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Bed Load Transport in Tapi River, India

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Abstract: River Tapi is westward flowing river of peninsular India. The length of river is 724 km. The Central Water Commission India has number of gauging staion, gauge and discharge station and discharge measurement stations on it. The Ukai dam is one of the major multipurpose dam constructed on down stream side of Savkheda gauging station. One of the problems faced by this dam is progressive silting of the dam and due to that considerable reduction in the life of the dam. Therefore, it is essential to study transportation of sediments in the river. Bed load is a part of sediment transport. In the computation of bed load, shear stress is used. Part of the shear stress is wasted in overcoming the resistance due to bed forms. Therefore, the total shear stress developed in the open channel requires correction in the form of correction factor called ripple factor. Different methods have been followed for correcting the actual shear stress in order to compute the sediment load like correction to hydraulic mean depth, deduction of wall shear find the total shear (suggested by Johnson), using the number of coefficients obtained graphically (as in Einstein's equation). However all these correction factors are based on particular characteristics grain size of particle. The effect of non uniformity of bed material on the sediment transport has been studied by various investigators in the past. They developed the transport rate equation for particular size of sediment in a non uniform bed material, where as the influence of other sizes of sediments has been neglected. In the present paper the ripple factor has been obtained for non uniform bed material considering the various variables like discharge, hydraulic mean depth, flow velocity, bed slope etc. by collecting the field data of Tapi River for 15 years, Monsoon season, Savkheda gauging station. The majority of the bed load formulae represent a functional relation between bed load transport and shear stress ($q_b = A\ f\ (t_0\text{-}t_c)$).The main objectives of this paper are to develop mathematical model using Bagnolds approach and estimate bed load of Monsoon season for Tapi river. The bed load equation can be approximated in exponential form as Y = a X b. For this purpose bed load, shear stress and critical shear stress are computed using 15 years of field data of Tapi River. The statistical analysis, multiple regression and curve fitting (by nonlinear square fitter) is carried out by using allometric function of Micro cal Origin 6.1. The modified bed load equation of Bagnolds for Tapi river, Monsoon season and for Savkheda gauging station is Y = 0.26636X 0.7649. The value of Ripple factor obtained by above analysis is 0.26636 and the value of index is 0.7649. This mathematical model is validated using 5years field data of Tapi River. The rmse, inequality coefficient and discrepancy ratio suggest good agreement between predicted and measured value of bed load.

Key words: Sedimentation . dam . bed load . bagnold . mathematical modeling . ripple factor

INTRODUCTION

The subject of sediment transport and flow in alluvial streams are gaining importance with the increasing utilization of water resources, considerable development has taken place in the field of fluvial hydraulics which is considered as complicated branch of engineering.

Valuable information are available in numerous journals, monographs and research publications on sediment transport relating to the problems of incipient motion, flow regimes, resistance to flow bed load, suspended load, total load transport and flow of sediment in pipes etc. based on various approaches and concepts used by various research scientists and thousands of equations are developed.

The majority of the bed load formulae represent a functional relation between bed load discharge and shear stress. The formulae are characterized by three aspects:

- The basic function $q_b = A\,f\,(t_0\text{-}t_c)$.
- The characteristic grain-size to be used.
- The correction of the bed load equations.

