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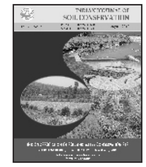

Dynamic modelling of runoff-sediment yield under different land uses of a hilly watershed of North East India

Pulkabha Chowdhury[1], P.P. Dabral[2] and R.K. Singh[1]

[1]ICAR Research Complex for NEH Region, Umaiam, Meghalaya; [2]Department of Agricultural Engineering, North Eastern Regional Institute of Science and Technology, Nirjuli, Itanagar-791109, Arunachal Pradesh.
[2]E-mail: ppdabral1962@gmail.com

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ABSTRACT

In the present study, runoff-sediment yield process was modelled by dynamic approach under different land uses of a hilly watershed situated in the farming system research project site at Indian Council of Agricultural Research Complex for North Eastern Hills Region, Umiam, Meghalaya (India). Nine micro watersheds having different land uses (livestock based farming system- W_1, timber plantation - W_2, agro-forestry - W_3, agriculture in bench terrace - W_4, agri-horti-silvipastoral system - W_5, horticulture - W_6, natural vegetation - W_7, fallow under shifting cultivation - W_8 and pine plantation - W_{AEW}) were considered under study. An attempt has been made to develop the runoff-sediment yield models by introducing input parameters like runoff (Q), sediment (S) and including two different indices, *i.e.* antecedent runoff index (AQI) and antecedent sediment index (ASI). Generalised models of runoff-sediment yield were developed using conservation factor as one of the independent variables. For runoff-sediment yield process, all linear and non-linear model developed were found statistically at par for all the micro-watersheds except W_7. Using generalised models of runoff-sediment yield; runoff and sediment yield of similar micro-watershed of a hilly area of the region can be predicted.

1. INTRODUCTION

In the eastern Himalayan region of India, soil erosion by water is one of the major factors of land degradation and environmental deterioration. The degradation process is often triggered and accelerated by in appropriate land use and/or poor management. Traditional slash and burn agriculture on steep slopes, rainfall of high magnitude and intensity compounds the problem manifolds. The region receives an average annual rainfall varying from 1242 to 11409 mm with the number of rainy days more than 100. The average annual erosion index in the mid hills of the region is estimated at 1218.77 m Mg cm ha^{-1} h^{-1} (Satapathy *et al.*, 1999).

Hydrological modeling is a tool for prediction of the hydrological behaviour of a watershed. Runoff patterns can be greatly influenced by proper land use treatments. Soil conservation measures play a definite role in reducing runoff and controlling damage caused by excessive runoff (Satapathy, 1994; Choudhary *et al.*, 2014). Sediment yield is defined as the total amount of eroded material to be delivered from its source to a downstream control point. The process of sediment yield is extremely complex and mainly consists of detachment and transport of sediment particles by rainfall and runoff. Determination of soil erosion and physical parameters, which affect the runoff and sediment yield processes, are challenging to measure either through field or laboratory experiments. Such assessment processes are expensive, time-consuming and labour intensive. The other acceptable alternative techniques are by using the mathematical models integrating the effects of various physical processes. Water is the medium involved in the sediment generation and transportation process. The sediment yield is connected with the runoff processes in the watershed system. In the design and operation of soil erosion control programme of the watershed, it is useful and necessary to consider the temporal and spatial distribution of runoff and sediment yield.

Hydrological processes are dynamic in nature. The dynamic models are better and more accurate in representation of the runoff-sediment process, because these models consider the effect of past events and assign equal weightage to each successive past event affecting the present event. However, the magnitude of past events on the present output may not be the same. That is the first immediately preceding event may have more weightage that the second preceding event and so on (Pyasi and Singh, 2004).

