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Soil Loss Prediction Equations

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Abstract : *Runoff is the main carrier of eroded soil as sediment washload in a fluvial system. Increasingly, prediction of sediment yield is becoming important for design and operation of reservoirs, water supply systems, sediment and flood control projects, & sediment pollution control.*

Suspended sediment yield (washload) models are still in a stage of their infancy. Recently some studies on diterministic, probablistic and stochastic processes have been carried out to model the suspended sediment yield process. The presently developed models can be catagorised into four main groups, namely, (1) Satistical regression models, (2) System models represented by unit sediment graph approach (3) Parametric sediment routing models, and (4) Stochastic and dynamic models.

Sedimentation is the detachment, entrainment transportation and deposition of of eroded soil. Most of the damage to the ecosystem is caused by accelarated erosion of soil which is in excess of geologic norm. Rainfall on bare land surface initiates the process of erosion. Thus, to begin with, regression models with rainfall as the input were developed. Later, it was observed that the runoff is a better predictor of sediment yield than the rainfall. Since runoff is the main carrier of washload, it was further observed that the hydrological properties of the two are the same. This brought in the concepts for application of system models and parameteric models on sediment yield, based on the techniques as used for runoff models. Similarly, stochastic and dynamic models were also successfully developed to predict sediment yield. In this paper an attempt has been made to critically review the recent work on soil erosion and sediment yield models and present them in a catagorised form.

1. Introduction

The sedimentation process consists of detachment, entrainment, transportation and deposition of eroded soil. The main cause of soil detachment from land surface is the rainfall energy, and the runoff water is the main carrier of the detached soil as suspended sediment. The hydrological properties of suspended sediment, which is also known as "washload" can be taken as similar to the runoff (Rendon Herrero, 1974; Williams, 1978).

Suspended sediment yield models are still in a stage of their infancy. Various approaches have been attempted for the modelling of suspended sediment yield process Shen and Li (1976) categorised the available models into four groups, namely, (i) Statistical regression models, (ii) Systems models represented by unit sediment graph approach, (iii) Parametric sediment routing models. and (iv) Stochastic models. In the present report, the above classification is being used for the survey of presently available models dealing with soil loss and sediment yield process.

2. Statistical regression models

Suspended sediment yield is the sediment transported per unit of time by the runoff in a suspended form from the up stream source area, at a particular cross section of the stream. The yield of the suspended sediment at a particular section of the downstream channel is mainly dependent on the gross erosion of upstream soil, and on the factors responsible for disposal of eroded soil to that section. The ratio of sediment yield to gross soil erosion is expressed by the term "Delivery ratio". Sediment yield has been estimated either directly through regression models or indirectly by computing gross soil erosion and then multiplying it by sediment delivery ratio. Many regression models have been developed for prediction of soil erosion.

Regression models for the estimation of soil erosion can be traced from Zingg (1940). He developed a set of relationships to relate soil loss rate (A) with slope length (L) and degree of slope in percentage (s). It was named as the slope Practice Method and the relationships were expressed as,

$$A_1 \propto L^{m} \qquad (1)$$

and $$A_1 \propto S_g^{m'} \qquad (2)$$

where, the values of m and m' are 0.6 and 1.49 respectively. Crop management factor or other factor were not considered by him. Improving upon this model, Smith (1941) modified the Zingg model by introducing a crop and conservation practice factor in it. The modified model was expressed by him as,

$$A = C' \, S_g^{7/5} \, L^{3/5} \qquad (3)$$

where, C' is a constant depending on the soil, crops, crop rotation, storm characteristics and other treatments. Later, Browning et. al. (1947) added the soil and management factor to the Smith's equation and gave a set of tables to simplify the field use of the equation. However, none of the above workers considered the impact of rainfall energy as an important factor in causing soil erosion.

The soil erosion process is initiated in the form of splash erosion which is caused by the impact of the rainfall energy on the soil surface. The concept to introduce rainfall factor in a soil loss prediction model was conceived by ths National Committee of U.S.A, under Musgrave (1947). The committee modified the above models and suggested the follgwing equation in FPS units,

$$A = F\,C \,\frac{S_g^{1.35}}{10} \,\frac{L^{0.35}}{72.6} \,\frac{P_{30}}{1.375} \qquad (4)$$

where, A is sheet erosion in tons/acre/year, F is the factor for basic erosion rate of soil in tons/acre/year, C is the crop cover-factor, and P_{30} is the maximum rainfall for 30 minutes duration for 2 years frequency in inches. This equation is known as the Musgrave equation. They also modified this equation and suggested the following relationship :

$$A = K\,C\,R \,\frac{S_g^{1.35}}{10} \,\frac{L^{0.35}}{72.6} \qquad (5)$$

where, R is the rainfall-factor (rainfall erosion index) and K is the soil-factor which is the soil loss in tons/acre/year/unit rainfall index.

