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Providing a mathematical model to calculate Manning roughness coefficient in mountainous rivers based on geotechnical properties of the substrate and the hydraulic properties of flow section

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Abstract: Through studding open channel hydraulics with rigid bed, roughness coefficient could be assumed unchanged and after assigning one of the flow resistance formulas could be directly used for calculating of longitudinal slope and channel depth. Butt in river hydraulic the bed is mobile and the resistance against the current or on the other word roughness coefficient is changeable. In this case, we cannot use flow resistance formulas directly and without knowing of changing of resistance coefficient through different condition of flow and sediment. According to Mahpoor research (1385), none of parametric models has a suitable engineering attention to predict roughness coefficient. Hence in this research by using some of USA rivers data a new parametric model will be extended. Mix of geotechnical and hydraulic parameters and by using a nonlinear regression models will be assess and finally a new comprehensive model create.
Key words: roughness coefficient, geotechnical parameters, hydraulic parameters, nonlinear regression

Introduction

Rivers as one of the main sources of surface water and important habitats of aquatics are considered as effective ecosystem within the dry lands. In addition to being involved in the climatic cycles of the Earth, water of rivers is one of the most important factors of erosion on the Earth. In the past few decades, considerable developments have been made engineering science. However, engineering community is waiting for an accurate method of calculation in some cases, including sediment transfer, turbulent flows, flood control, and river response to environmental factors. River network refer to a set of waterways that carry outs the task of discharging the surface flows at the area surface. Some of these waterways are in the form of perennial rivers, while some of them are seasonal and some others are watercourses that water can flow on them only during the raining (Alizadeh, 813, 2005). It is for a long time that water has been flowed in it and many people, both in cities and in rural areas, are using it. One of these water sources are surface flows and rivers. As natural channels to collect and to transfer the atmospheric precipitation, rivers have been considered by human societies, and they have affected directly or indirectly the lives and efforts of many people. In the long history on this land, water has always played a key and it has been considered as one of the main problems of the people living in Iran so that in the case of lack of raining, people's lives might be threatened. Originally, Water in Avesta language has been "Ap" and in the Pahlavi language, it has been "Uv" and the common Persian word for it has been derived from Pahlavi and Avesta words (Farhanghi, 15, 2004). Hydraulic roughness coefficient of rivers is one of the factors needed for engineering studies of rivers. The exact determination of this factor is an essential to determine factors such as depth and flow velocity

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accurately. Hydraulic roughness coefficient is affected by various factors in different and complex situation of rivers. Therefore, extensive research has been conducted on various conditions of flow in rivers and wide range of equations has been proposed. For this reason, complete understanding of effective factors and various situations of rivers by rivers engineering studies experts is proceeded by determining the roughness of rivers. The awareness of these experts of various equations in determining the roughness coefficient at various conditions of rivers is also essential (Technical and Executive System Office of Deputy of Planning and Strategic Supervision of the President, 2011).

Materials and methods

In order to provide a mathematical model for determining the Manning roughness coefficient in mountainous ranges based on current field data, geotechnical and hydraulic information of 10 American rivers and 75 ranges of Jarrett research were collected. In selecting the mentioned rivers, it was taken into consideration that used sections to be included in the mountainous range of river and the slope of river at that place to be higher than 1 percent. Parametric methods for estimating Manning roughness coefficient:

Another method to determine n, especially in the rivers, is the use of experimental equations special for river engineering. These equations generally depend on the diameter of particles forming the wall and bed of waterways. Most of known equations are as follows:

1. In 1923, Strickler equation provided the following equation for estimating Manning roughness coefficients:

$$(١)\ n = 0.047 d_{50}^{1/6}$$

Where d50 is the assumed size based on mm that 50% of the materials pass through it. He believed that roughness coefficient is independent of the depth of flow and it is a function of bed particles size. His equation and other equations that are based on this have special use limitation since they will be applicable only when flow is turbulent and decline is totally derived from bed materials roughness (Yen, 2002).

٢. In 1938, Keulegan proposed an equation similar to previous work:

$$(٢)\ n = \frac{d_{50}^{1/6}}{46.9} = 0.021 d_{50}^{1/6}$$

Where d50 is expressed in foot.

٣. In continuation of previous work, Keulegan proposed another concept of bed resistance against flow in the form of two following equations:

$$(٣)\ \frac{u}{u*} = 8.12 \left(\frac{R}{K_s}\right)^{1/6}$$

and:

$$(۴)\ \frac{u}{u*} = 5.75 \log\left(\frac{R}{Ks}\right) + 6.25$$

Where Ks is equivalent to Nicholatse sand and it is considered d85.