Various researchers have developed dynamic models of runoff-sediment yield in the different region of India. Kumar and Das (2000) made an attempt to develop a dynamic model of daily runoff and sediment yield of Ramganga (India). Pyasi and Singh (2001) developed a weekly sediment yield dynamic model for Naula Watershed of Ramganga reservoir (India). In their study, the linear and non-linear weekly sediment yield prediction models based on the concept of determining and assigning the varying weightage to the antecedent events of runoff and sedimentation were developed. Pyasi and Singh (2004) modelled the runoff-sediment process of the Naula watershed of Ramganga river catchment in the state of Uttaranchal (India) by applying dynamic approach. It was found that the linear system technique can be extended to model the runoff-sediment process in terms of alog-transformed daily data sequence and only non-linear sediment yield dynamic models were found suitable for the study area. Inclusions of new independent variable of AQI and ASI in this study were found to have a significant impact on the prediction of sediment yield models.

Panigrahi (2007) has also developed linear regression models to predict sediment yield with known values of runoff for watersheds of Odisha. Ranjan *et al.* (2011) developed a dynamic model of runoff sediment yield for the Kushinagar watershed of Vamsadhara river catchment, Orissa (India). They developed linear and nonlinear daily sediment yield prediction models based on the concept of determining and assigning the varyingweightage to antecedent events for the rainfall-runoff-sediment process. Kumar *et al.* (2013) developed non-linear (log-log transformed) dynamic model of runoff-sediment yield for Giridih watershed of the Barakar river basin, Jharkhand (India) considering present day runoff and past values of runoff and sediment yield as the input variable, to estimate the sediment yield of catchment on a daily basis. The coefficient of multiple determinations for the non-linear dynamic model was found 0.873. Amin *et al.* (2015) developed linear model for the runoff and sediment yield for Dachigam watershed of Kashmir valley (India).

In the hilly region of the North East (NE) India, the majority of people are farmers, who practice shifting cultivation. Initial studies on alternative farming systems to replace the shifting cultivation have indicated that the mixed land use system may be better from the conservation and production point of view. The selected site of the current study is located in the ICAR Research Complex for North Eastern Hills Region, Barapani (Umiam) in the state of Meghalaya (India). Considering the potentialities of land uses in the hilly regions of the NE India, the farming systems studies were live stock based farming system (W_1), timber based plantation (W_2), agro-forestry (W_3), agriculture in the bench terrace (W_4), agri-horti-silvipastoral system (W_5), horticulture (W_6), natural vegetation (W_7), fallow under shifting cultivation (W_8) alongwith pine (W_{AEW}). Bench terraces, contour trenches, contour bunds and half-moon terraces were the major soil conservation measures.

Water is usually the medium involved in the sediment generation and transporting process. The sediment yield is connected with runoff processes in the watershed system. Since hydrological processes are dynamic in nature; the dynamic models are better. It is, therefore, needed to develop sediment yield prediction dynamic models in the perspective of North Eastern hilly topography of India.

In this study, a separate attempt has been made to develop the runoff-sediment yield models by introducing input parameters like runoff (Q), sediment (S) and including two more different indices, *i.e.* AQI and ASI. The AQI reflects the physiographic and soil characteristics of the catchment. The ASI reflects, the past values of sediment incidence stored in the memory of the watershed system. The present study is undertaken for the FSRP site of ICAR Research Complex, Umiam (Meghalaya), India with the objective to develop and validate dynamic models for runoff-sediment yield under different land uses of a hilly watershed.

2. MATERIALS AND METHODS

Study Area

The site of the present study is at the ICAR Research Complex for North Eastern Hills Region situated at Barapani (presently Umiam) in the state of Meghalaya. Barapani (Umiam). It is located at 25°41'N latitudes and between 91°54' to 91°63'E longitudes. The site is located 22 km away from Shillong (Meghalaya). The area consisted of typical hilly undulating terrain with the altitude varying between 952 and 1082 meters above mean sea level (msl). The area (Fig. 1) is a part of Ri-Bhoi district and comprises of rolling terrains and steep slopes interspersed with valleys and plateaus.