Working further on the rainfall factor, Wischmeir and Smith (1968) developed a functional relationship to compute the kinetic energy of rain storms as a function of rainfall intensity and its interaction with soil loss. They suggested the following empirical equation for the calculation of rainfall energy as a function of rainfall intensity and amount :

$$E = \sum_{k=1}^{r} 210.3 + 89 \log_{10} I_k \, P_k \qquad (6)$$

where, E is the rainfall energy of storm is tonnes-meter/cm of rainfall, I_k is the rainfall intensity for the time interval 'k' of rain storm, P_k is the rainfall amount with in the time interval k, and r is the number of time-intervals in which the storm is divided.

Then based on the Musgrave equation and the developed rainfall energy concept, Wischmeier and Smith (1969) proposed the Universal Soil Loss Equation (USLE) to predict annual field soil loss or gross soil erosion. The equation became very popular, and was used as a guide for conservation farm planning. The developed equation was stated as,

$$A = R\,K\,L\,S\,C\,P \qquad (7)$$

where, A is the computed soil loss in tonnes/acre/year which is the unit selected for soil erodibility factor K, R is the rainfall erosivity factor calculated as :

$$R = \sum_{0}^{t} \frac{EI_{30}}{100} \qquad (8)$$

where, t is the duration for which soil loss is to be estimated by the USLE, I_{30} is the maximum 30 minutes intensity of rain storm, K is soil erodibility factors, which is the measured soil loss rate per unit erosion index for a specified soil on the unit plot at 9% uniform slope and 22.2m (72.6 ft) long continuously cleaned tilled fallow, L is slope length factor which is the ratio of soil loss from actual field length to standard length of 22.2m under identical conditions, S is slope steepness factor, which is the ratio of soil loss from actual field slope to standard field of 9% slope while remaining conditions are the same, C is cover and management factor, which is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow, and P is the soil conservation practice factor, which is the ratio of soil loss with specified conservation practice on tilled fallow to that of up and down tilled fallow land under identical condition.

Tables and nomographs developed by the USDA to obtain the above factors are widely available. The USLE was developed primarily to estimate annual soil loss through sheet or rill erosion from upslope farm lands, and it did not include erosion from gullies, streams etc. Looking at the model from a system point of view, the area where erosion is taking place can be taken as a memoryless-lumped-system consisting of the characteristic parameters of the gross erosional system, namely, K, L, S, C and P. To this system, the rainfall factor is the input, and the gross soil erosion is the output. For the application of the USLE in India, Singh et. al. (1969) determined the different parameters of USLE for Dehradun region. Along with it they also developed the following empirical relationships for the calculation of monthly and daily EI_{30} values from the measured data of rainfall depth.

$$Y = 3.1 + 0.533X \text{ on daily basis} \qquad (9)$$

and $$Y = 1.9 + 0.64X \text{ on monthly basis} \qquad (10)$$

where, Y = the mean monthly and daily total rainfall energy in tonnes — m / hectare multiplied by the maximum 30 minutes rainfall intensity in cm/hr.

X = monthly or daily rainfall in mm

However, the USLE gives the generated soil erosion and is not recommended for estimation of sediment yield from large watersheds. The Delivery ratio must be used to calculate sediment yield in such cases.

With the development of USLE, the soil loss sediment yield models started growing from their infancy. The U.S.B.R. in early seventies recommended that the runoff is a better predictor of sediment yield than the rainfall. At the same time it was observed that for water quality modelling generally a shorter time interval than a year is required. Williams (1972, 1975) modified the USLE and developed a sediment yield model on per storm basis by applying the empirical approach. He replaced the rainfall erosivity factor of the USLE with a runoff factor consisting of runoff volume and peak flow rate as multiples. His model stated that,

$$Y = 11.8\ (Q * q_p)^{0.56}\ KLSCP \qquad (11)$$

where, Y is the per storm sediment yield in tonnes, Q is the storm runoff volume is cubic meters and q is the peak flow rate of storm runoff in cubic meter per second. In this model, runoff factor represents the input to a memoryless watershed fluvial system and the per storm sediment yield as the output from it.

