Comparative Analysis of Sediment Transport Load for Indian River

Kamleshkumar Manharlal Rana

I/c Head of the Applied Mechanics Department, Government Polytechnic, Valsad, Gujarat, India

Abstract: ***One of the major problems that interrupt the stability of any river is sedimentation. Excessive sedimentation causes an increase in riverbed elevation (siltation) & at the same time can increase water level which may also result in flooding situation. By numbers of applicability of new theories for calculation of sedimentation in rivers is investigated using sediment transport in Natural River as well as filed measurements from water. This study aims to evaluate various methods of estimating sediment transport which gives its best level of accuracy for existing sediment transport methods. Here it have to be discussed about the outcome of comparative analysis of the applicability of Bagnold (1966), Wuiff (1985), etc. suspended load transport methods for Indian Rivers. The computed method is considered accurate if and only the percentage of compliance with the highest discrepancy ratio (r) ranges from available data. Sediment parameter data computation is done by taking observed data to estimate the concentration of suspended sediment, bedload sediment sample and samples of bedload material using the correct standard data retrieval.***

Keywords: Suspended load, Statistical analysis, Bagnold, Wuiff, Comparative analysis, Indian River

1. Introduction

Rivers and canals convey water as well as sediment from the catchment to the sea or outfall of the canal. As a result, all natural mobile boundary streams are subject to change, either through erosion or deposition. [1, 4, 5]. However, sediment process in alluvial channel and streams also lead to various other engineering and environmental effects such as Land Erosion and Soil conservation, silting of reservoirs, degradation, aggradations, local scour, flood damage, etc. [3,5] One of the major issues of sedimentation research is the estimation of the amount of sediment material, which a specific flow can carry. In order to deal with various problems such as dislodging and transportation of soil particles along with water due to soil erosion, suitable channel characteristics requirements for one of the modes of transport such as navigation channels, etc. are to be assessed. Computation of total sediment transport rate in alluvial streams can be carried out using various approaches based on different concepts like probability, regression, stream power, regime, etc

For the purpose of sustainable water resource management, especially for river ecosystems, it is very important to be able to estimate the total amount of sediment loads a little more accurately according to the river's carrying capacity. This study aims to evaluate the method of estimating sediment transport that gives the best level of accuracy of existing sediment transport methods [8, 10]. The method is considered accurate if the percentage of compliance with the highest discrepancy ratio (r) ranges from the available data. This research methodology analyses and compares several methods of estimating the total sediment load that are most suitable for the taken river tributary data. Sediment parameter data inventory is done by taking water samples to estimate the concentration of suspended sediment, bed load sediment samples and samples of the bed load material using the correct stranded data retrieval. In addition, measurement of river hydraulic parameters is needed, including flow velocity and river water temperature. [12] Based on the analysis, the method that works best to calculate the sediment transport values in sequence must be made reference to calculate sediment transport load for that river. The Van Rijn method, the Wuiff method, the Bagnold method, the Celik & Rodi (1991) method, etc. which is close to 30% fulfilling the discrepancy ratio (r) ($0.5 \leq r \leq 2.0$)

The process of particles settling to the bottom of a body of water is called sedimentation. Sedimentation can be traced back to the Latin sediment, "a settling or a sinking down. "In general, the greater the flow, the more sedimentation that will be conveyed.[18]

There are 4 types of sedimentation:
1) Lithogenous
2) Hydrogenous
3) Biogenous
4) Cosmogenous

Sediment transport is the movement of organic and inorganic particles by water. In general, the greater the flow, the more sediment that will be conveyed. Water flow can be strong enough to suspend particles in the water column as they move downstream, or simply push them along the bottom of a waterway. Transported sediment may include mineral matter, chemicals and pollutants, and organic material.

Another name for sediment transport is sediment load.

2. Factors that influence sediment transport

Sediment transport is not constant. In fact, it is constantly subject to change. In addition to the changes in sediment load due to geology, geomorphology and organic elements, sediment transport can be altered by other external factors. The alteration to sediment transport can come from changes in water flow, water level, weather events and human influence.[22]

a) **Water Flow**

Whether sediment will be eroded, transported or deposited is depended on the particle size and the flow rate of the water.