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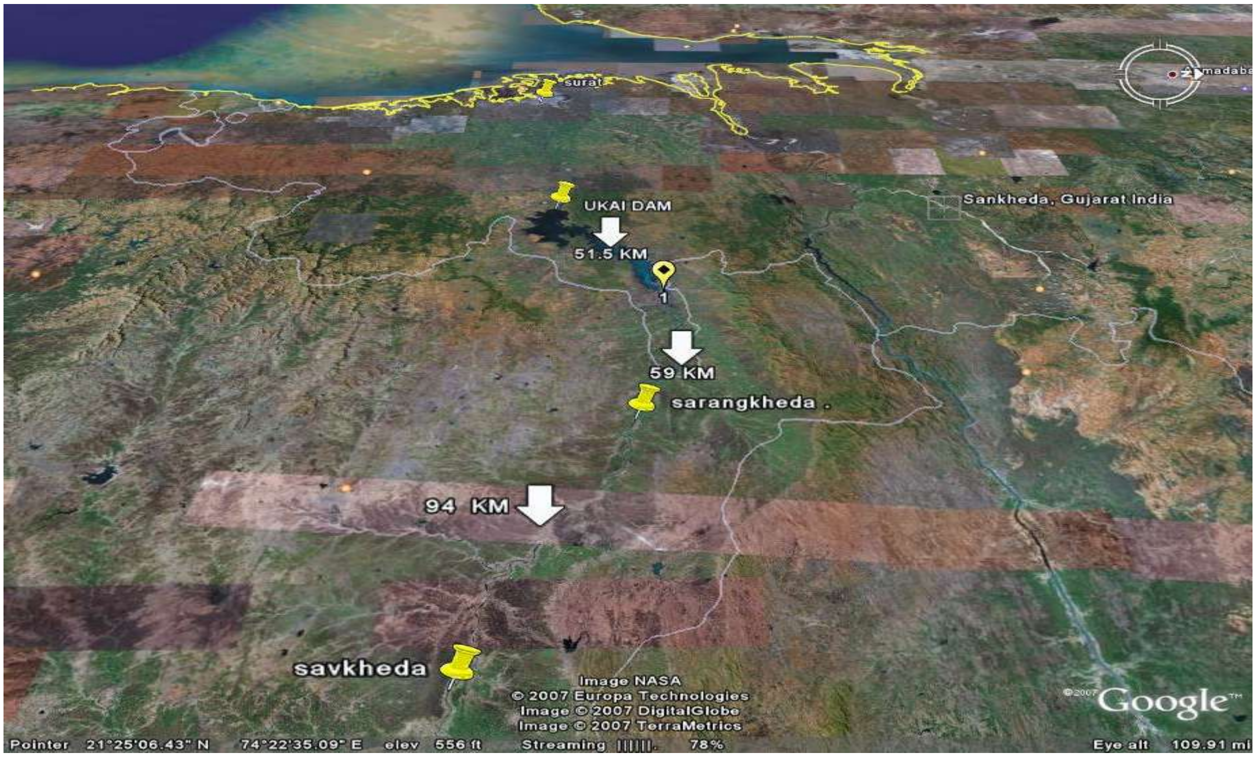

Fig. 1: Digital image of study area showing Savkheda, Sarangkheda gauging station and Ukai dam

This means that the formulae cannot be compared easily. The transport of sediment defined as a volume transported per unit width and time as if it were settled has advantages over real volume or mass. The main advantage lies in the fact the formulae are mainly used to predict sedimentation and erosion. By using bulk volume (i.e. including pores) in the formulae this link can easily be made. The correction factor 'μ' allows also known as Ripple factor, for the fact that only part of shear stress is used for transport and it also acts as a correction factor to adopt the basic formula to transport measurements.

OBJECTIVES

The main objectives of this paper are:

- Using various measured parameters determine q_b, t_0 and t_c.
- To develop modified bed load equation for Bagnolds approach.

STUDY AREA AND DATA COLLECTION

Tapi is the second largest westward flowing river of peninsular India.The total length of the river is 724 kms from origin to Gulf of Cambay. The Tapi basin is situated between latitudes 20o N to 22o N, 80% of the basin lies in Maharashtra and the balance in the state of Madhya Pradesh and Gujarat as shown in Fig. 2. Digitize images of the study area helps in the interpretation of movement of sediments in to the river.

Central Water Commission, Tapi Division, Surat is regularly collecting daily data of discharge and sediment at gauging site Savkheda on river Tapi. Savkheda is situated at a distance of about 488 kms from origin. The daily data during Monsoon are collected for 15 years period from 1981 to 1995. Bed load data (seasonal) from 1981-95 and suspended load data from 1984-94 are collected for study.

DISCHARGE AND SEDIMENT OBSERVATIONS

Discharges are observed once in a day at 08:00 hours at all the sites and calculated by area-velocity methods. Cross-section is divided into 15 to 25 segments as per IS1192:1981. Depths are measured by sounding rods as per IS 3912: 1966. Necessary air and wet line corrections are done as per IS 1192:1981. Velocity is measured by cup-type current meter as per 3910:1966 suspended sediment samples are collected in Punjab Bottle Samplers at a depth of 0.6 D from the water surface.