Onstand and Foster (1975) also tried to use the concepts of USLE for stormwise application. They developed an event based sediment yield model in which soil detachment and transportation were related to an energy factor which consisted of a storm rainfall term EI units of USLE in addition to storm runoff volume and peak runoff rate. They proposed the following equation :

$$A = WKLSCP \qquad (12)$$

where, W is runoff and rainfall factor and is equal to $ak + bQ\ (q^{1/3})$ where Q is the runoff volume, q is peak rate of runoff and a, b are constants.

During the same period, Jansen and Painter (1974) developed a linear regression model which related annual sediment yield with climatic and topographic variables for a river basin comprising an area of 5000 km².

Later. Mc Pherson (1975) for stream basins in the southern Alberta region of Canada developed an empirical sediment yield model for the computation of total annual sediment yield and proposed the following set of equations :

$$\text{Log TSE} = 0.8797 \text{ Log MLS} - 0.690 \text{ Log BD} + 0.6462 \text{ Log MCL} + 1.1035 \qquad (13)$$

$$\text{Log SSE} = 0.5532 \text{ Log MLS} - 0.5859 \text{ Log SCA} + 0.8332 \text{ Log MCL} + 1037878 \qquad (14)$$

$$\text{Log DSE} = 8.2495 \text{ MLS} - 1.503 \text{ BD} + 15.5397 \qquad (15)$$

where, SSE is the suspended sediment yield, DSE is the dissolved sediment yied, TSE is the total (suspended + dissolved) sediment yield, BD is the basin diameter, SCA is the sediment contributing area, MCL is the main channel length and MLS is the mean land slope.

During the same period in Australia, Loughran (1977) developed a procedure for calculating the suspended sediment transport rate for different seasons in the N.S.W. region of Australia and suggested the following relationships :

$$C = 15.7\ Q^{0.485}\ \text{(Summer 1970-71)} \qquad (16)$$

$$C = 16.0\ Q^{0.437}\ \text{(Winter (1970-71)} \qquad (17)$$

$$C = 10.3\ Q^{0.521}\ \text{(Summer (1973-74)} \qquad (18)$$

$$C = 12.8\ Q^{0.552}\ \text{(Winter 1973-74)} \qquad (19)$$

where, C is the suspended sediment concentration in mg/litre, and Q is discharge in cubic meter per second.

The USLE was then again modified in the southern part of Africa in Zambia (formerly known as Rhodesia).. by Elwell (1978). He presented a model based on a modified technique of USLE for the estimation of mean annual soil loss from arable land. The main soil loss model proposed by him comprised of three sub-models, namely, the soil erodibility sub-model K, the canopy cover sub-model C, and the topographic sub-model X. The multiples of these three sub-models gave the total sediment yield. Mathematically it was expressed as,

$$Z = K\ C\ X \qquad (20)$$

where, Z is the predicted mean annual soil loss in tonnes/ha/year, K is the mean annual soil loss in tonnes/ha/year from standard field plot of 30m × 10m at a 4.5% slope for a soil of known erodibility F under a weed free bare fallow surface and determined by the following relationship :

$$\ln K = b \ln E + a \qquad (21)$$

where, E is the seasonal rainfall energy in J/m². The values of a and b could be obtained from the following relationships :

$$a = 2.884 - 8\,1209\ F \qquad (22)$$

$$b = 2.4681 - 0.7663\ F \qquad (23)$$

where, F is the soil erodibility value and C is the ratio of soil loss from a cropped plot to that soil loss from bare follow land. The required relationship for C was expressed as,

$$C = e^{(-0.06\,i}\ \text{when i } 50\% \qquad (24)$$

$$C = (2.3 - 0.01\ i)/30,\ \text{when i } 50\% \qquad (25)$$

where, i is percentage rainfall energy intercepted by the crop cover and X is the ratio of soil loss from a plot of length L and slope percent S to that soil loss from the standard plot. The value of X was to be determined from the following relstionship :

$$X = \frac{L^{1}/^{2} - (0.76 + 0.53\ S + 0.076\ S^{2})}{25.65} \qquad (26)$$

An attempt was made to apply Elwell's relationship in India. Jaiswal (1982) and Tiwari (1986) applied this model on the Himalayan subcatchments of Ramganga river on a per storm basis. They modified the equation to adapt it to the available data, and defined their model as.