Water flow, also called water discharge, is the single most important element of sediment transport [18]. The flow of water is responsible for picking up, moving and depositing sediment in a waterway. Without flow, sediment might remain suspended or settle out but it will not move downstream. Flow is required to initiate the transport [12, 25]. There are two basic ways to calculate flow. Water discharge can be simplified as area (a cross-section of the waterway) multiplied by velocity, or as a volume of water moved over time [29].

b) Weather Events &Water Level

Most changes in water level are due to weather events such as rainfall. Precipitation causes water levels to initially rise, and then return to previous levels (base flow) over the course of hours or days [25, 26]. Rainfall, whether slight or heavy can affect water flow and sediment transport. The extent to which a weather event will influence sediment transport is dependent on the amount of sediment available. Snowmelt in a glaciated area will result in a high sediment load due to glacial silt [32, 34]. Heavy rainfall over an area of loose soil and minimal vegetation will create runoff, carrying loose particles into the waterway. Likewise, flooding will also pick up sediment from the local area. In fact, most of a waterway's sediment load occurs during flood events.

c) Human Influence

Human land use, such as urban areas, agricultural farms and construction sites will affect the sediment load, but not the transport rate. These effects are indirect, as they require heavy rainfall or flooding to carry their sediment into the waterway. However, anthropogenic land use is one of the leading contributors to excessive sedimentation due to erosion and runoff. This increase occurs because "disturbed sites" (logging, mining, construction and farm sites) often expose or loosen top soil by removing native vegetation. This loose soil is then easily carried into a nearby river or stream by rainfall and runoff [38].

3. Study Area

Purna is one of the major rivers in the Indian state of Gujarat. The river has its origins in Saputara Hill ranges in the Dang district of Gujarat. Zankhririver is main tributary of Purna river. Sediment transport load of Purna River are measured by central water commission at hydrological observation site, Mahuva which is situated in Surat district of Gujarat.

3.1 River Geometry

Purna river has a drainage area of 2431 km^2 and its travels 180 km before joining with Arabian sea. The basin lies between 72°45' to 74°00' East longitude and 20°41' to 21°05' North latitude. The level of the river bed drops steeply from 1300 m at source to about 115 m at the proposed Kelwan dam site as the river in this reach passes through hilly area covered with dense forest and patches of cultivated land.

