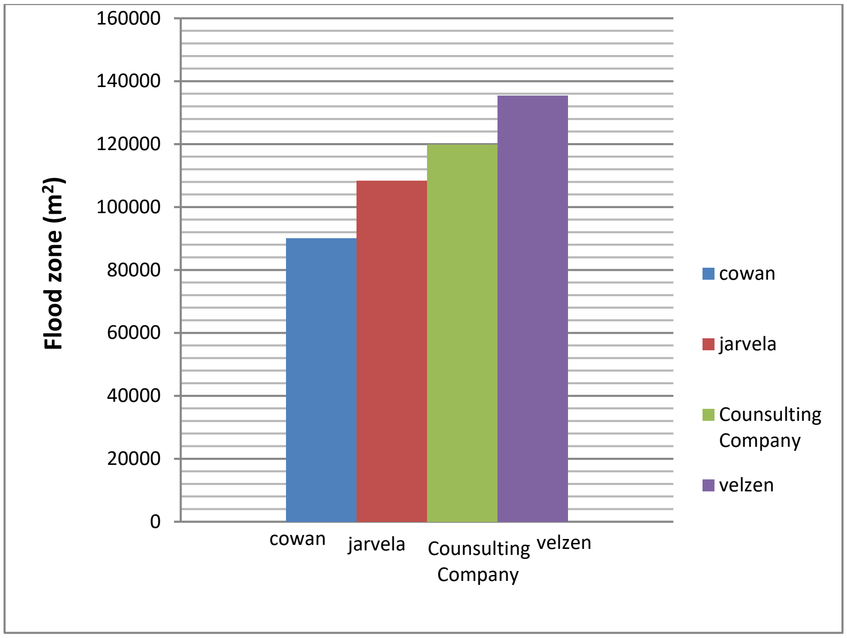

Figure 1: A comparison of the computational zone values with the proposed methods with the consulting company flood zone

In the following, to determine the sensitivity of the proposed methods to the river discharge flow rate, the flood zone value for the 50 m^3/s discharge flow rate was recalculated based on the consultant's information, that the values of roughness coefficient (n) and the flood zone for them were compared and presented based on the proposed methods and the consultant company values. Tables 10 and 11 and Fig. 2 also present a comparison of the computational zone with the consulting company flood zone.

Note: In this condition, vegetation is in the non-immersed state; consequently, non-immersed methods (Fathi Moghadam, Jarvela, and Cowan) have been used.

Table 10: Flood zone values based on the introduced methods with a 50 m^3/s discharge flow rate

Investigated methods	Flood zone (m^2)
Jarvela	11925.21
Fathi-Moghadam	20310.45
Cowan	19411.69616
counsulting company	16789.22

Table 11: Difference of flood zone of different methods with values of consultant's flood zone with a 50 m^3/s discharge flow rate (%)

Investigated methods	Percentage difference of the flood zone area
Jarvela	-28.98
Fathi-Moghadam	20.96
Cowan	15.62

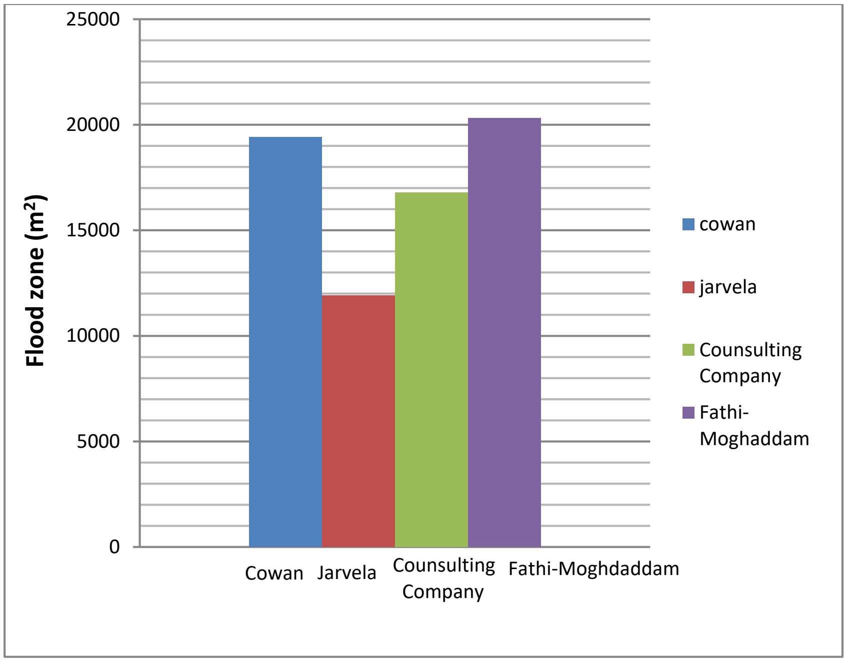

Figure 2: Comparison of the flood zone with the introduced methods with the consulting company flood zone with a 50 m^3/s discharge (m^2)

Conclusion

In this paper, different methods have been used to calculate the roughness coefficient that according to the obtained results, the area of the river flood zone based on the exact calculation of vegetation roughness, is different from -29 to +21 percent with consultant's designated values. Since design margin of safety will not be considered in line with determining the boundary of river bed due to facing with legal issues and land ownership, like other engineering issues, but the boundary of river bed should be determined with the uppermost accurateness, thus this difference points to the importance of this issue. It means that scrutinizing estimation of the vegetation roughness on a practical scale should be done with superior exactness, especially with aboriginal research on plant species of each region.

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