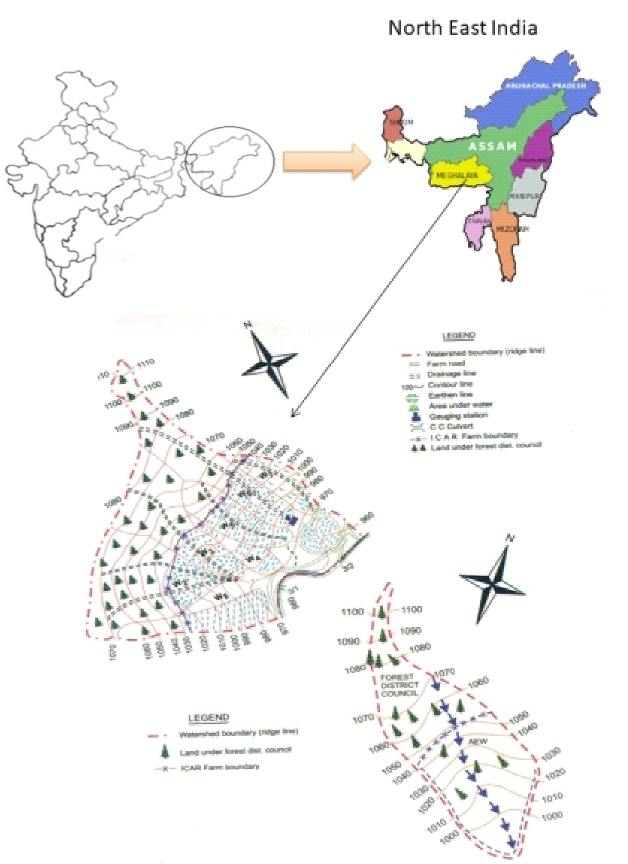

Figure not to scale (Source: Satapthy, 1996)

Fig. 1. Location map and experimental micro watersheds W_1 - W_8 and W_{AEW}

Climate

The study area typically represents the soil and climate conditions of North Eastern Region. The mean annual rainfall is 2390 mm with more than 88% occurring during the period from May-October. The daily temperature during a year was recorded to vary widely between 1 to 32.5°C. The relative humidity remains between 75 to 83% during the most of the period, but reduces to as low as 58% during the 15th week and attains peak values of 90% during August and October. Bright sunshine hours vary from 9 to 11 during November to April and remain in the range of 2 to 8 hours during May to October. During the period from February to April, the wind velocity is quite prominent and stays in the range of 4.2-12.9 km hr^{-1}. The evaporation rate during March and April remains very high in the range of 4.1 to 9.0 mm day^{-1}. The average value of evaporation rate during the rest of the period of the year was found to be ranging from 1.7 to 3.8 mm day^{-1}.

Soil

The experimental area comes under the class VII land. The soil belonging to typespaleudalf series with clay loam texture has a pH from 5.4 to 6.2. Surface soils were more acidic than subsurface. pH tended to increase with depth in samples collected from the middle and lower portion of watersheds, while it remained almost unchanged in forest soils.

Details of Nine Hilly Micro Watersheds

Nine small hilly micro watersheds in the research farm were identified in the year 1983 to determine the effect of land use systems on runoff and soil loss. Nine micro watersheds with area ranging from 0.52 to 3.8 ha were demarcatedwith reference to the outlet of the channels in the lower reaches. Demarcation of the physical boundaries of the watersheds was done so that one of them functioned as an independent basin. None of the micro-watershedsis completely within the farm boundary as the upper portion of the hills is under reserve forest. The average slope of the experimental watersheds varied from 32.02 to 53.18%. Details of the experimental watersheds under various farming systems are presented in Table 1.

Land Use and Surface Runoff

The hydrological behaviour of watersheds for a nine-year period (1998 to 2006) in terms of total water yield, base flow and peak rate of flow has been