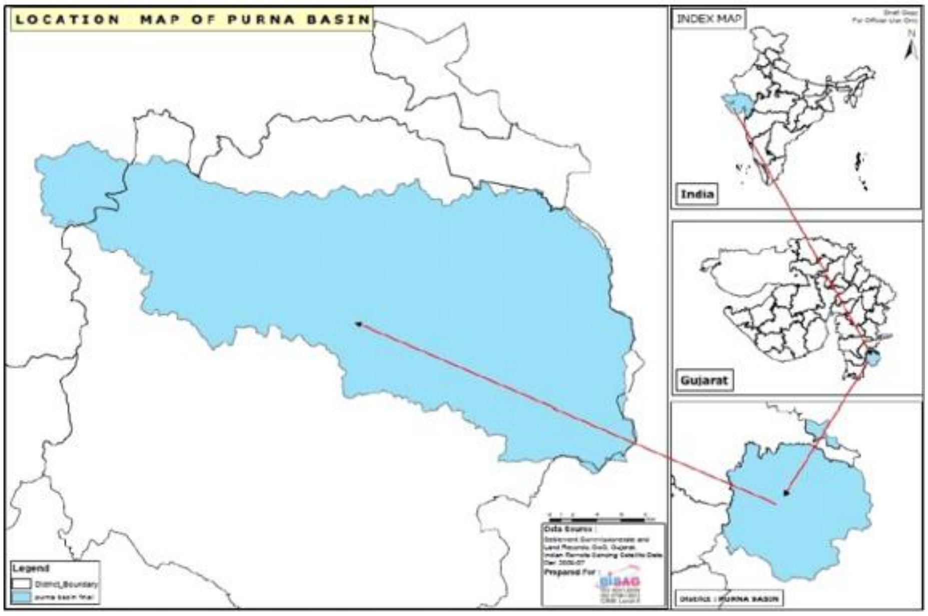

Figure 1: Location map of Purna basin

3.2. Purna basin

- There are 24 rain gauge stations located in and around the Purna basin.
- Location of mahuva rain gauge station is shown in Fig-3.4
- The details of period of availability, average annual rainfall are given below in Table 3.1.

Table 1: Periods of Availability and Average Annual Rainfall

Sr. No.	RG station	Period of Availability of Data	Average Annual Rainfall (mm)
1.	Laochali	1971 to 2006	1603
2.	Dhanmodi	1971 to 2006	1295
3.	Kalibel	1962 to 2006	1559
4.	Ahwa	1903 to 2003	1972
5.	Navsari	1927 to 2003	1469
6.	Nizar	1963 to 2003	782
7.	Jamkhadi	1965 to 2006	1617

8.	Chimar	1971 to 1997	1217
9.	Zankhari	1962 to 2006	1550
10.	Raniamba	1969 to 2006	1538
11.	Satem	1973 to 2001	1460
12.	Subir	1964 to 2006	1601
13.	Valod	1901 to 2003	1451
14.	Garkhadi	1967 to 2006	1787
15.	Antapur	1965 to 2006	1733
16.	Mahuva	1962 to 2003	1419
17.	Sarbhon	1973 to 2006	1420
18.	Wankaner	1973 to 2006	1448
19.	Ugat	1974 to 2002	1392
20.	Vesma	1973 to 2006	1462
21.	Maroli	1969 to 1997	1246
22.	Vyara	1962 to 2003	1477
23.	Astagam	1970 to 1997	1558
24.	Dosvada	1972 to 2003	1279

For knowing the actual data collection, we went to the Mahuwa gauge station and there we got the whole explanation about the entire process of data collection.

This involves the particle size analysis, velocity of the flow of river, water depth, reduced level, slope, discharge etc.

4. Velocity Measurement in river

Stream gaging generally involves 3 steps:
1) Measuring stream stage—obtaining a continuous record of stage—the height of the water surface at a location along a stream or river
2) The discharge measurement—obtaining periodic measurements of discharge (the quantity of water passing a location along a stream)
3) The stage-discharge relation—defining the natural but often changing relation between the stage and discharge; using the stage-discharge relation to convert the continuously measured stage into estimates of streamflow or discharge.

5. Equation used for the sediment load transport

Wiuff (1985) used simple formula based on energy exchange in alluvial streams for estimation of suspended load. Wiuff (1985) related the suspended load discharge to a particular dimensionless efficiency formula which was defined as a ratio of gain in potential energy of the suspended materials to the dissipation of turbulence energy. Wiuff (1985) efficiency formula is basically same as a suspended load efficiency factor in Bagnold's (1966) theory. Using the experimental results of Guy et al (1966), Wiuff (1985) showed that despite assumption of Bagnold (1966), the suspended load efficiency is not constant but varies linearly with Shields dimensionless shear stress parameter.

Unlike Bagnold (1966), Wiuff (1985) argued that the use of a constant value for modified suspended load efficiency ηs is not sufficient. Using linear regression analysis Wiuff (1985) concluded that Shields parameter τ* is the best dominant variable. The correlation obtained was

$$\eta s = 0.016\tau *$$

Where in τ* is expressed by

$$\tau * = \tau_o / [\rho s - \rho\, g ds]$$

Where τo =ρgDS and ds representing sediment diameter.