4. In 1946, based on frictional slope, Lacy provided the following equation (Nguyen, 2004):

$$(۵)\ n = 0.0928 S_f^{\frac{1}{6}}$$

On the other hand, to consider the effect of other sizes of alluvial materials grading, other than (Keulegan, 1947), two following equations were added to previous set:

$$(۶)\ n = \frac{d_{90}^{1/6}}{49} = 0.02 d_{90}^{1/6} \qquad (۷)$$

$$n = \frac{d_{65}^{1/6}}{29.3} = 0.034 d_{65}^{1/6}$$

Where d90 and d65 are expressed in foot.

5. In Muller unit, Meyer-Peter (1948) provided the following equation:

$$(۸)\ n = 0.0385 d_{90}^{1/6}$$

Where d90 is expressed in meter. This equation can be used when the bed is covered with rubble (Shafaie, 2005, 470).
۶. In 1949, in metric unit, Irmay proposed the following equation (Rahmeyer, 2006):

$$(۹)\ n = \frac{d_{65}^{1/6}}{24}$$

In research similar to what was mentioned above, by studying on San Luis Valley canals that had rubble bed, the following equation was proposed to estimate roughness coefficient by Lane and Karl Son (1953) (Shafaie , 2005, 470):

$$(۱۰)\ n = 0.026 d_{75}^{1/6}$$

D_{75} is expressed in inch.

8. In 1965, Henderson provided an equation similar to the equation (47-2):

$$(11)\ n = 0.034 d_{50}^{1/6}$$

d_{50} is expressed in foot.

9. After a comprehensive discussion about the selection of size typical aggregates forming the bed of given waterway for calculating roughness coefficient and using d_{63} in millimeters, (Raudkivi, 1967) suggests that:

$$(۱۲)\ n = 0.013 d_{63}^{1/6}$$

Equation (12) used in a study conducted by Iman Shoar and Taher Shamsi (2006) on accuracy of available equations to estimate roughness coefficient in rivers, results more rational than other equations were obtained. They concluded that these equations are more consistent with European rivers climate and they should be changed in order to use them for Iranian rivers so that they can be consistent with climate conditions and conditions (Iman Shoar, 2007).

10. In 1968, Anderson et al proposed the following equation (Rahmeyer, 2006):

$$(١٣)\ n = \frac{d_{50}^{1/6}}{20.5}$$

11. In 1970, Limerinos et al used hydraulic radius for estimating roughness coefficient, and the particles that he had considered in this formula was generally coarse-grained (Rice, 1998) and they proposed the following equation:

$$(١۴)\ n = \frac{0.0926R^{1/6}}{1.16 + 2\log\left(\frac{R}{d_{84}}\right)}$$

In 1976, Burkham and Dawdy showed that this formula could also be used in sandy rivers.
١٢. In 1975, by examining a series of alluvial rivers, ChiEmeka could provide relational shear stress to calculate n (ChiEmeka, 1975).

$$(١۵)\ f = 0.017\exp(0.4\frac{\tau_0''}{\tau_0'})$$

$$(١۶)\ \frac{\tau_0''}{(\gamma_s - \gamma_w)D_{50}} = 0.0246(\frac{\tau_0}{\tau_c})$$

$$(١٧)\ \tau_0 = \gamma_w RS$$

$$(١٨)\ \tau_0' = \tau_0 - \tau_0''$$

$$(١٩)\ n = 0.012R^{\frac{1}{6}}\exp(0.2\frac{\tau_0''}{\tau_0'})$$

13. In 1976, by considering the area, hydraulic radius and slope of water surface, Riggs provided the following equation (Nguyan, 2004):

$$(٢٠)\ n = \frac{1}{1.55}A^{-0.33}R^{\frac{2}{3}}S_w^{0.45+0.056\log S_w}$$

14. In studies conducted by Simons & Senturk in 1976, it is observed that:

$$(٢١)\ n = 0.047d_{50}^{1/6}$$

Where d_{50} is expressed in meters. They concluded that the equation cannot be applied in flows with moving bed (Van Rijn, 1993).