Table: 1
Details of experimental micro-watersheds under various land use system

Land Use/Watersheds	Total Area (ha)	Relief (m)	Maximum Length (m)	Maximum Width (m)	Average slope (%)	Soil Texture	Soil and Water Conservation Measures
Agriculture (fodder crops) - W_1	1.39	99.0	301	65	32.00	Clay	Contour bunds, contour trenches and bench terraces
Forestry (timber, fuel, fodder) - W_2	3.80	100.0	320	230	38.00	Clay	-
Agro-forestry (timber, fuel fodder, trees, pine apple, fodder, grasses, legumes crops) - W_3	2.94	100.0	295	175	33.00	Clay	-
Agriculture (Food crops) - W_4	0.64	82.0	240	65	32.18	Clay	Contour bunds and bench terraces
Agri-horti-silvipastoral system (Food fodder and Fodder crops) - W_5	1.58	89.0	260	85	32.42	Clay	Contour bunds, Bench terraces and half moon terraces
Horticulture (Fruit and vegetable crops) - W	3.13	138.0	515	85	41.77	Clay	Contour bunds, Bench terraces and half moon terraces
Natural vegetation (Natural flora) - W_7	1.03	91.0	250	70	53.18	Clay	-
Agriculture (Fallow under shifting cultivation) - W_8	0.52	65.0	185	48	54.87	Clay	-
Pine plantation and natural vegetation (Pine tree and natural flora) - W_{AEW}	3.54	120.0	464	126	32.37	Clay	-

(Source: Satapathy and Panda, 2006; Satapathy, 1996)

presented in Table 2. Surface runoff from the undisturbed hilly watersheds and those with the substantial vegetative cover were very small. Large intense rainfall events with high antecedent moisture content in soils generated most of the runoff from the undisturbed and treated watersheds. Land use and conservation practices varied; however, in their effectiveness for controlling surface runoff. The mean water yield recorded from the watersheds varied from 0.43 to 16.78% of annual rainfall. Surface runoff from silvipastoral system and mixed block forest plantation with no physical soil conservation measures was 15-16% of the total water yield. The runoff data indicate that even after best land and crop management practices, on an average 17.47-28.98 mm went out as runoff annually from agricultural and agri-horti-silvipastoral watersheds, which can be stored either for a fishery or for supplemental irrigation in the donor watersheds.

The contributions to streams flow in the watersheds having a sizable area under natural forest are primarily by subsurface flow (base flow). Three of the nine watersheds, with relatively large areas, namely, W_2 (3.8 ha), W_3 (2.94 ha), W_{AEW} (3.59 ha) and substantial area under forest had continuous base flow which appeared on the upper reaches of the gauging stations. These watersheds on an average had a continuous flow for 156, 116 and 190 days, respectively in a year. The annual base flow from these watersheds constitutes about 80% of the total water yield. As expected, the watersheds (W_8) treated with *Jhum* (fallow under shifting cultivation) yielded the highest peak runoff (86.10 mm hr^{-1}) while the one left undisturbed with natural vegetation (W_7) gave the minimum peak runoff (4.49 mm hr^{-1}) during the period. However, the provision of trenches in fodder based agriculture most effectively conserved moisture and produced peak runoff 7.81 mm hr^{-1} during the period.

Soil Conservation Measures

The detailed conservation measures in each land use system are presented in Table 1.

Available Data

In the present study, rainfall data were collected for the period 1983-2006 from the Agrometeorological Observatory adjacent to the FSRP site, ICAR Research Complex, Umiam, Meghalaya (India). Daily rainfall was recorded with the use of both self-recording and non-recording type of rain gauges. The runoff data were estimated by chart analysis collected from the various F-type stage level recorders installed in the nine different micro watersheds in the study area. Volumetric measurements of runoff were also taken daily to cross check the stage level data. The recorded runoff hydrographs for the study watersheds for each storm were analysed for computation of runoff rate and runoff volume from the respective watersheds. Measured daily runoff volume at the outlet of the watershed was converted to daily runoff depth (in mm) using the area of the watershed. On the day following the runoff events, water samples were drawn from the water collecting drum connected to Coshocton wheel. Sediment concentration was determined from a water sample of known volume using a standard technique. Total sediment loss on each day was computed by multiplying sediment concentration by the runoff volume. The runoff coefficient from an individual rainstorm is defined as runoff divided by the corresponding rainfall both expressed as a depth over the catchment area (mm).