Suspended load transport per unit time and unit width in volumetric ratio can be written as:

$$q_s = 0.016 \frac{(VDS)^2}{\Delta 2 ds \omega}$$

Where,
V = velocity (m/s)
D = Depth of water (m)
ds = median grain size(m)
S = Slope
ω = fall velocity (m/s)

Required data: V, D, S, ds, Δ, ω
- Output: ω and qs
- Calculation procedure:

1) Calculate fall velocity of bed material ωfor ds = d50.

$$\omega = \frac{\Delta g\, ds^2}{(18\, v)} \quad \text{for ds} \leq 0.1\text{mm}$$

$$\omega = \left(\frac{10v}{ds}\right)\{[1 + (0.01\, \Delta g\, [ds]^3/v^2]^{0.5} - 1\}$$

for 0.1mm<ds<1.0mm

$$\omega = 1.1 \quad (\Delta g\, ds)^{0.5} \quad \text{for } 0.1\text{mm} \leq ds$$

Where,
g = acceleration of gravity
v = kinematic viscosity of flow

6. Result and Discussion

Comparison between observed values and predicted results obtained for Wiuff equation by using the Purna River data set is shown in Table 1 and Fig 2 & 3.

Table 2: Wiuff equation calculation

Total transport load(observed)	Total transport load (Predicted)	Percentage error
q_s(g/l)	q_s (g/l)	%
0.379	0.338060115	-12.1102383
2.336	3.853741752	39.38358743
0.506	0.993597881	49.07396548
0.754	1.256119032	39.97384159
0.432	0.850057751	49.17992344
0.036	0.022728156	-58.39384365
0.015	0.028142258	46.6993734
0.070	0.046092494	-51.86854389
0.050	0.028055866	-78.21584894
0.030	0.018371203	-63.29905264
0.020	0.012213043	-63.75935161
	AVG	51.29690497

