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Analysis of Stream Power Approach for Predicting Suspended Load Transport Rate

[1]Ankita C. Upadhyay [2]S. I. Waikhom [3]Dr. S. M. Yadav
[1]P. G Scholar [2]Associate Professor [3]Professor
[1,2,3]Department of Civil Engineering
[1,2]Dr. S & S. S. Ghandhy GEC Surat, Gujarat, India [3]SVNIT, Surat, Gujarat, India

Abstract

The present paper discusses the outcome of the detailed analysis to check the applicability of Bagnold (1966) Stream Power approach for river data. 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 formula. Graphical comparisons are done to demonstrate the performance and variations for different data sets. Score in terms of percentage of discrepancy ratio within the range 0.5 to 2.0 are calculated for comparison. Bagnold (1966) approach is tested for various river data sets. Analytical evaluation reveals that Bagnold (1966) approach for suspended load transport rate over-predicts for Chulitna River, Susitna River near Alaska and Sacremento Butte City and under predicts for Susitna River near Talkeetna and Sacramento Colusa City in the present study. Comparison between the predicted sediment transport rate and observed values indicates acceptable discrepancy ratio. Best predictability is observed for Sacremento Colusa City data set. It can be concluded that Bagnold's suspended sediment transport function predicts well for low to mild range of slope.
Keyword- Bagnold, Stream Power Approach, River Data, Suspended Sediment Transport Rate, Statistical Analysis

I. INTRODUCTION

Sediment particles remain suspended in flowing water because the gravitational forces causing them to fall towards the bed are at times exceeded by the upward-acting lifting forces induced by the flow current. In contrast, particles denser than water will always fall through standing water because the gravitational forces are unopposed by flow-induced lifting forces. Gravity will cause a particle to quickly accelerate towards the bed until the gravity force is opposed equally by the forces resisting movement, a state of balance in which the particle is said to have reached its terminal fall velocity or settling velocity. It will be very useful for us to consider the processes governing the settling velocity of sediment grains in standing water because the forces involved are at the heart of the suspension phenomenon.

Bagnold (1956) argue that, even in isotropic turbulence, in which turbulence scale and intensity are uniform throughout the flow, the strength of the upward velocity component is same as downward component and suspension can be maintained.

Bagnold (1966) defined stream power as the time rate of potential energy expenditure for the fluid flow. This energy is partly used to transport suspended load particles. Bagnold (1966) further developed model correlating the rate of bed and suspended load transport to the stream power.

The various approaches which are used to predict suspended load transport rate includes approaches of Lane kalinske (1941), Einstein (1950), Brooks (1963), Yalin (1963), Bagnold (1966), Chang simons Richardson (1967), Toffaleti (1967), Van Rijn(1984b), Wiuff (1985), Samaga et al (1986), Celik & Rodi (1991), Habibi & sivakumar (1992), Dr Saleh (2014). A comparative study of Bagnold (1966) and Wiuff (1985) suspended load transport function by Pritika et.al (2016) found that Bagnold (1966) suspended load function under predicts for river data and over- predicts for the selected range of hydraulic data. Therefore, in the present analysis, verification of Bagnold (1966) suspended load is done using only the river data of varying slope, ranging from mild to steep slope.

II. METHODOLOGY AND DATA COLLECTION

A. Bagnold (1966) Stream Power Approach (SPA)

Bagnold proposed new dimensionless equations for estimating bed and suspended load transport rates based on the concept of energy balance in alluvial flows. From physical point of view, the stream power supplies energy for the fluid flow, which is used partially in transportation of bed and suspended load particles

According to Bagnold, a particle is suspended when the bed shear velocity, u_* exceeds its fall velocity ω and the general expression to compute suspended load transport rate can be described as:

$$q_s = \frac{0.01}{\frac{\rho_s - \rho}{\rho}\omega} \tau_0 V^2 \quad (1)$$

Where τ_o is the average shear stress, V as mean flow velocity ρ and ρ_s are the density of water and sediment respectively.

B. Experimental Data Used for Verification

The summary of data sets used for verification is given in Table 1.

