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Comparative Analysis of Hydraulic Roughness Coefficient at Purna River Sites

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Abstract

In all engineering studies conducted on rivers and in designing structures intersecting these rivers, such as bridges, diversion weirs, intake ports, etc. where knowing the depth and velocity of the flow is required as well, the exact determination of the roughness coefficient is needed. The manning's n is a coefficient which represents the Roughness or Friction applied to the flow by the channel. Hydraulic roughness is highly variable parameter which depends upon the number of factors such as surface roughness, vegetation, channel irregularities, channel alignment, channel slope etc. The present paper discusses the predictability of different equations for determining the hydraulic roughness coefficient at the Garudeshwar and Gopalkheda site stations on Purna river in Gujarat. Statistical parameters such as mean percentage error (MPE), root mean square error (RMSE), discrepancy ratio (DR) and inequality coefficient (U) have been computed for evaluating the performance of selected formulas. Graphical comparisons are done to demonstrate the performance and variations for different data sets. Predicted values are compared with those observed by using Manning's Equation, empirical relations such as: Limerinous, Strickler, Meyer–Peter and Muller and using Cowan's tables. Little variation in results is observed for Manning equation at Garudeshwar and Chow equation at Gopalkheda station.
Keyword- Cowan's table, Hydraulic Roughness Coefficient, Manning's equation, Garudeshwar, Gopalkheda

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I. INTRODUCTION

The manning's n is a coefficient which represents the Roughness or Friction applied to the flow by the channel. The hydraulic roughness coefficients of rivers are influenced by many factors as rivers flow under various complex conditions. In all the engineering studies conducted on rivers, and in designing structures intersecting rivers such as bridges, diversion weirs, intake ports, etc. hydraulic roughness is a highly variable parameter which depends upon the number of factors such as surface roughness, vegetation, channel irregularities, channel alignment, channel slope and degree of meandering (Cowan, 1956) etc., where knowing the depth and velocity of the flow is required as well, and thus the exact determination of the roughness coefficient will be needed. Calculations of hydraulic roughness coefficients of flows are needed to determine hydraulic factors such as depths and velocities of flows. Therefore, while conducting engineering studies on rivers it is must to have a thorough knowledge of effective factors influencing rivers and the various site specific conditions. There is a series of equations that can be used in determining (or predicting) the values of n, none of which can, by itself, predict the discharge of the river being studied. The hydraulic roughness coefficient of a river is one of the factors needed in carrying out engineering studies on rivers.

The roughness coefficient incorporates the many factors that contribute to the loss of energy in a stream channel. The major factor is channel-surface roughness, which is determined by the size, shape, and distribution of the grains of the material that line the bed and sides of the channel (the wetted perimeter). Although empirical studies in this area have been carried out for over a century, research on this subject is continuing by government and private organizations in many countries. The morphology of a natural channel depends on the collision of the fluid passing through it with the erosive materials present on the channel bed. Flow velocity is strongly dependent on the resistance to flow, and this resistance is one of the most import ant elements in this collision. Engineers have used draw-down resistance equations, such as that of the roughness of particles, or a combination of these equations, but Manning's roughness coefficient is used extensively in the world to predict the degree of roughness in natural channels.

II. STUDY AREA

The Narmada, also called the Rewa, is a river in central India and the fifth longest river in the Indian subcontinent. The river travels a distance of 1,312 km before it falls into Gulf of Cambay in the Arabian Sea near Bharuch in Gujarat (NVDA, 1985). The Narmada River basin extends over an area of 98,796 sq. km and lies between longitudes 72° 32' E to 81° 45' E and latitudes 21° 20' N to 23° 45' N (Narmada basin, 2005). Further, there are 31 gauge and discharge sites being maintained by State Government of Gujarat in Narmada basin. The The Purna River is a river of Western India. It is one of the Chief Tributaries of Tapti river and empties in it at Changdev in Jalgaon, Maharashtra. The Purna River basin extends over an area of 9500 sq. km and lies beween longitudes 760