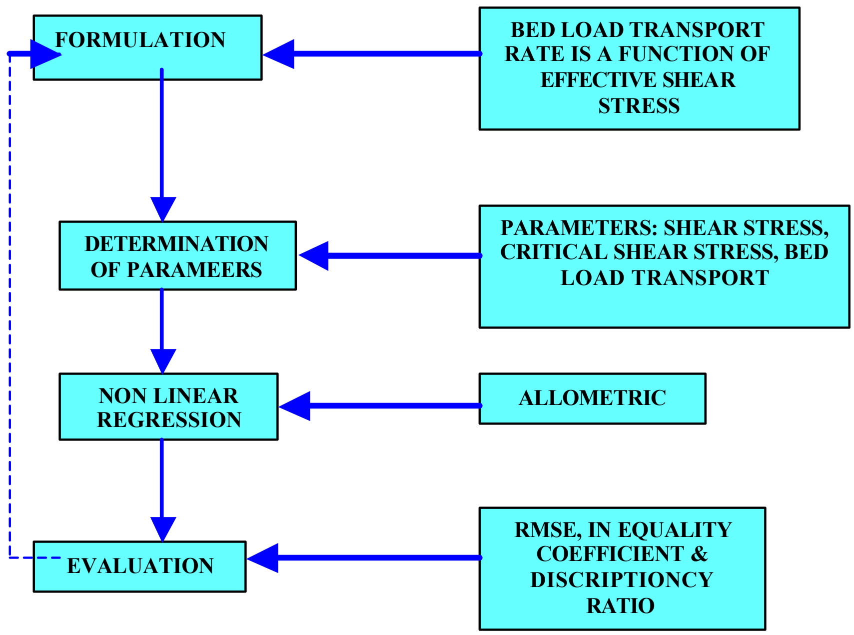

Fig. 2: Flow chart for mathematical modeling

METHOD OF ANALYSIS

The function $q_b = A\ f\ (t_0\text{-}t_c)$ can be approximated by an exponential function Y= a X b. Majority of the bed load equations follow three different approaches viz. empirical, dimensional consideration and semi theoretical approach which are based on mainly four different concepts like excess shear stress, fall velocity criteria, turbulence modern theory and stream power concept of dispersion of solid particles under shear. The Einstein Brown equation follows semi theoretical approach based on fall velocity criteria. The equation is converted in to *X-Y* form (non dimensional) so that they can be easily compared.Incase of Bagnolds equation,

$$\frac{q_B}{\gamma_s d\sqrt{\left(\frac{\rho_s}{\rho_f}-1\right) gd \cos\theta}} = AB_b\left\{\frac{\tau_0}{(\gamma_s-\gamma_f)\,d\cos\theta} - \frac{\tau_{0c}}{(\gamma_s-\gamma_f)\,d\cos\theta}\right\}$$

$$\times\left\{\frac{\tau_0}{(\gamma_s-\gamma_f)\,d\cos\theta}\right\}^{\frac{1}{2}}$$

COMPUTATION OF BEDLOAD AND RELATED PARAMETERS

From the observed and calculated daily data like discharge, area, velocity, wetted perimeter, hydraulic mean depth, Manning's and Chezy's constants, average diameter of sediment, mean diameter of sediment etc. are grouped under mainly five heads i.e., monthly, pre-monsoon, monsoon, post-monsoon and yearly to facilitate the use of these data in analysis. In this paper the discussion is done for Monsoon season, Bagnolds approach.

Following steps has been followed to develop the above model.

Step 1: The field daily data of 15 years has been converted in to monthly and seasonal data.
Step 2: Using the field data such as bed width, slope, hydraulic mean depth, discharge, velocity, temperature, mean diameter of particle the average and critical shear stress are computed.
Step 3: The Bagnolds equation is used to compute bed load transport in weight per unit width (q_b).
Step 4: The model formulation is done by assigning bed load transport in weight per unit width (q_b) as dependent variable Y and effective shear stress (t_0-t_c).
Step 5: The non linear curve fitting is carried out using origin software. The hundreds of models were analyzed and allometric model was proposed.
Step 6: The proposed model is tested using five years of field data other than used for model development.
Step 7: The testing of model is carried out by determining the statistical measures like root mean square error, inequality coefficient and discrepancy ratio.

The statistical analysis, multiple regression and curve fitting (by nonlinear square fitter) is carried by using allometric function of Micro cal Origin 6.1.

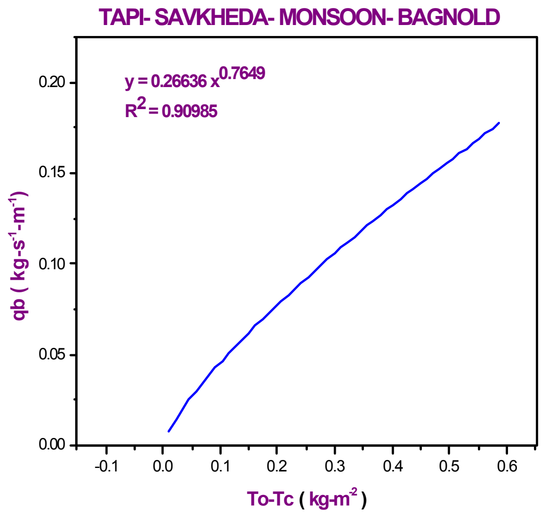

Fig. 3: The graph of bed load discharge versus effective shear stress

Figure 3 shows the flow chart for mathematical modeling.

RESULT ANALYSIS

During Monsoon, the computed values of bed load discharge, shear stress and critical shear stress obtained using Bagnolds approach are plotted as shown in Fig. 3. The stastical analysis is carried out using Microcal Origin 6.1.The proposed new bed load equation and value of Ripple factor a is given below.

$$Y = a\,X\,b$$

The value of ripple factor is 0.26636 and index is 0.7649.