$$S_{yi} = S_{ki}\ X_{li}\ C_{pi} \qquad (27)$$

where, S_{yi} is the estimated sediment yield in tonnes/storm event from sub-watershed (i), S_{ki} is the sediment yield in tonnes per storm event evaluated through the following regression equation developed for the region,

$$\ln S_k = 0.8973 \ln E + 2.382\ (r^2 = 0.9999) \qquad (28)$$

where, E is the storm rainfall energy in Joules/m², X_{li} is the topographic factor for sub-watershed (i) determined by the contour length method of Williams (1976) suggested for large watersheds, C_{pi} is the canopy cover factor of sub-watershed (i) developed by Jaiswal (1982) based on the relationships of Elwell (1978). The weighted canopy cover was determined by the following equation :

$$C_p = \sum_{i-1}^{n} \frac{C_i\ A_i}{A} \qquad (29)$$

where, C_i is the canopy cover value for land use (i) on the area (i), A_i is the watershed area covered by land use (i). A is the total watershed area, and N is the number of land use areas in the watershed. The canopy cover factors proposed by Jaiswal (1982) were as under :

1.	Crop land	0.32
2.	Hayland and grazing land	0.21
3.	Reserve forest and wood land	0.02
4.	Rokhar and miscellaneous land	1.00

During the same period when Elwell was working, in another African country Kenya, Dunne (1979) developed a relationship between the sediment yield and the land use measures. He analysed sediment yield from 61 Kenyan catchments and suggested the following relationship :

$$S_y = U\ Q^{a}\ S^{b} \qquad (30)$$

where, S_y is the mean annual sediment yield in tonnes/km²/year. Q is the mean annual runoff in mm, S is the relief ratio and U indicates land use expressed in terms of four categories, forest, forest agriculture, agriculture forest, and range land. He developed the values of constants for different categories of land use, and suggested the following set of equations.

For completely forested catchment

$$S_y = 1.56\ Q^{0.46}\ S^{-0.03}\ (R^2 = 0.98) \qquad (31)$$

For forested catchments agricultural catchments

$$S_y = 0.14\ Q^{1.48}\ S^{-0.51}\ (R^2 = 0.74 \qquad (32)$$

For agricultural catchments forested catchments

$$S_y = 0.14\, Q^{1.48}\, S^{-0.51} \quad (R^2 = 0.74) \qquad (33)$$

For range land catchments

$$S_y = 4.26\, Q^{2.17}\, S^{1.12} \quad (R^2 = 0.87) \qquad (34)$$

During the period of 1980-82, an attempt was made to apply Williams model in India. Das (1982) and Das and Chauhan (1990) modified the Walliams sediment yield model for applying it on the Himalayan sub-catchments of Ramganga catchment. They found that the exponent value of the runoff needed a change from 0.56 (as suggested by Williams) to 0.257. The average equation proposed by them for Bino and Chaukhutia sub-catchments was of the following from :

$$Y = 11.8\, (Q \times q_p)^{0.257}\, KISCP \qquad (35)$$

where, the parameters are as per the definitions of the Williams model. Later, Tiwari (1986) applied the model (Eq 35) on other Himalayan sub-catchments of the Ramganga catchment and found the predicted values of sediment yield in close agreement with the measured values of sediment yield from the respective subcatchments. Later Mehta (1986) applied the model of Das on the sub-catchments oı Ramganga catchment by calculating Q through the curve numbers technique and q_p through some developed regression equations. He applied it on sixty six storm events, and found the results compared favourably with the measured sediment data.

In the Ramganga catchment, attempts were also made to adapt some conceptual models. Agrawal (1990) applied the Tank Model of Suguware of Japan on the Chaukhutía sub-watershed of Ramganga catchment to predict runoff with rainfall depth as the input. Taking the predicted runoff as the input he then developed a regression sediment yield model to simulate annual sediment yield graphs.

3. Parametric Sediment Routing Models

There has been development of parametric hydrological models in recent times such as Stanford Watershed model and similar other models. Similarly, attempts have also been made to develop analogous models of sediment yield.

Williams (1975) developed a sediment routing Model based on his sediment yield model (Eq. 11). He routed sediment yield from the sub-watersheds ($\leqslant 25$ mi^2) through the stream and the valley to the outlet of the entire watershed. The procedure was based on the assumption that sediment deposition depends on settling velocities of the sediment particles, length of travel time and the amount of sediment in suspension. The equation was stated as,

$$RY = \sum_{i=1}^{n} Y_i\, e^{-BT_i \sqrt{D_i}} \qquad (36)$$

where, RY is the sediment yield from an individual storm for the entire watershed, Y_i is the sediment yield from sub-watershed (i) predicted by Eq. (11), B is the routing coefficient determined through an iteration procedure, T_i is the travel time from sub-watershed (i) to watershed outlet, D_i is the median diameter of sediment particles of the sub-watershed (i).