Name of data set	*Discharge*	*Width of flow*	*Depth of flow*	*Slope*	*Sediment diameter*
	Q (m^3/s)	*B (m)*	*D (m)*	*(s x 10^{-3})*	*D_{50} (mm)*
Susitna River near Talkeetna	*238 to 1160*	*165 to 202*	*1.1 to 2.3*	*0.0011 to 0.0018*	*0.004 to 7*
Chulitna River	*212 to 1350*	*98.5 to 136*	*1.7 to 3.6*	*0.00039 to 0.0026*	*0.0056 to 0.15*
Susitna River near Alaska	*130 to 2740*	*174 to 311*	*2.1 to 4.4*	*0.0012 to 0.0024*	*0.006 to 0.15*
Sacramento River Butte City	*150.1 to 2242.8*	*2.009028 to 8.076202*	*0.518839 to 1.768922*	*0.99 to 2.88*	*0.33 to 6.3*
Sacramento River Colusa City	*142 to 1122.9*	*2.645963 to 8.167779*	*0.666667 to 1.233008*	*1.21 to 1.83*	*0.35 to 2.0*

Table 1: Summary of hydraulic parameters for different data sets

C. Statistical Analysis

The discrepancy ratio, D.R (ratio of calculated value to measured value) for each set of data is considered for comparison of performance. If the ratio is less than one or greater than one the equation under or over predicts measured data respectively. 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 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. 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.

III. VERIFICATION OF BAGNOLD (1966) STREAM POWER APPROACH

The Bagnold (1966) Stream Power approach is tested against large experimental data collected from natural rivers. To examine the accuracy and applicability of the approach, deviation of predicted value from the observed value are computed by calculating percentage error and mean percentage error (MPE) is found out as given in Table 2. Positive mean percentage error indicates over prediction and negative MPE indicates under prediction. The calculated values are plotted against the observed values as shown in Fig 1 to 5, and the scatter about the perfect agreement line (45-degree red line) is also determined.

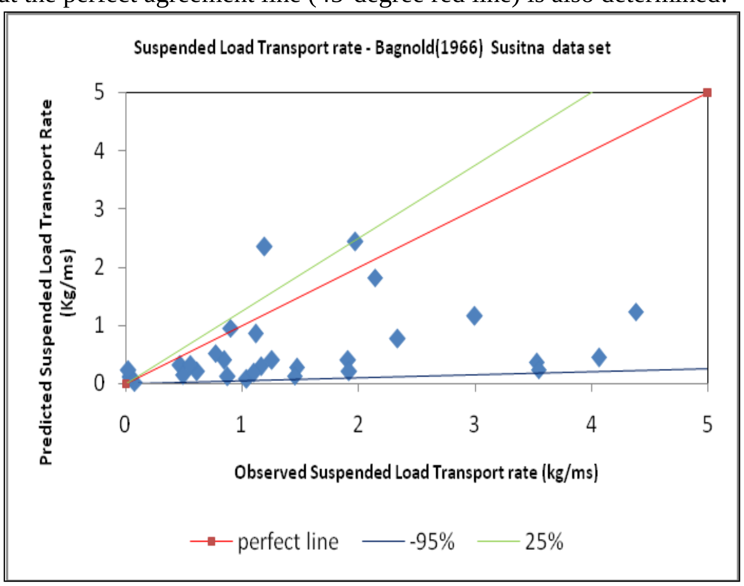

Fig. 1: Comparison between predicted results and observed values for Bagnold's Suspended load transport function using Susitna river data set

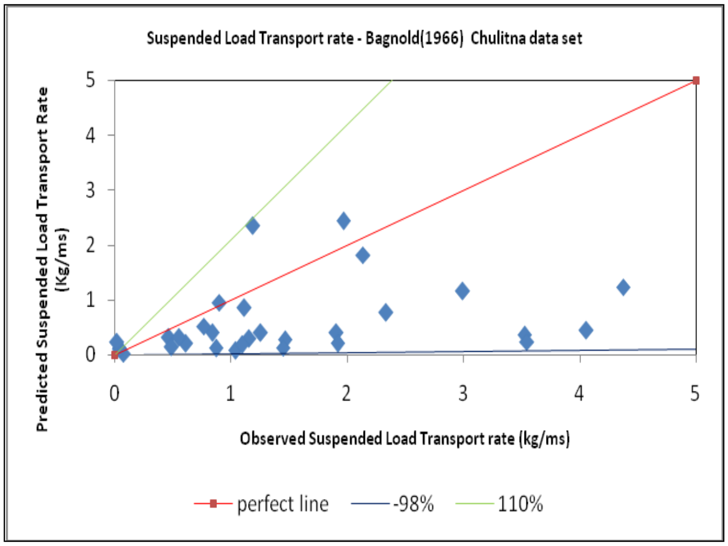

Fig. 2: Comparison between predicted results and observed values for Bagnold's Suspended load transport function using Chulitna river data set