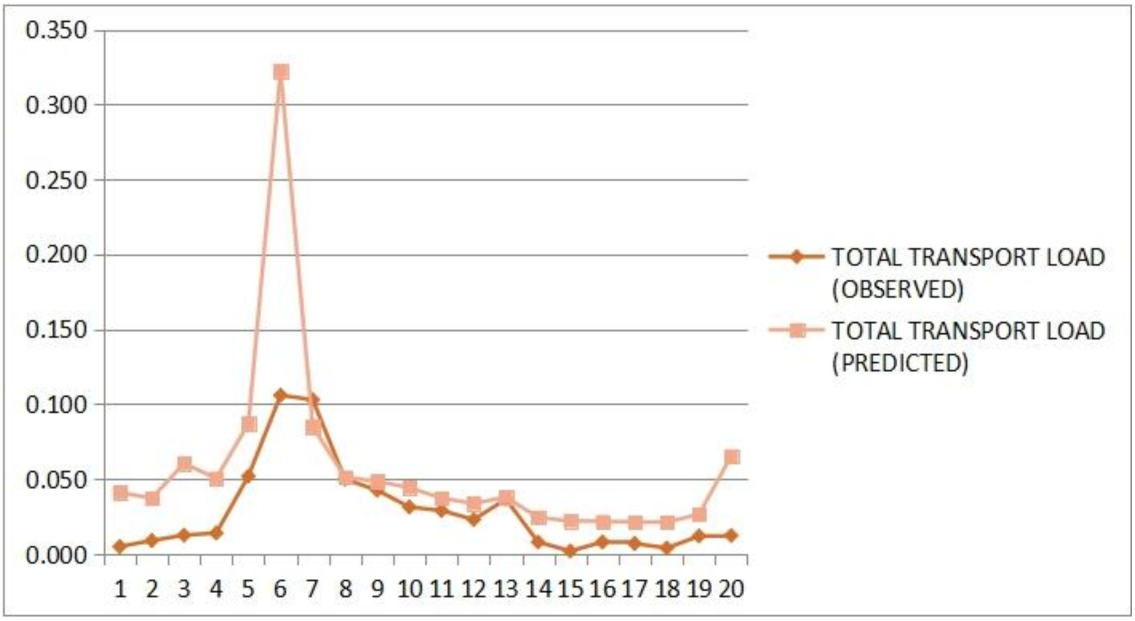

Figure 2: Wiuff equation comparison graph

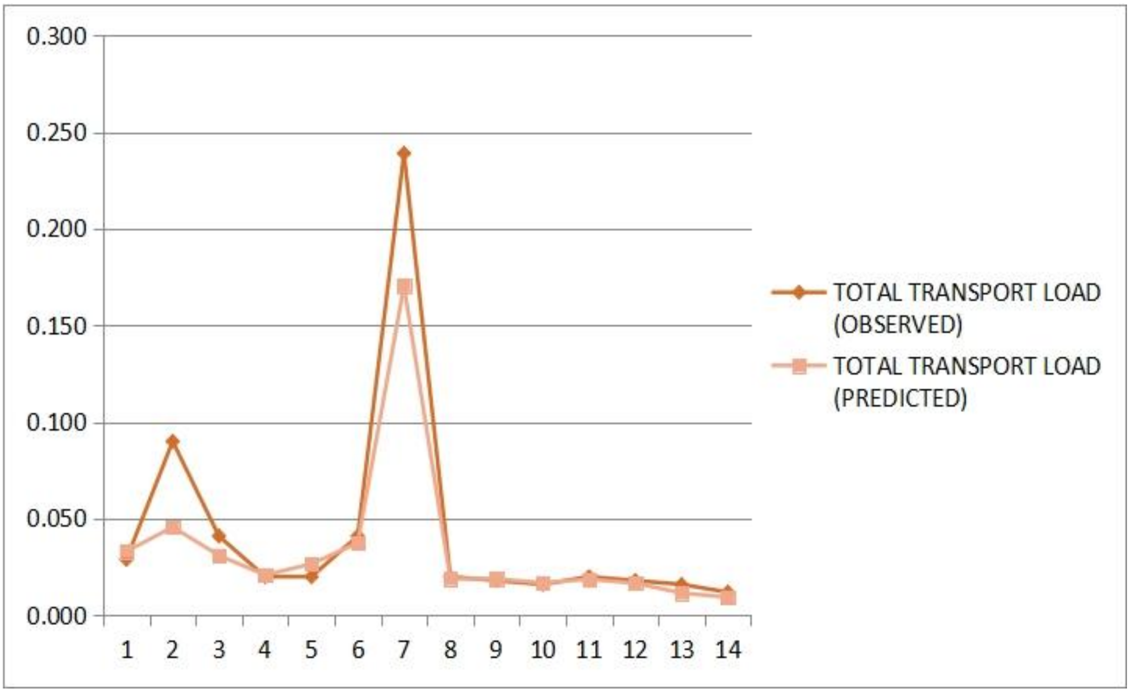

Figure 3: Wiuff equation Comparison graph.

The percentage error between the observed and predicted transport rate in the range of -99% to +99% but most of data lying between error ranging from -40% to 50% as shown in Table-3. So this formula can be acceptable for River Purna.

Statistical Analysis		
Discrepancy Ratio	Root Mean Square Error	Inequality Coefficient
r	RMSE	U
43.15177177	1.000023564	0.98497887

This is the average statistical analysis of the Wiuff Equation which is been calculated for Purna River Basin.

References

[1] Alexandrov, Y., Laronne, J.B., Reid, I., 2007. Intra-event and inter-seasonal behaviour of suspended sediment in flash floods of the semi-arid northern Negev, Israel. Geomorphology 85, 85–97. doi:10.1016/j.geomorph.2006.03.013

[2] Asselman, N.E.M., 2000. Fitting and interpretation of sediment rating curves. J. Hydrol. 234, 228–248. doi:10.1016/S00221694(00)00253-5

[3] Belmont, P., Gran, K.B., Schottler, S.P., Wilcock, P.R., Day, S.S., Jennings, C., Lauer, J.W., Viparelli, E., Willenbring, J.K.,

[4] Engstrom, D.R., Parker, G., 2011. Large shift in source of fine sediment in the upper Mississippi River. Environ. Sci. Technol. 45, 8804–8810. doi:10.1021/es2019109