15. Grade and Raju said that Strickler analyzed data from the various flows available in Switzerland that bed materials had no wave-like motions (Soleimani, 2005, 140) and they provided the following equation:

$$(٢٢)\ n = 0.039d_{50}^{1/6}$$

16. The modified equation was also proposed in 1979:

$$(۲۳)\ \frac{u}{u*} = 5.62\log\left(\frac{5.85R}{3.5d_{84}}\right) + 2.85$$

17. By considering only the slope of water surface, Bray (1982) found the following equation (Nguyan, 2004):

$$(۲۴)\ n = 0.104S_w^{0.177}$$

In 1982, Subramanya referred to the following equation:

$$(۲۵)\qquad n = 0.0474d_{50}^{1/6}$$

d $_{50}$ is expressed in meters.

18. Based on his studies regime for both higher and lower regimes in channels, Browine (1983) could provide a formula in English unit (Rahmeyar, 2006):
-For the lower regime where $F_g \le F_g'$, we have:

$$(۲۶)\ n = \left[1.694\left(\frac{R}{d_{50}}\right)^{0.1374} S^{0.1112}\sigma^{0.1605}\right]0.034d_{50}^{0.167}$$

- and in the case of higher regime($F_g > F_g'$), we have also:

$$(۲۷)\ n = \left[1.0213\left(\frac{R}{d_{50}}\right)^{0.0662} S^{0.0395}\sigma^{0.1282}\right]0.034d_{50}^{0.167}$$

$$(۲۸)\qquad \sigma = 0.5\left(\frac{d_{84}}{d_{50}} + \frac{d_{50}}{d_{16}}\right)$$

$$(۲۹)\qquad F_g = \frac{V}{\sqrt{(S-1).g.d_{50}}}$$

$$(۳۰)\qquad F_g' = \frac{1.74}{\sqrt{S}}$$

19. Based on a series of experiments, Thorne & Zevenberg (1985) could provide the following equation, where V, f and n are related to each other (Thorne, 1985):

$$(۳۱)\qquad \frac{V}{\sqrt{gRS}} = \left(\frac{8}{f}\right)^{0.5} = \frac{R^{\frac{1}{6}}}{n\sqrt{g}}$$

They believed that this formula is not true on mountainous rivers because:
- Substrate materials in mountainous rivers were coarse-grained, while the Foothill Rivers are generally sandy and fine-grained.
- Slope of bed in mountainous streams is greater than foothill streams.
-Relative buoyancy ($\frac{D}{d_{84}}$) in mountainous streams is greater than foothill streams.

20. By considering the ratio of $\frac{R}{d_{84}}$, Madrid provided Froude number and the bed slope of following equations (Papanicolaou, 2004):

$$(٣٢)\ \frac{R}{d_{84}} > 1 \qquad n = \left(0.183 + \ln\left(\frac{1.7462 S^{0.1581}}{F_d^{0.2631}}\right)\right) \times \frac{d_{84}^{\frac{1}{6}}}{\sqrt{g}}$$

$$(٢\text{-}٧٢)\ 1 < \frac{R}{d_{84}} < 12.5 \qquad n = \left(0.183 + \ln\left(\frac{1.3014 S^{0.0784} R^{0.0211}}{F_d^{0.205} d_{84}^{0.2011}}\right)\right) \times \frac{d_{84}^{\frac{1}{6}}}{\sqrt{g}}$$

Then, based on findings, Miller and Quick in 1994 stated that (Rahmeyar, 2006):
(٣٣)

$$(٣٣)\ n = \frac{K_n R^{\frac{1}{6}}}{\sqrt{g}\, 5.75 \log\left(12.2 \frac{Y_0}{3.5 D_{90}}\right)}$$

22. In 1997, Dingman and Sharma provided an equation similar to Manning equation (Dingman 1997):

$$(٣٤)\ n = \frac{1}{1.564} A^{-0.173} R^{0.267} S_w^{0.5+0.0543\log S_w}$$

In order to develop the mathematical equation for roughness coefficient in the ranges with supercritical slope in 1997, Grant provided a hypothesis on balance between waterway hydraulic and bed form based on his observations on rivers with sandy bed and the formation of bed forms in them and then generalizing these observations to steep rivers with greater and coarser grading (Mahpour, 110, 2006).