59’ 14” E and latitudes 200 52’ 35” N. and The watershed lies mostly in eastern Vidarbha region of Maharashtra state and is nearly 18,929 km². It rises in the eastern Satpura range of southern Madhya Pradhesh State, and flows westward draining Maharashtra's Marathwada, Vidarbha region before emptying into the Arabian Sea. It originates in Pokharni Village which is 2 km away from Bhainsdehi. Bhainsdehi is a thasil place in Betul district Madhya Pradesh adjoining Amravati district of Maharashtra and flows through Akola, Buldhana, and Jalgaon districts. Total length of Purna River is 334 km. The location of Garudeshwar and Gopalkheda has been shown in Figure 1

Garudeshwar

Gopalkheda

Fig. 1: Location of Study area

III. METHODOLOGY

The discharge rate data of Narmada and Purna river at the Garudeshwar and Gopalkheda station is collected from the Central Water Commission, Surat, Gujarat. Many researchers like Cowan (1959), Limerinous (1970), Strickler (1923), Meyer – Peter and Muller (1948) and Manning (1985) had done hydraulic roughness coefficient analysis of river data. Some researchers have developed different hydraulic roughness coefficient formula using different methods. For the present study, in the absence of roughness coefficient data at the Garudeshwar and Gopalkheda, roughness coefficients are computed using different methods. The following selected roughness coefficient equation is used for obtaining roughness coefficient at the Garudeshwar and Gopalkheda.

A. Manning’s Equation

Discharge in a uniform steady state is computed with Manning’s formula (Eq.1). This equation can also be applied to non-uniform flow through modification reflecting head loss due to bed friction (Jarrett and Petsch, 1985)

$$Q = \frac{1}{n} A R^{2/3} {S_F}^{1/2} \tag{1}$$

where,
Q is the discharge (m^3/s),
n is Manning’s roughness coefficient,
A is the flow area (m^2),
R is the hydraulic radius (m), and
S_f is the friction slope.

The water surface slope can be input into Eq (1) as a substitute for the friction slope to compute the roughness coefficient of each cross section, but this neglects the effect of frictional head loss.

If there are multiple sections, the roughness coefficient is calculated from Eq. (2) (Barnes, 1967; Hicks and Mason, 1991)

$$n = \frac{1}{Q}\sqrt{\frac{(h_1 + h_{v_1}) - (h_m + h_{v_m}) - \sum_{i=2}^{m}(k_{i-1,i}\Delta h_{v_{i-1,i}})}{\sum_{i=2}^{m}\frac{L_{i-1,i}}{Z_{i-1}Z_i}}} \tag{2}$$

Where,
Z equals $AR^{2/3}$, and
m is the number of sections

B. Cowan’s Method

(Chow, 1956) assumed that the roughness coefficient of a straight, uniform and smooth channel depends on the materials of the channel bed, and suggested the following relation for calculating roughness coefficient

$$n = (n_0 + n_1 + n_2 + n_3 + n_4)\, m \tag{3}$$

where,
n_0 = A base value of n for a straight, uniform, smooth channel in natural materials
n_1 = A correction factor for the effect of surface irregularities
n_2 = A value for variations in shape and size of the channel cross section,

n_3 = A value for obstructions
n_4 = A value for vegetation and flow conditions
m = A correction factor for meandering of the channel

He also listed the values of roughness coefficients of materials forming the channel bed in a table (Chow, 1956). In 1959, Chow conducted comprehensive studies on the values of 'n' and the results obtained are a comprehensive reference for engineering problems, and the tables constructed for same are available in most books written on hydraulics.