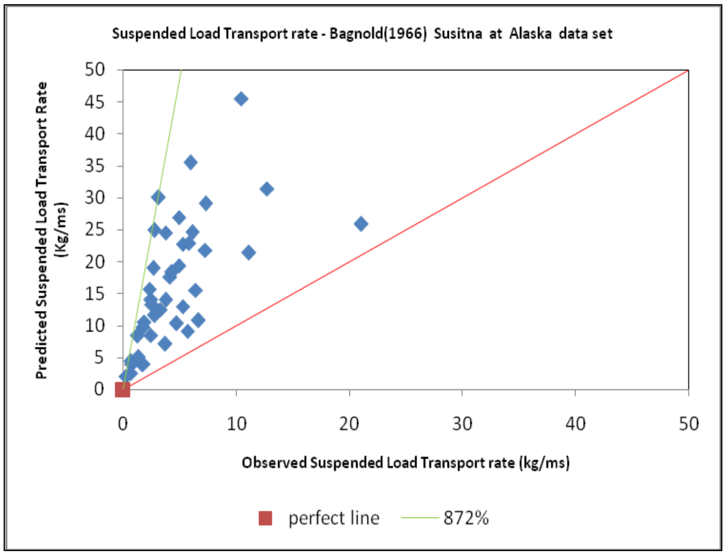

Fig. 3: Comparison between predicted results and observed values for Bagnold's Suspended load transport function using Susitna at Alaska Rriver data set

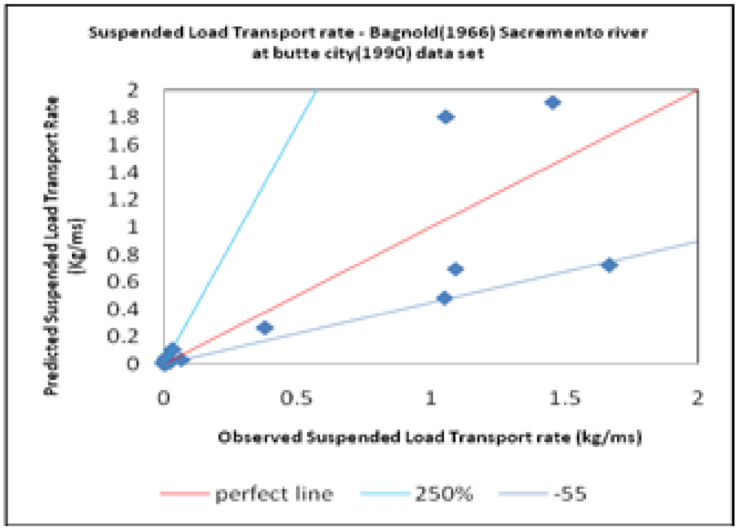

Fig. 4: Comparison between predicted r.sults and observed values for Bagnold's Suspended load using Sacramento Butte City data set

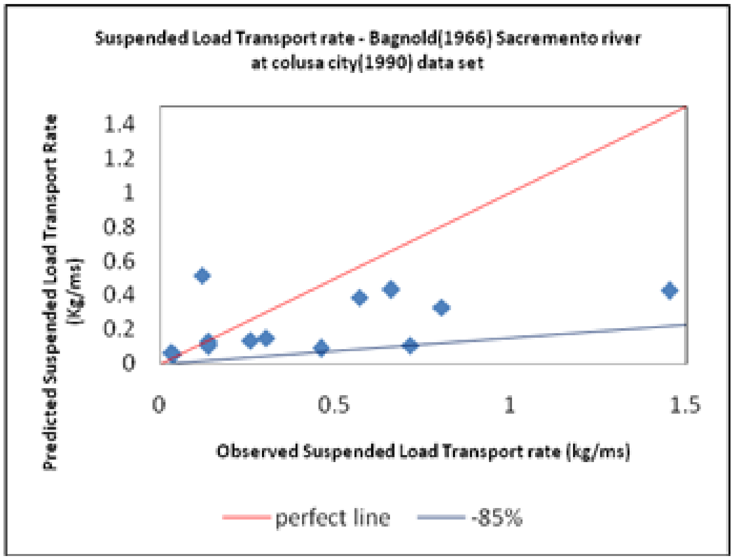

Fig. 5: Comparison between predicted results and observed values for Bagnold's Suspended load using Sacramento Colusa City data set