In this hypothesis, a flow adjusts his bed accurately with discharge and other dominant features in that waterway so that it provide the velocity needed for transfer of sediments that basin creates. Concluding his observations and using Keulegan resistance equation (1938) and Shields criterion for motion threshold of substrate materials, the following equation was obtained:

$$Fr = 2.18\left[\ln\left(1.65 \frac{\tau_{cr}^{*}}{s}\right) + 1.35\right] g^{0.5} \qquad (٣٥)$$

Where τ_{cr}^{*} equals to 0.06 based on Shields diagram. He has shown that by combining one of the equations provided for n and equation (33-2), we can achieve to an equation provides an estimation of roughness coefficient in these types of flows in which the interaction between bed and waterway hydraulic causes that Froude number does not exceed more than one (Yen, 2002):

$$(۳۶)\ n = \frac{d^{1/6}}{2.18\left[\ln\left(1.65\frac{\tau_{cr}^{*}}{s}\right)+1.35\right]g^{0.5}}$$

It should be noted that although the equation (70-3) is a suitable and reasonable base for estimating roughness coefficient in the ranges with supercritical slope, by comparing the equations mentioned in this section, it can be concluded that the most of researchers believed that the most important factor in formation of resistance against flow is typical size of grains of alluvial materials. In other words, they have ignored geotechnical parameters of alluvial materials. Additionally, the most important and effective thing influencing the roughness coefficient in the Manning equation can be roughness of aggregates surface. Although in most of river downstream ranges, the aggregates forming the waterway are without corner and rounded due to being slipped, in the mountain ranges, due to large amounts of debris on one hand, and closeness to head waters on the other hand, aggregates are angular and relatively sharp. Therefore, the geometry of aggregates or the surface roughness of aggregates is an important factor in forming bed resistance against the flow.
Therefore, according to writers of thesis view, the difference among the equations proposed by researchers is rooted in this fact that size of aggregates can singly reflects the impact of bed materials on roughness coefficient.
23. Considering that the parameters of the hydraulic radius and slope of surface water are important, Sauer (1998) provided the following equation (Nguyan, 2004):

$$(۳۷)\ n = 0.11 S_w^{0.18}\left(\frac{R}{0.3048}\right)^{0.08}$$

Based on their experiences, Marion et al. (1998) provided the following equation (Hatami, 2006, 140):

$$(۳۸)\ n = \frac{d_{90}^{1/6}}{26}$$

China and Mai (1998) also found the following equation by a study on the Yellow River (Hatami, 2006, 140):

$$(۳۹)\ n = \frac{d_{65}^{1/6}}{19}$$

Consistency of observational data to develop mathematical model:
Hydraulic data
In order to perform hydraulic calculations in rivers, some characteristics of sections used greatly include:

- Flow cross section (A): in one place, it refers to the area of flow cross section perpendicular to the general direction of flow.
- Open surface width (T): it refers to the length of the flow cross section that is in contact with the open air
- if we subtract from general environment of cross section the surface of open water width, the wetted perimeter is achieved representing flow contact range with channel bed.

•hydraulic radius (R): it is defined as the ratio of surface of cross section to wet surrounding of hydraulic radius called, in other words:

$$R = \frac{A}{P} \qquad (۴۰)$$

•hydraulic depth (D): it is the ratio of the flow cross section to open water surface width:

$$D = \frac{A}{T} \qquad (۴۱)$$

The above information is related to the geometric characteristics of sections and cases such as flow velocity, flow friction slope, and the slope of the surface water should be measured and calculated in order to bed used in Manning equation. After reviewing the information and calculations needed, the results of investigations have been represented in Table 1.

Table (1)- hydraulic data

site	Sf	D(ft)	D(m)	R(m)	R(ft)	n
1	0.026	3.61	1.1003	0.99	3.24	0.142
	0.023	4.66	1.4204	1.22	3.99	0.132
	0.021	5.22	1.5911	1.36	4.46	0.112
	0.025	5.75	1.7526	1.48	4.85	0.11
	0.026	6.58	2.0056	1.68	5.51	0.086
2	0.015	1.02	0.3109	0.31	1.02	0.138
	0.017	1.54	0.4694	0.46	1.5	0.084
	0.018	2.08	0.634	0.61	2	0.084
	0.019	2.71	0.826	0.79	2.6	0.067
3	0.03	0.88	0.2682	0.27	0.9	0.159
	0.034	1.24	0.378	0.37	1.2	0.097
	0.033	1.43	0.4359	0.46	1.51	0.052
	0.03	2.03	0.6187	0.56	1.85	0.058
4	0.003	0.73	0.2225	0.22	0.72	0.045
	0.004	1.27	0.3871	0.39	1.27	0.046
	0.004	1.7	0.5182	0.52	1.7	0.041
	0.004	2.34	0.7132	0.68	2.24	0.028
5	0.003	1.21	0.3688	0.37	1.21	0.054
	0.004	1.36	0.4145	0.41	1.35	0.051
	0.004	1.44	0.4389	0.43	1.42	0.052
	0.004	2.02	0.6157	0.62	2.02	0.05
	0.004	3.54	1.079	1.07	3.51	0.041
	0.004	4.09	1.2466	1.23	4.03	0.037
6	0.003	0.54	0.1646	0.18	0.6	0.057
	0.003	0.7	0.2134	0.21	0.7	0.044
	0.002	1.17	0.3566	0.36	1.17	0.03