C. Empirical Relations

Another method of determining roughness coefficients is to use empirical relations, some of these used in this study, are as follows:

Sr. No.	*Approaches to compute roughness coefficient*	*Year*	*Equation*
1	*Strickler Formula*	*1923*	$n = \frac{d_{50}^{\frac{1}{6}}}{21.1}$
2	*Meyer-Peter & Muller Formula*	*1948*	$n = \frac{d_{90}^{\frac{1}{6}}}{26}$
3	*Limerinous Formula*	*1970*	$n = \frac{0.11R^{\frac{1}{6}}}{0.35 + 2\, log_{10} \frac{R}{d_{50}}}$

Table 1: Empirical formula to determine roughness coefficient

IV. RESULT ANALYSIS

The predictability of different equations for determining the hydraulic roughness coefficient at the Garudeshwar and Gopalkheda station is assessed. Statistical parameters such as mean percentage error (MPE), root mean square error (RMSE), discrepancy ratio (DR) and inequality coefficient (U) have been computed for evaluating the performance of selected formulas. Graphical comparisons are done to demonstrate the performance and variations for different data sets. Predicted value are compared with those observed by using Manning's Equation, empirical relations such as: Limerinous , Strickler , Meyer – Peter and Muller and using Cowan's table. The summary of observed and predicted roughness coefficient values obtained using selected equation is shown in Table 2.

Sr. No.	*Approaches to compute roughness coefficient*	*Average computed roughness coefficient at Garudeshwar*	*Average computed roughness coefficient at Gopalkheda*
1	*Manning's Formula*	*0.06996*	*0.035955*
2	*Strickler Formula*	*0.021614*	*0.017712*
3	*MPM Formula*	*0.019478*	*0.017871*
4	*Limerinuos Formula*	*0.024555*	*0.020148*
5	*Chow*	*0.04555*	*0.0345*
	Observed Roughness Coefficient	*0.070007*	*0.035956*

Table 2: Summary of obtained roughness coefficient using selected equations and observed values of roughness coefficient

From Table 2, the observed roughness coefficient can be compared with predicted roughness coefficient using different equations at Garudeshwar and Gopalkheda. Deviation of the computed value from the observed one is found out by calculating percentage error. Comparative summary of the obtained roughness coefficient (observed) and predicted roughness coefficient using different methods and the deviation of predicted value from observed value in term of Mean Percentage Error (MPE) is given in Table 3.

Sr. No.	*Approaches to compute roughness coefficient*	*%MPE*	*%MPE*
1	*Manning's Formula*	*-0.157*	*-0.0017*
2	*Strickler Formula*	*-224.19*	*-103.00*
3	*MPM Formula*	*-259.74*	*-101.20*
4	*Limerinuos Formula*	*-185.36*	*-78.46*
5	*Chow*	*-53.83*	*-4.22*

Table 3: Comparison between Mean Percentage error at Garudeshvar and Gopalkheda

From Table 3, it is observed that the best prediction of roughness coefficient is found when Manning's (1985) formula is used to compute roughness coefficient with mean percentage error of -0.15723% and -0.001704 % respectively at the Garudeshwar and Gopalkheda and Chow (1959) formula is used to compute roughness coefficient with mean percentage error of -53.831% and -4.22029% respectively at the Garudeshwar and Gopalkheda.

It is also found that the roughness coefficient predicted using Manning's equation as unmeasured roughness coefficient gives near equal value to the results obtained (observed) roughness coefficient.

From analysis it is found that the obtained roughness coefficient and unmeasured roughness coefficient gives large difference in result as compared with the results obtained for all the selected Eight roughness coefficient equations which is discussed in the present paper.