[5] Bezak, N., Šraj, M., Mikoš, M., 2016. Analyses of suspended sediment loads in Slovenian rivers. Hydrol. Sci. J. 1–15. doi:10.1080/02626667.2015.1006230
[6] Bilotta, G.S., Brazier, R.E., 2008. Understanding the influence of suspended solids on water quality and aquatic biota. Water Res. 42, 2849–2861. doi:10.1016/j.watres.2008.03.018
[7] Bilotta, G.S., Burnside, N.G., Cheek, L., Dunbar, M.J., Grove, M.K., Harrison, C., Joyce, C., Peacock, C., Davy-Bowker, J., 2012. Developing environment-specific water quality guidelines for suspended particulate matter. Water Res. 46, 23242332. doi:10.1016/j.watres.2012.01.055
[8] Bracken, L.J., Turnbull, L., Wainwright, J., Bogaart, P., 2015. Sediment connectivity: a framework for understanding sediment transfer at multiple scales. Earth Surf. Process. Landforms 40, 177–188. doi:10.1002/esp.3635
[9] Bridge, J., 2003. Rivers and Floodplains: Forms, Processes, and Sedimentary Record. Blackwell Science, Oxford.
[10] Brosinsky, A., Foerster, S., Segl, K., Kaufmann, H., 2014a. Spectral fingerprinting: sediment source discrimination and contribution modelling of artificial mixtures based on VNIR-SWIR spectral properties. J. Soils Sediments 14, 1949–1964. doi:10.1007/s11368-014-0925-1
[11] Brosinsky, A., Foerster, S., Segl, K., López-Tarazón, J.A., Piqué, G., Bronstert, A., 2014b. Spectral fingerprinting: characterizing suspended sediment sources by the use of VNIR-SWIR spectral information. J. Soils Sediments. doi:10.1007/s11368014-0927-z
[12] Cao, Z., Li, Y., Yue, Z., 2007. Multiple time scales of alluvial rivers carrying suspended sediment and their implications for mathematical modeling. Adv. Water Resour. 30, 715–729. doi:10.1016/j.advwatres.2006.06.007
[13] Carter, J., Owens, P.N., Walling, D.E., Leeks, G.J.L., 2003. Fingerprinting suspended sediment sources in a large urban river system. Sci. Total Environ. 314–316, 513–534. doi:10.1016/S0048-9697(03)00071-8
[14] Chang, C., Harrison, J.F., Huang, Y., 2015. Modeling Typhoon-Induced Alterations on River Sediment Transport and Turbidity Based on Dynamic Landslide Inventories: Gaoping River Basin, Taiwan. Water 7, 6910–6930. doi:10.3390/w7126666
[15] Chen, F., Zhang, F., Fang, N., Shi, Z., 2016. Sediment source analysis using the fingerprinting method in a small catchment of the Loess Plateau, China. J. Soils Sediments. doi:10.1007/s11368-015-1336-7
[16] Cobaner, M., Unal, B., Kisi, O., 2009. Suspended sediment concentration estimation by an adaptive neuro-fuzzy and neural network approaches using hydro-meteorological data. J. Hydrol. 367, 52–61. doi:10.1016/j.jhydrol.2008.12.024
[17] Collins, A.L., Walling, D.E., 2004. Documenting catchment suspended sediment sources: problems, approaches and prospects. Prog. Phys. Geogr. 28, 159–196. doi:10.1191/0309133304pp409ra
[18] Cooper, R.J., Krueger, T., Hiscock, K.M., Rawlins, B.G., 2014a. High-temporal resolution fluvial sediment source fingerprinting with uncertainty: A Bayesian approach. Earth Surf. Process. Landforms. doi:10.1002/esp.3621