7	0.003	0.66	0.2012	0.18	0.6	0.058
	0.004	1.46	0.445	0.46	1.5	0.052
	0.006	2.28	0.6949	0.7	2.3	0.034
	0.006	3.02	0.9205	0.91	2.98	0.044
8	0.011	0.48	0.1463	0.15	0.5	0.109
	0.016	1.09	0.3322	0.32	1.05	0.062
	0.014	1.5	0.4572	0.43	1.42	0.042
9	0.019	2.3	0.701	0.68	2.23	0.087
	0.014	2.87	0.8748	0.87	2.85	0.052
	0.014	3.07	0.9357	0.92	3.03	0.054
	0.014	3.14	0.9571	1.02	3.36	0.049
10	0.019	1.28	0.3901	0.37	1.2	0.098
	0.023	2.3	0.701	0.65	2.12	0.062
	0.024	2.72	0.8291	0.77	2.53	0.056

Data of Soil Mechanics

The results of mechanical analyzes, including grading tests, are drawn usually on semi-logarithmic paper that is called as soil-grading curve. Grains diameter is drawn to logarithmic horizontal axis and the percentage of relevant passing is drawn to vertical non-logarithmic axis. The curve could be used to compare different soils. Two basic parameters used for classification of granular soils and can be determined on grading curve include:

$$C_u = \frac{D_{60}}{D_{10}} \quad (۴۲)$$

$$C_c = \frac{D_{30}^2}{D_{10} \times D_{60}} \quad (۴۳)$$

Where:

‘

C_u= Uniformity coefficient of soil
C_c= Coefficient of soil gradation
D_{10}: diameter related to percentage of 10% of passing on grading curve
D_{30}: diameter related to percentage of 30% of passing on grading curve
D_{60}: diameter related to percentage of 60% of passing on grading curve

Based on materials grading curves of bed, the diameter of particles can be determined based on its passing percentage. This issue is important since in most of the equations in determining the manning roughness coefficient, especially Strickler equations and other equations derived from it, the effective diameter of particles is needed that in the different cases, researchers have selected different diameters as effective diameter based on their observations. Generally, effective diameter of particles in mountainous rivers id d_{84}, which means that 84% of the particles have a diameter of less than that. Based on their diameter, particles have different names. In 1953, Wellman provided a table where the position of each particle is determined in terms of diameter (Jarrett, 1984), Table (2). Table 3 shows the geotechnical parameters calculated for each of the sections.

Table (2)- classification of particles based on diameter

Group name	(mm) Particles size
Sand and Silt	< 2
Gravels	2 - 4
	4 - 6
	6 - 8
	8 - 12
	12 - 16
	16 - 24
	24 - 32
	32 - 48
	48 - 64
Cobbles	64 - 96
	96 - 128
	128 - 192
	192 - 256
Boulders	256 - 384
	384 - 512
	512 - 1024
	1024 - 2048
	2048 - 4096
Bedrock	> 4096

Table 3 - Soil Mechanics data of Colorado river bed materials

site	d_{100}	d_{90}	d_{80}	d_{63}	d_{60}	d_{50}	d_{30}	d_{20}	d_{15}	d_{10}	d_0	Cc	Cu	e	S_{90}
1	1.272	0.975	0.799	0.538	0.502	0.427	0.329	0.198	0.15	0.142	0.124	1.53	3.55	32.9	0.001
2	1.099	0.701	0.491	0.247	0.219	0.183	0.065	0.044	0.03	0.029	0.019	0.67	7.52	30.6	0.002
3	0.828	0.64	0.427	0.243	0.22	0.152	0.082	0.061	0.05	0.042	0.03	0.72	5.24	29.8	0.002
4	0.26	0.213	0.183	0.144	0.138	0.122	0.085	0.073	0.061	0.061	0.053	0.87	2.25	28.5	0.005
5	0.433	0.305	0.243	0.169	0.166	0.122	0.073	0.043	0.03	0.03	0.024	1.07	5.53	30.3	0.004
7	0.563	0.457	0.37	0.259	0.243	0.213	0.129	0.105	0.094	0.085	0.069	0.81	2.86	29.7	0.002
8	0.675	0.427	0.368	0.18	0.162	0.091	0.067	0.039	0.029	0.027	0.019	1.02	5.96	29.8	0.003
9	0.654	0.488	0.416	0.283	0.265	0.244	0.135	0.107	0.089	0.086	0.068	0.8	3.09	30.1	0.002
10	0.84	0.671	0.544	0.376	0.352	0.305	0.183	0.148	0.12	0.119	0.095	0.8	2.97	30.5	0.002