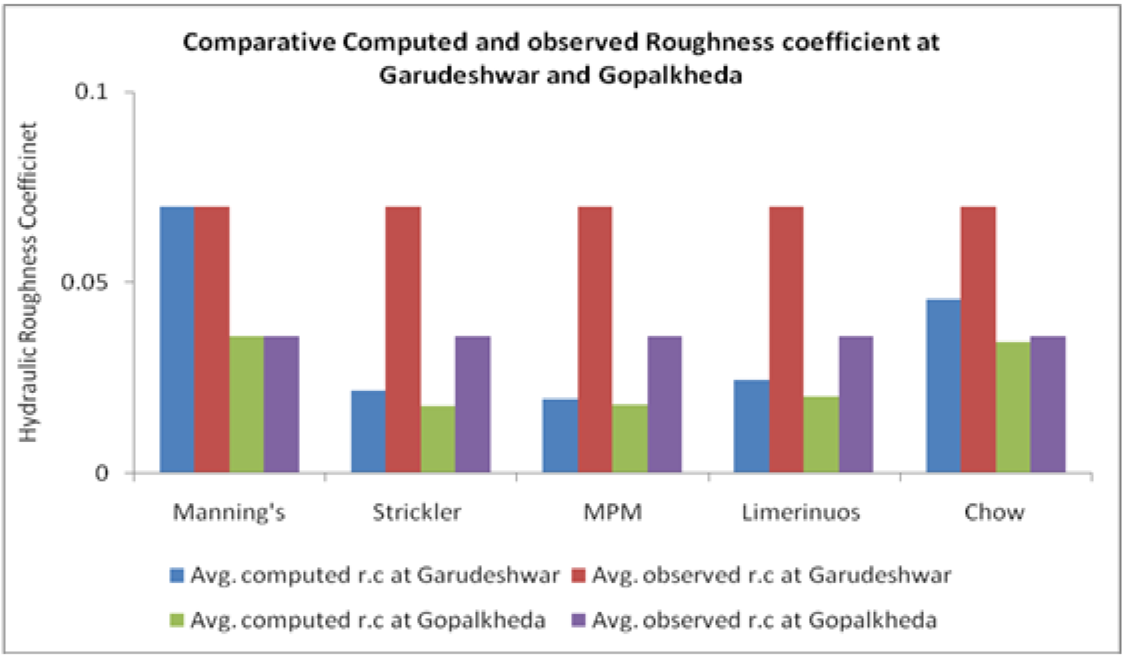

Fig. 2: Percentage error for roughness coefficient using Different Equations at Garudeshwar and Gopalkheda

From the Fig 2, graphical comparisons are done to demonstrate the performance and variations for different data sets. Predicted values are compared with those observed by using Manning's Equation, empirical relations such as: Limerinous, Strickler, Meyer – Peter and Muller and using Cowan's tables at Garudeshwar and Gopalkheada. Little variation in results is observed for both Chow and Manning equation at Garudeshwar and Gopalkheda station.

To check the roughness coefficient equations at Garudeshwar and Gopalkheada, various statistical measures are calculated. The discrepancy ratio (ratio of calculated value to measured value) for each data points is considered for comparison of performance. If the ratio is less than one or greater than one, the equation under predicts or over predicts measured data respectively. Deviation of predicted value from the observed value using roughness coefficient equations are plotted by calculating percentage error as shown in Fig 2. The percentage of data coverage between accepted lower and upper limits of the discrepancy ratio (score in terms of percentage of discrepancy ratio within the range of 0.5 to 2.0 are calculated and their statistical properties such as root mean square error (RMSE), inequality coefficient (U) is taken as the criteria of the goodness of fit. The root means square error (RMSE) is one of the most convenient and precise statistical parameter for assessing simulation models. It measures the deviation between the trend of the predicted values and measured ones. The zero value of RMSE indicates a perfect fit between measured and predicted values. Inequality coefficient is a simulation statistics related to the RMSE. If U equals to zero value, then predicted values are equal to observed values and there is a perfect fit. The statistical measures are calculating in Table 3

Sr. No.	*Approaches to compute roughness coefficient*	*Garudeshwar*	*Gopalkheda*
1	*Manning's Formula*	*0.999953*	*1.00008*
2	*Strickler Formula*	*0.395161*	*0.589777*
3	*MPM Formula*	*0.356981*	*0.595975*
4	*Limerinuos Formula*	*0.44905*	*0.670861*
5	*Chow*	*0.649936*	*0.959506*

Table 3:Statistical analysis in D. R. using Roughness coefficient formula at Garudeshwar and Gopalkheda

Thus, unmeasured roughness coefficient at Garudeshwar and Gopalkheda may be obtained using different formulas. Graphical representation of discrepancy ratio for different roughness coefficient is shown in Fig 3.