[19] Cooper, R.J., Rawlins, B.G., Lézé, B., Krueger, T., Hiscock, K.M., 2014b. Combining two filter paper-based analytical methods to monitor temporal variations in the geochemical properties of fluvial suspended particulate matter. Hydrol. Process. 28, 4042–4056. doi:10.1002/hyp.9945
[20] Cox, N.J., Warburton, J., Armstrong, A., Holliday, V.J., 2008. Fitting concentration and load rating curves with generalized linear models. Earth Surf. Process. Landforms 33, 25–39. doi:10.1002/esp
[21] Croke, J., Fryirs, K.A., Thompson, C., 2013. Channel-floodplain connectivity during an extreme flood event: Implications for sediment erosion, deposition, and delivery. Earth Surf. Process. Landforms 38, 1444–1456. doi:10.1002/esp.3430
[22] Davis, C.M., Fox, J.F., 2009. Sediment Fingerprinting : review of the method and future improvements for allocating nonpoint source pollution. J. Environ. Eng. 137, 490–505.
[23] De Girolamo, A.M., Pappagallo, G., Lo Porto, A., 2015. Temporal variability of suspended sediment transport and rating curves in a Mediterranean river basin: The Celone (SE Italy). Catena 128, 135–143. doi:10.1016/j.catena.2014.09.020
[24] Dean, D.J., Topping, D.J., Schmidt, J.C., Griffiths, R.E., Sabol, T.A., 2016. Sediment supply versus local hydraulic controls on sediment transport and storage in a river with large sediment loads. J. Geophys. Res. Earth Surf. 182–110. doi:10.1002/2015JF003436
[25] De Vente, J., Poesen, J., Arabkhedri, M., Verstraeten, G., 2007. The sediment delivery problem revisited. Prog. Phys. Geogr. 31, 155–178. doi:10.1177/0309133307076485
[26] Dominic, J.A., Aris, A.Z., Sulaiman, W.N.A., 2015. Factors controlling the suspended sediment yield during rainfall events of dry and wet weather conditions in a tropical urban catchment. Water Resour. Manag. 29, 4519–4538.
[27] Duvert, C., Gratiot, N., Evrard, O., Navratil, O., Némery, J., Prat, C., Esteves, M., 2010. Drivers of erosion and suspended sediment transport in three headwater catchments of the Mexican Central Highlands. Geomorphology 123, 243–256. doi:10.1016/j.geomorph.2010.07.016
[28] Eder, A., Strauss, P., Krueger, T., Quinton, J.N., 2010. Comparative calculation of suspended sediment loads with respect to hysteresis effects (in the Petzenkirchen catchment, Austria). J. Hydrol. 389, 168–176. doi:10.1016/j.jhydrol.2010.05.043
[29] Fang, N.F., Shi, Z.H., Chen, F.X., Zhang, H.Y., Wang, Y.X., 2015. Discharge and suspended sediment patterns in a small mountainous watershed with widely distributed rock fragments. J. Hydrol. 528, 238–248.doi:10.1016/j.jhydrol.2015.06.046
[30] Francke, T., Werb, S., Sommerer, E., López-Tarazón, J.A., 2014. Analysis of runoff, sediment dynamics and sediment yield of subcatchments in the highly erodible Isábena catchment, Central Pyrenees. J. Soils Sediments 14, 1909–1920. doi:10.1007/s11368-014-0990-5