The above equation can be used to calculate the correct bed load transported by Tapi River in case of Monsoon season for Savkheda gauging station. It is observed that increase in effective shear stress increases the bed load transport rate.

VALIDATION OF MODEL

The above mathematical modified model is tested using five years of data. The root mean square error (rmse) is one of the most convenient approaches for assessing simulation models. It measures the deviation between the trend of the predicted values and measured ones.

$$rmse = \left[\sum_{i=1}^{n} \frac{(Q_{bo} - Q_{bp})_i^2}{n}\right]^{1/2}$$

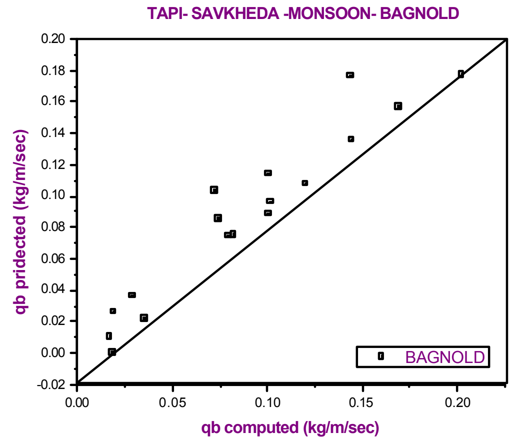

Fig. 4: The graph of $q_{b\,computed}$.v/s q_b *predicted*

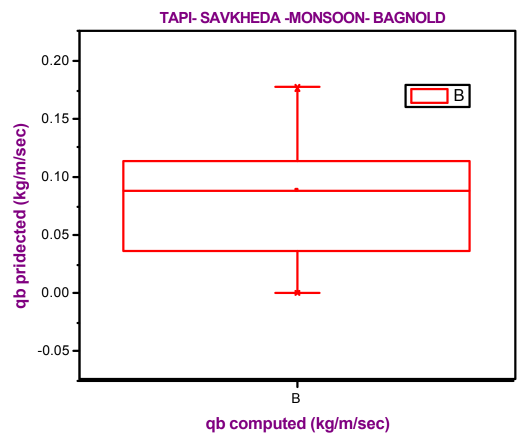

Fig. 5: Stastical box graph of qb $_{computed}$ against q_b *predicted*

The value of rmse is zero indicates a perfect fit between measured and predicted values.

The discrepancy ratio is the measured of an equation to replicate data accurately. It is the ratio of a predicted to the measured bed load discharge. This ratio was selected because it is widely accepted and easily interpreted. It this ratio is one, the equation exactly predicts the measured rate. If the ratio is less than one or greater than one the equation under or over predicts measured data respectively.

The inequality coefficient is a simulation statistics related to the rmse, defined as under.

$$U = \frac{rmse}{\left[\frac{1}{n}\sum_{i=1}^{n}(Q_{bo})_i^2\right]^{1/2} + \left[\frac{1}{n}\sum_{i=1}^{n}(Q_{bp})_i^2\right]^{1/2}}$$

The numerator is the root mean square error. If U=0 then qbp = qbo and there is a perfect fit. If U=1, then qbp $\neq$ qbo and the lacks predicative value.

The value of root mean square error, Discrepancy coefficient and Inequality coefficient for above model are 0.0375, 1.5006 and 0.1977.

The rmse value is close to zero, Discrepancy ratio is more than one and inequality ratio is close to zero which confirms the models good agreement.

EVALUATION OF PROPOSED BEDLOAD FORMULA

To examine more closely the accuracy of model, the computed bed load transport rates per unit channel width, $q_{b\ computed}$ using field data are plotted in Fig. 4 against the corresponding predicted values, q_b *predicted*. In this figure the solid line represents the condition of perfect agreement. Box plot (Fig. 5) shows distribution characteristics of $q_{bcomputed}$ against q_b *predicted* for examined bed load transport relation.

CONCLUSION

A new bed load transport relation for alluvial river has been proposed. The relation is an empirical fit to the data of Tapi river are considered to represent the two limits of the spectrum of bed load transport rate observed in the field and computed. The unique feature of this model is the bed load transport rate is function of effective shear stress. The proposed bed load equation for Tapi River, Monsoon season and for Savkheda gauging station is Y = 0.26636 X 0.7649.The value of Ripple factor obtained by above analysis is 0.26636 and the value of index is 0.7649. The rmse, inequality ratio and discrepancy ratio suggest good agreement between computed and predicted bed load.

NOTATIONS

qb = Rate of bed load transport in weight per unit width
t0 = Average shear stress on channel boundary
tc = Critical tractive stress
a,b = Regression parameters
d = Sieve diameter of particle
R = Hydraulic radius
S = Bed slope
Qbp = Predicted bed load transport in weight per unit width
Qbo = Measured/computed bed load transport in weight per unit width
U = Inequality coefficient
μ = Ripple factor

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