From Fig 1 it can be observed that Bagnold (1966) suspended sediment transport approach over predicts as well as under predicts. The percentage error between the observed and predicted transport rate is in the range of +25% to -95%

From Fig 2 it can be observed that Bagnold (1966) suspended sediment transport approach over predicts as well as under predict. The percentage error between the observed and predicted transport rate is in the range of 110% to -98%

From Fig 3 it can be observed that Bagnold (1966) suspended sediment transport approach over predicts. The percentage error between the observed and predicted transport rate is in the range of 872%

From Fig 4 it can be observed that Bagnold (1966) suspended sediment transport approach over predicts as well as under predict for Sacramento River Butte city. The percentage error between the observed and predicted transport rate is in the range of +250% to -55%.

From Fig 5 it can be observed that Bagnold (1966) suspended sediment transport approach under-predicts for Sacramento River Colusa city. The percentage error between the observed and predicted transport rate is in the range of -85%.

Sr No	*Name of data set*	*MPE*	*Remark*
1	*Susitna River near Talkeetna*	*-7.08*	*Under-predicts*
2	*Chulitna River*	*120.56*	*Over-predicts*
3	*Susitna River near Alaska*	*402.82*	*Over-predicts*
4	*Sacramento River butte City*	*102.67*	*Over-predicts*
5	*Sacramento River Colusa City*	*-2.28*	*Under-predicts*

Table 2: Summary of mean percentage error

IV. RESULT ANALYSIS

Various statistical parameters such as root mean square error (RMSE), inequality coefficient(u) and discrepancy ratios (D.R) are used to evaluate the performance of Van Rijn (1984 b) sediment transport approach. Root Mean Square Error measures the deviation between the trend of the predicted results and observed values. Discrepancy ratio(r) is the ratio of predicted to observed data whose value signifies the accuracy of each of the selected equations. Score in terms of % of DR within the range of 0.5-2.0 is also calculated. Comparative summary of discrepancy ratio and mean normalized error (MNE) using selected different suspended transport rate formulas is given in Table 3

Sr No	*Data Set*	*D.R*	*MNE*	*RMSE*	*U*	*Score (% of DR within the range of 0.5-2.0)*	*Rank*
1	*Susitna River near Talkeetna*	*0.929244*	*-7.07559*	*2.1530*	*0.503087*	*26.66667*	*4*
2	*Chulitna River*	*2.205612*	*120.561*	*71.3814*	*0.216761*	*41.86047*	*3*
3	*Susitna River near Alaska*	*4.447882*	*344.788*	*205.296*	*0.511511*	*12.19512*	*5*

4	*Sacramento Butte city*	*2.02672*	*102.672*	*3128.24*	*0.125007*	*62.5*	*1*
5	*Sacramento Colusa city*	*0.977175*	*-2.28251*	*1759.431*	*0.371811*	*53.84615*	*2*

Table 3: Summary of Statistical Measures for Bagnold (1966) eq.

V. CONCLUSIONS

From the detailed analysis above followings can be concluded regarding Bagnold (1966) suspended sediment transport function:

- Function under predicts for Susitna river data set scores 26.7% with an average error of -7.07%
- Function over-predicts for Chulitna river data set and Susitna River near Alaska with scores 41.86%, 12% and an average percentage error of 120.5 %, 344.788% respectively.
- Best predictability of the Function is observed for Sacramento Butte city with 62.5% scores followed by Sacramento Colusa city with 53.84% score.
- From evaluation it is observed that the Function over predicts to large values for the river data of Susitna River near Alaska having high range of slope.
- Overall it can be concluded that the Function predicts well for low to mild range of slope.

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