Walling (1983) analysed the above sediment yield model, but expressed doubts on consideration of certain parameters for general applicability of the equation. Novotny (1980) also found its applicability limited to shallow flow and impoundments.

Later Das (1982) and Das and Chauhan (1990) developed a sediment routing model based on the principles of Williams model to predict per storm sediment yield for Naula watershed of Ramganga catchment. The simplified Eq. (36) by eliminations the sediment particle diameter factor and taking a lumped value of storage coefficient. The equation proposed by them is of the form :

$$S_y = \sum_{i=1}^{n} Y_i \, e^{-T_i / K_s} \qquad (37)$$

where, S_y = per storm total sediment yield, tonnes

T_i = time of travel of sediment in stream upto watershed outlet from water shed (i) outlet

K_s = Sediment storage coefficient determined through an iterative process

n = number of sub-watersheds

Y_i = sediment yield from sub-watershed (i) determined by Eq. (36).

Tiwari (1986) verified the above equation developed by Das (1982) for Naula sub-catchment and applied it on Marchuala sub-catchment of Ramganga catchment with success.

Tiwari (1986) further developed a sediment routing model by using his sediment yield model (Eq. 27). He defined the developed equation as,

$$S_y = \sum_{i=1}^{n} S_{yi} \, e^{-T_i/K_s} \qquad . \ (38)$$

where, S_y is the per storm total sediment yield in tonnes, S_{yi} is the sediment yield in tonnes from sub-catchment (i) obtained from Eq (27). T_i is the time of travel in hours between the outlet of sub-catchment (i) and the catchment outlet, and n is the number of sub-catchments. To determine K_s, he developed the following equation :

$$ENJ_T = \sum_{i=1}^{n} ENJ_i \, e^{-T_i/K_s} \qquad .. \ (39)$$

where, ENJ_t is the total kinetic energy of rainfall per day, and ENJ_i is the kinetic energy of rainfall from sub-catchment (i). The value of K_s was determined through an iterative process, where ENJ_T, ENJ_i and T_i were known through the measured data,

4 System Models

In a hydrological analysis, a unit depth of excess rainfall uniformly distributed over a T hour period causes a T-hour unit-hydrograph, and is expressed as u (T,t). A unit hydrograph of zero duration of time u (O, t) is called an instantaneous unit hydrograph which is also known as a time invariant impulse response function. To develop design hydrographs, the unit hydrograph is convolved with excess rainfall. The same approach has also been applied for unit sediment graphs of suspended sediment, because, surface runoff that produces a hydrograph is in many situations also the cause of and argent for transport of upslope sediment to the streams.

Rendon-Herrero (1974) and (1978) proposed a model based on unit sediment graphs. Unit sediment graphs are one unit of sediment yield for a given duration distributed over a watershed. To develop storm sediment graphs he calculated "Mobilized sediment" in place of "excess runoff" by developing a relationship between excess rainfall/runoff and excess sediment yield called "mobilized sediment". To avoid the use of this relationship, he then developed "series graphs" to design sediment graphs by using source runoff volume as the input This model has also been adopted by some workers (Asokan 1981, etc) for Ramganga catchment. Renard and Laurson (1975) computed sediment graphs by multiplying the storm hydrograph flow rate with concentration predicted with a sediment transport model, developed by Laursen in 1958. During the same time, Bruce et al (1975) based on erosion and transport capacity, described a sediment graph model. They proposed that the detachment of surface material depends primarily on rainfall intensity.

Williams (1978) developed an instantaneous unit sediment graph (IUSG) model for predicting sediment graph from agricultural watersheds. He predicted storm sediment graphs by convolving source runoff volume with instantaneous unit sediment graph. He defined IUSG as the distribution of sediment from an Instantaneous burst of rainfall producing one unit of direct runoff. Das (1982) developed a synthetic unit sediment graph model and an instantaneous unit sediment graph model based on the Clark's model of runoff for application on Himalayan catchments of Ramganga river. To develop design sediment graphs, he took mobilized sediment as the input.