[31] Franz, C., Makeschin, F., Weiß, H., Lorz, C., 2014. Sediments in urban river basins: identification of sediment sources within the Lago Paranoá catchment, Brasilia DF, Brazil - using the fingerprint approach. Sci. Total Environ. 466–467, 513–23. doi:10.1016/j.scitotenv.2013.07.056
[32] Gao, J.H., Xu, X., Jia, J., Kettner, A.J., Xing, F., Wang, Y.P., Yang, Y., Qi, S., Liao, F., Li, J., Bai, F., Zou, X., Gao, S., 2015. A numerical investigation of freshwater and sediment discharge variations of Poyang Lake catchment , China over the last 1000 years. The Holocene. doi:10.1177/0959683615585843
[33] Hollister, J.W., August, P. V., Paul, J.F., 2008. Effects of spatial extent on landscape structure and sediment metal concentration relationships in small estuarine systems of the United States' Mid-Atlantic Coast. Landsc. Ecol. 23, 91106. doi:10.1007/s10980-007-9143-1
[34] Horowitz, A.J., 2009. Monitoring suspended sediments and associated chemical constituents in urban environments: lessons from the city of Atlanta, Georgia, USA Water Quality Monitoring Program. J. Soils Sediments 9, 342–363.doi:10.1007/s11368-009-0092-y
[35] Horowitz, A.J., 2008. Determining annual suspended sediment and sediment-associated trace element and nutrient fluxes. Sci. Total Environ. 400, 315–43. doi:10.1016/j.scitotenv.2008.04.022
[36] Kisi, O., 2005. Suspended sediment estimation using neuro-fuzzy and neural network approaches. Hydrol. Sci. J. 50, 683–696. doi:10.1623/hysj.2005.50.4.683
[37] Kisi, O., 2004. Daily suspended sediment modelling using a fuzzy differential evolution approach. Hydrol. Sci. J. 49, 183–197. doi:10.1623/hysj.49.1.183.54001
[38] Koiter, A.J., Lobb, D.A., Owens, P.N., Petticrew, E.L., Tiessen, K.H.D., Li, S., 2013a. Investigating the role of connectivity and scale in assessing the sources of sediment in an agricultural watershed in the Canadian prairies using sediment source fingerprinting. J. Soils Sediments 13, 1676–1691. doi:10.1007/s11368-013-0762-7
[39] Lohani, A.K., Goel, N.K., Bhatia, K.K.S., 2007. Deriving stage–discharge–sediment concentration relationships using fuzzy logic.Hydrol. Sci. J. 52, 793–807. doi:10.1623/hysj.52.4.793
[40] Morgan, R.P.C., 2005. Soil Erosion & Conservation. Blackwell Publishing Ltd, Oxford.
[41] Park, E., Latrubesse, E.M., 2014. Modeling suspended sediment distribution patterns of the Amazon River using MODIS data. Remote Sens. Environ. 147, 232–242. doi:10.1016/j.rse.2014.03.013
[42] Renard, K.G., Foster, G.R., Weesies, G. a., Porter, J.P., 1991. RUSLE: Revised universal soil loss equation. J. Soil Water Conserv. 46, 30–33.
[43] Sear, D.A., Malcolm, D.N., Thorne, C.R., 2003. Guidebook for Applied Fluvial Geomorphology, R&D Technical Report FD1914. London.
[44] Tananaev, N.I., 2015. Hysteresis effects of suspended sediment transport in relation to geomorphic conditions and dominant sediment sources in medium and large rivers of the Russian Arctic. Hydrol. Res. 46, 232. doi:10.2166/nh.2013.199
[45] Vale, S.S., Fuller, I.C., Procter, J.N., Basher, L.R., Smith, I.E., 2016. Characterization and quantification of suspended sediment sources to the Manawatu River, New Zealand. Sci. Total Environ. 543, 171–186. doi:10.1016/j.scitotenv.2015.11.003
[46] Wohl, E., 2015. Legacy effects on sediments in river corridors. Earth-Science Rev. 147, 30–53. doi:10.1016/j.earscirev.2015.05.001
[47] Yellen, B., Woodruff, J.D., Kratz, L.N., Mabee, S.B., Morrison, J., Martini, A.M., 2014. Source, conveyance and fate of suspended sediments following Hurricane Irene. New England, USA. Geomorphology 226, 124–134. doi:10.1016/j.geomorph.2014.07.028
[48] Zeiger, S., Hubbart, J.A., 2016. Quantifying suspended sediment flux in a mixed-land-use urbanizing watershed using a nested-scale study design. Sci. Total Environ. 542, 315–323. doi:10.1016/j.scitotenv.2015.10.096

Author Profile

Kamleshkumar M. Rana working as a Lecturer and Incharge Head of the Applied Mechanics Department of Government Polytechnic Valsad. His specialization is Master Degree in Civil Engineering in Environmental Engineering. He has total 17 years of teaching experience and 8 year of experience in the industry.