In the study area, almost 70-80% of the annual rainfall is confined to just monsoon months (June-September). Therefore, the daily rainfall and runoff data for these four months were used for the development of the rainfall-runoff-sediment model. The daily data set for runoff and sedimentation yield for all 18 years (1983-2000) were used for model development and daily data set for runoff and sedimentation yield for six years (2001-2006) were used for model validation. From 2006 onwards, runoff and sediment data were not available for the study site.

The total water yield, base flow, surface flow and peak flow were estimated through stage level recorder chart analysis. Values of average precipitation, threshold rainfall, annual water yields range, base flow range and maximum peak flow under different micro watersheds for the study period are presented in Table 3.

Model Development for Runoff-Sediment Process

Considering the watershed as a lumped system, the causative factor such as runoff (Q), AQI and ASI can be treated as input to the system and sediment yield as the output (Pyasi and Singh, 2004). The mathematical expression of sediment yield can be functionally represented in linear form as:

$$S = \alpha_0 + \alpha_1 Q + \alpha_2 AQI + \alpha_3 ASI \quad ...(1)$$

Where, S = daily sediment yield in tones, Q = daily runoff flow depth in mm, AQI = antecedent runoff

Table: 2
Annual water yield, base flow and peak flow from different micro-watersheds (1998-2006)

Watershed	Annual water yield range (mm)	Mean water yield (mm)	Mean water yield as % of annual rainfall	Base flow range (mm)	Mean base flow as % of mean water yield	Maximum peak flow (mm hr^{-1})
W_1	0 - 66.69	9.56	0.37			7.81
W_2	67.42 - 1013.88	371.90	4.73	55.04 - 774.02	83.11	13.54
W_3	39.31 - 648.26	241.14	9.55	34.65 - 542.77	85.20	12.87
W_4	0.60 - 62.49	12.47	0.69	NA	-	20.71
W_5	0.24 - 121.91	28.98	1.14	NA	-	12.07
W_6	6.41 - 556.55	108.06	4.28	NA	-	11.40
W_7	0 - 51.39	11.77	0.46	NA	-	4.49
W_8	0 - 517.72	102.94	4.07	NA	-	86.10
AEW	257.61 - 1311.11	696.78	27.60	232.50 - 1071.82	85.50	9.40

(Source: Satapathy and Panda, 2006; Satapathy, 1996)

Table: 3
Average precipitation, threshold rainfall, annual water yield range, base flow range and maximum peak flow under different micro-watersheds (1998-2006)

Micro Watersheds	Average Precipitation (mm)	Threshold * rainfall (mm)	Annual water yield range (mm)	Base flow range (mm)	Maximum Peak flow (mm hr^{-1})
W_1	2399.3	363.2	0.0 - 66.69	-	16.99
W_2	2399.3	399.9	67.42 - 1013.88	55.04 - 774.02	30.70
W_3	2399.3	533.7	39.31 - 648.26	34.65 - 542.77	28.66
W_4	2399.3	364.3	0.60 - 62.49	NA	32.55
W_5	2399.3	348.6	0.24 - 121.91	NA	5.89
W_6	2399.3	541.7	6.41 - 556.55	NA	21.45
W_7	2399.3	541.7	0.0 - 51.39	NA	7.59
W_8	2399.3	1634.5	0.0 - 517.72	NA	35.07
WAEW	2399.3	399.9	257.6 - 1311.11	232.5 - 1071.82	15.50

**Cumulative rainfall during calendar year beyond which runoff gets initiated* index in mm and ASI = antecedent sediment index in tones. $\alpha_0, \alpha_1, \alpha_2$ and α_3 are regression coefficients.