Results and Discussion

Firstly, manning roughness coefficients should be calculated using the new model for Colorado, Karaj and Greenville rivers. Certainly, compared with the observed roughness obtained from Manning Equation, the obtained results show inconsistencies that must be evaluated by statistical methods. For this purpose, the two criteria of sum of squared errors (SSE) and mean squared error (MSE) can be used. Therefore:

$$(۴۴)\ SSE = \sum \left(n - n_j\right)^2$$

$$(۴۵)\ MSE = \frac{\sum \left(n - n_j\right)^2}{N}$$

Where n_j is the Manning roughness coefficient estimated by the model and N is the number of withdrawals.

Table (4) Studying Colorado Rivers

First, using data from the Colorado River, Manning roughness coefficient was calculated by using the new model ($n = 0.255 S_f^{0.197} C_c^{0.274} C_u^{-0.068} (\frac{D}{d_{84}})^{-0.5} R^{0.19}$ Equation). Then, the errors available in estimation of roughness coefficient were calculated by this model. Table (4) shows the calculated values based on proposed formula and error value in calculations.

Calculation of n for Colorado Rivers with new model

Site	$n=0.255S_f^{0.197}C_c^{0.274}C_u^{-0.068}(D/d_{84})^{-0.5}R^{0.19}$	n	SE
1	0.1085	0.1420	0.001123022
	0.0970	0.1320	0.001226238
	0.0919	0.1120	0.000404728
	0.0921	0.1100	0.000321419
	0.0889	0.0860	8.12823E-06
2	0.0926	0.1380	0.002059694
	0.0833	0.0840	5.29653E-07
	0.0765	0.0840	5.6922E-05
	0.0711	0.0670	1.68738E-05
3	0.1026	0.1590	0.003176641
	0.0941	0.0970	8.46288E-06
	0.0908	0.0520	0.00150408
	0.0776	0.0580	0.000385125
4	0.0503	0.0450	2.79912E-05

	0.0450	0.0460	1.02305E-06
	0.0411	0.0410	4.80723E-09
	0.0368	0.0280	7.80716E-05
5	0.0496	0.0540	1.96546E-05
	0.0505	0.0510	2.98025E-07
	0.0495	0.0520	6.35907E-06
	0.0448	0.0500	2.72145E-05
	0.0375	0.0410	1.20772E-05
	0.0358	0.0370	1.32858E-06
7	0.0723	0.0580	0.000204434
	0.0615	0.0520	8.99332E-05
	0.0577	0.0340	0.000562478
	0.0527	0.0440	7.59086E-05
8	0.1072	0.1090	3.2865E-06
	0.0884	0.0620	0.000698855
	0.0777	0.0420	0.001272334
9	0.0764	0.0870	0.000112923
	0.0675	0.0520	0.000239126
	0.0659	0.0540	0.000142216
	0.0665	0.0490	0.000305447
10	0.1056	0.0980	5.76059E-05
	0.0910	0.0620	0.000842983
	0.0872	0.0560	0.000972041

Coefficient of correlation between calculated and observational n for Colorado Rivers in this model is 0.67. SSE = 0.021 and MSE= 0.003. Arithmetic mean of difference percentages is 42.89 varying from -18.3 to 182.08 %. This shows the tendency of this model for overestimation in the n estimation, that this error value is lower based model presented by Jarrett. Therefore, the presented model has greater reliability and accuracy in estimating the manning roughness coefficient.

Conclusion

Using the table (4) which is derived from investigation and field data processing related to the United States, the results show that unlike proposed equation of Jarrett soil mechanics factors also have mutual impact on accuracy of Manning roughness coefficient estimation that this is evident in the obtained results.

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