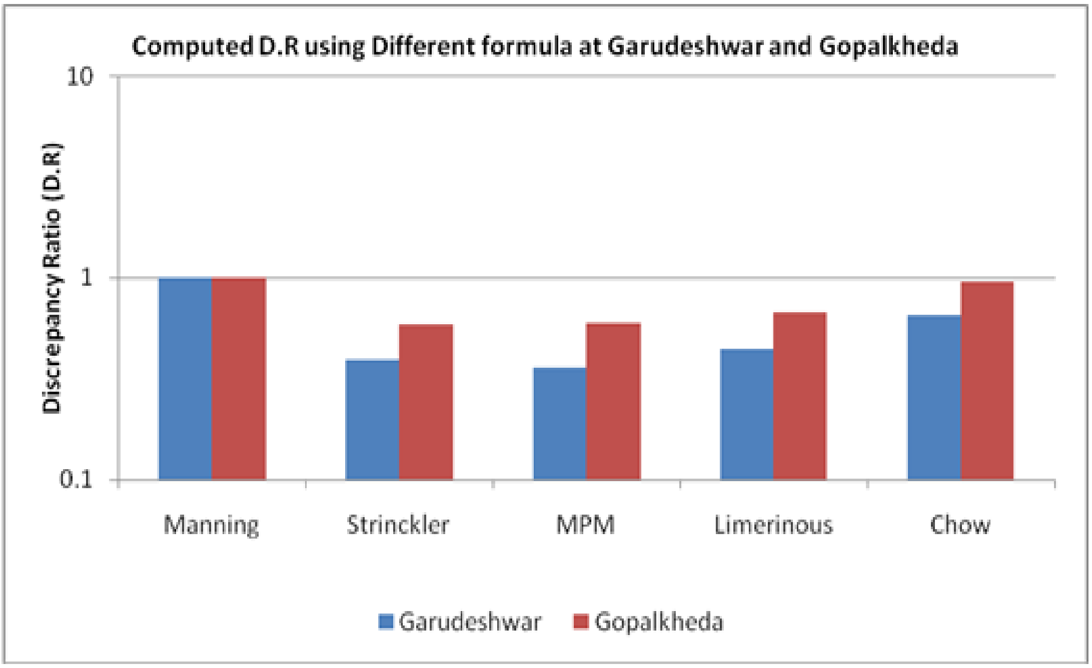

Fig. 3: Computed D.R Using different roughness coefficient formulas at Garudeshwar and Gopalkheda

For comparing the accuracy of Manning and Chow equations for Purna river data, the percentage of data within discrepancy ratio of 0.5 to 2.0 as score are also shown in Table 4 and the equation having higher score is ranked first.

Sr. No.	*Approaches to compute roughness coefficient*	*Score (discrepancy ratio within the range 0.5 to 2.0) at Garudeshwar*	*Score (discrepancy ratio within the range 0.5 to 2.0) at Gopalkheda*
1	*Manning's Formula*	*88.46%*	*100%*
2	*Strickler Formula*	*13.03%*	*65.93%*
3	*MPM Formula*	*32.91%*	*75.62%*
4	*Limerinuos Formula*	*32.91%*	*75.62%*
5	*Chow*	*100%*	*100.00%*

Table 4: Summary of comparisons of accuracy of Roughness coefficient equations at Garudeshwar and Gopalkheda

V. CONCLUSION

The Comparative analysis using different equations for determining the hydraulic roughness coefficient at the Garudeshwar and Gopalkheda station can be concluded as following:

– Predicted values are compared with those observed by using Manning's equation and other empirical relations such as: Limerinous , Strickler , Meyer – Peter and Muller and using Cowan's tables.
– Best predictability in results is obtained when hydraulic roughness coefficient is computed using Manning's equation with minimum discrepancy with good score and almost zero percent error at Garudeshwar.
– Best predictability is obtained when hydraulic roughness coefficient is computed using Chow's equation with minimum discrepancy ratio with good score and nearly zero percent error at Gopalkheda.

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