A non-linear relation in the form of the logarithmically transformed variables can be expressed as:

$$In\,(S) = In\alpha_0 + \alpha_1 In\,(Q) + \alpha_2 In\,(AQI) + \alpha_3 In\,(ASI) \quad ...(2)$$

The antecedent sediment index (ASI) was estimated by the following equations (Pyasi and Singh, 2001, 2003 and 2004).

$$ASI = Y_1S_1 + Y_2S_2 + Y_3S_3 + \ldots + Y_jS_j + \ldots + Y_mS_m \quad ...(3)$$

$$ASI = \sum_{j=i}^{m} S_j\, Y_j \quad ...(4)$$

Where, S_j = daily sediment yield in the j^{th} day under consideration, m = an integer, also called memory parameter, Y_j = weightage given to the runoff and sediment event occurred in the day under consideration. (*J=1* refers to event immediately preceding the current event), which can be estimated by solving the following equation (Ojasvi *et al.*, 1994).

$$Y_j = \frac{e^{[-j-1/m]}}{\sum_{j=1}^{m} e^{[-j-1/m]}} \quad ...(5)$$

Where, *j = 1, 2, 3..........m*. For the runoff-sediment process, the appropriate value of 'm' was worked out by an iterative procedure. In the present study 'm' values ranging from 2 to 7 were tried and 'm' equal to 3 were found yielding the highest value of the coefficient of determination (R^2) for the study area. Thus, the weightage, (Y_j, *j = 1, 2, 3*) for the three prior events were found by using eq. 5 and were obtained 44.1, 33.45 and 23.32, respectively.

Parameter Estimation

Data were analysed using Statistical Package SPSS in Windows version 16.0. One-way multi variate analyses were used to determine the multiple step regression on runoff, sediment yield and ASI variables. In the case of runoff-sediment yield relationship, sediment yield was dependent variable and runoff, ARI and ASI were independent variables.

Model Testing and Validation

The memory based runoff-sediment yield time variant models were developed by using the daily event data series of for the month of June-September of eighteen years, *i.e.* 1983-2000. The validation of the models was done with the measured data for the period 2001-2006.

Qualitative Evaluation of Model Performance

The acceptability of a model is judged by goodness of fit between measured values, and the values estimated by a model. For qualitative comparison between observed and predicted values, the following statistical measures were employed. The qualitative performance of the models was ascertained by estimating the value of the coefficient of multiple determination (R^2), correlation coefficient (CC) absolute prediction error (APE), integral square error (ISE) and coefficient of efficiency (CE), root mean square error (RMSE) and deviation (%).

Qualitative Evaluation of Runoff-Sediment Yield Model Performance

Pyasi and Singh (2001, 2003 and 2004) suggested the allowable limits for APE, ISE and CE for the runoff-sediment model as 35, 15 and 60%, respectively. In the present study, the allowable limits for R^2, APE, ISE, CE, RMSE and deviation (%) for the runoff-sediment yield model were taken close to 1, 35%, 15%, 60%, close to zero and ± 10, respectively.

Generalised Models for Runoff-Sediment Using Conservation Factor (CF)

Besides rainfall, there are other factors like land use, soil conservation measures and human or animal actives that also govern the amount of runoff and soil loss from the slope of the watershed. The effects of conservation measures, land use as well as human or animal interference have been accommodated in CF evolved by Singh (1987) for predicting watershed runoff and sediment yield. In this study, using indices, Q, AQI, ASI runoff-sediment yield prediction models were developed for the different micro-watersheds of the study site. Therefore, there is a need to develop a generalised model for predicting runoff and sediment for watershed using CF as one of the independent variables. This approach has been used by Satapathy and Panda (2006) also.

Estimation of CF

CF evolved by Singh (1987) for calculating watershed runoff was modified by Satapathy and Panda (2006) by assigning priority numbers 5 to 50 for major land uses and soil conservation measures in order of risk involved for soil erosion (Table 4); the numbers arrived through trial and error after it tallied with the order of effectiveness of land uses in the study area.The CF for the mixed land use systems is computed by the following expression:

$$CF = \frac{A_1(NL_1 + NC_1 + NH_{a1}) + ...A(NL_n + NC_n + NH_{an})}{A_n + ...A_n} \quad ...(6)$$

Where, A_1 … A_n = area under various land uses in ha, NL_1… N, L_n = number assigned to various land uses (Table 5), NC_1…NC_n = numbers assigned to different conservation measures and NH_{a1}...NH_{an} = numbers assigned to various human and animal activities.