Raghuvanshi (1986) developed an IUSG model by using the time area and the Laureson methods for the Chaukhitia sub-catchment. Alongwith it, Kumar and Rastogi (1987) developed a conceptual model of instantaneous unit sediment graph based on the principles of IUH model developed by Nash for a sub-catchment of Ramganga catchment by routing the mobilized sediment through a series of linear reservoirs. Jha (1986) developed a sediment graph model based on instaneous unit sediment graph for an Himalayan sub-catchment of the Ramganga reservoir catchment by routing the mobilized sediment volume through a series of linear reservoirs. Kumar (1989) developed an instantaneous unit sediment graph model with minimum number of parameters to predict sediment graph from Gagas sub-catchment of Ramganga catchment. They took mobilized sediment as the input to develop design sediment graphs from IUSGs.

In some of the above unit sediment graph models, the determination of storage coefficient by graphical methods from the sediment graph drawn with discrete data is questionable. Based on the model of Das (1982) then Das and Agarwal (1990) developed a conceptual model of an instantaneous unit sediment graph on the concepts of time area diagram of Clark by proposing an iterative technique for the evaluation of sediment storage coefficient. They also developed three regression models to determine the values of sediment storage coefficients. The model was applied and tested on the Naula sub-catchment of Ramganga catchment with success. They used mobilized sediment as the input for developing design sediment graphs

Bajpai (1986) developed an IUSG model by combining the concepts of Williams (1978) and the sediment routing model of Das (1982) and applied it on Naula sub-catchment of Ramganga catchment. Dube (1987) continuing the same work developed a HYMO sediment model based on the concepts of curve number of Das (1982), Bajpai's (1986) model, sediment routing model of Das (1982) & the Nash Model for IUH. He divided his model into five sub-models, namely, rainfall-runoff relationship sub-model, two parameter conceptual sub-model for IUH, sediment yield sub-model, IUSG sub-model, and design sediment graph sub-model. With this model, sediment graphs were predicted with daily rainfall depth as input. This was a great achievement, as the regression relationship used in earlier models to determine the mobilized sediment (where regression coefficients were very low) was completely avoided, and with discrete data of rainfall depth as the input, sediment graphs were obtained.

5. Stochastic Models

There have been attempts to develop stochastic and dynamic models for the discrete data of suspended sediment in runoff water in streams. Woolhiser and Todorvic (1971) developed a stochastic model of sediment yield event basis, by considering the probabilistic inter relationships among the sediment yield, rainfall and runoff processes.

Sharma and Dickinson (1979) proposed a discrete dynamic model to represent the sediment yield of a Canadian watershed. They found that the first order dynamic model for monthly sequences and the second order dynamic model for daily sequence as adequate. Further, Sharma and Dickinson (1980) also developed for the same watershed a system model of daily sediment yield, and concluded that a linear discrete dynamic model is possible in terms of the log transformed daily runoff and sediment data.

Vanseckle (1982) found that in the Pacific North Western U.S A. nearly all sediment is transported during brief distinct runoff events. He described the event sequence stochastically by combining a Poisson process, a flow frequency analysis and a sediment rating curve. He used the model to predict long term distribution of annual suspended sediment yield from two small watersheds.

In India, Chaurasia (1985) developed an autoregressive (2) stochastic model of sediment flow for the Naula sub-catchment of Ramganga catchment to generate likely future sequences of sediment flow and short-term forecasting of future events. However, he got some negative generated values with this model. Continuing this work, Agarwal, Das, Manglik and Chauarasia (1989) suggested a second order autoregressive seasonal model of suspended sediment yield for Naula sub-catchment of Ramganga catchment. The results were found to be better than the model proposed by Chaurasia (1985) and no negative generated values were obtained with this model.

Pathak (1990) applied the Walsh autoregressive model on Bino watershed of Ramganga catchment to predict weekly rainfall. Using the predicted rainfall data as the input, he developed weekly sediment yield model for one year advance prediction of sediment yield for the watershed. Singh (1990) continuing the same work, developed a new technique of data characterization through fourier spectrum analysis in conjunction with Box-Jenkins type autoregessive model to predict weekly rainfall. Using the predicted rainfall as the input, he developed a sediment yield model for Bino sub-catchment. Hall (1990) developed a stochastic model of rainfall for forecasting of future rainfall events. These forecasted rainfall values on monthly and yearly basis were applied as input to a sediment yield model to simulate sediment yield of future events for Naula sub-catchment of Ramganga catchment. With this model the simulated sediment yield values on yearly basis were found to be more close to the measurd data as compared to the sediment yield on monthly basis.

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