The CFs of different micro-watersheds of the study area were computed by using eq. 6 by Satapathy and Panda (2006) and are presented in Table 5. Taking modified values of CFs for different micro-watersheds and other different indices as independent variables, linear and non-linear models for rainfall-runoff and runoff-sediment yield were developed using the SPSS-v 16 software.

3. RESULTS AND DISCUSSION

Model Development for Runoff-Sediment Yield Process

Using eqns. 1 and 2, both linear and nonlinear dynamic models were tried. Altogether, 16 linear and non-linear models of runoff-sediment yield relationship were selected for eight different micro watersheds having different land uses. For micro watershed W_7 (natural cultivation based farming system); no model could be developed because no sediment producing events occurred during the study period. While developing linear runoff-sediment models, in the micro-watersheds W_1, W_2, W_3, W_4 and W_5 independent variables, *i.e.* runoff (Q), ASI contributed to predict dependent variable sediment yield (S). In thecase of the micro-watersheds W_6, W_8 and W_{AEW} variable AQI and ASI indices showed a significant role in developing linear runoff-sediment yield models (Table 6). Values of R^2 for the linear models showed the range between 0.987 to 1.00. A good runoff-sediment yield model generally satisfies the criteria of APE less than 35%, ISE less than 15% and CE more than 60%, (RMSE) close to zero and deviation ±10 %. Analysis revealed that the values of ISE (%), APE (%), CE (%), RMSE and deviation (%) of linear models were in the range of 3.95×10^{-11} to 1.61×10^{-2}, 5.81×10^{-3} to 3.15×10^{-2}, 100, 0 to 1.98×10^{-9}, 0 to 2.48, respectively for the micro-watersheds W_1, W_2, W_3, W_4,W_5, W_6, W_8 and W_{AEW}, respectively indicating the fulfilling the criteria of a good model (Table 6).

In the micro-watersheds W_1, W_4, W_5, W_6 and W_8 independent variables, *i.e.* runoff (Q) and ASI were highly contributing input variables to predict sediment yield (S) while developing non-linear runoff-sediment yield models. In the micro watershed W_2, it was observed that input variable ASI had a significant role in developing linear runoff-sediment yield models (Table 6). Also in the micro watershed W_{AEW}, input variables AQI and ASI were contributing

Table: 4
Numerical values assigned to various items of conservation factor

Land use	Assumed number	Conservation measure	Assumed numerical value	Human/animal activity	Assumed numerical value
Agriculture/ shifting cultivation	20	No measure	10	Intensive	5
Horticulture/ silvipasture /plantation	30	Contour bund/Contour bench	20	Moderate	10
Forest/ Natural vegetation	50	Bench terrace	30	Negligible	20

(Source: Satapathy and Panda, 2006; Satapathy, 1996)

Table: 5
Details of conservation factor indifferent micro- watersheds under various land use systems

	Experimental watersheds under details								
	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8	AEW
Land use	Agriculture (fodder)	Forestry (fuel, fodder)	Agro-forestry	Agriculture (food crops)	Agri-horti-silvil -pastora	Horticulture	Natural vegetation	Fellow under shifting cultivation	Pine plantation and natural vegetation
Conservation factor	61.33	75.80	70.81	57.34	62.91	73.62	80.00	36.73	80.00

(Source: Satapathy and Panda, 2006; Satapathy, 1996)

to predict dependent variable sediment yield S. Values of R^2 for the non-linear models showed the range between 0.97 to 1.00. Analysis revealed that the values of ISE (%), APE (%), CE (%), RMSE and deviation (%) of non-linear models were in the range of 1.23×10^{-3} to 1.78×10^{-2}, 1.79 x 10-3 to 3.07×10^{-2}, 100, 0 to 0.009 and 0 to 2.48, respectively for micro watersheds W_1, W_2, W_3, W_4, W_5, W_6, W_8 and W_{AEW}, respectively indicating the fulfilling criteria of a good model (Table 6). Comparing the values of R^2, ISE, APE, CE, RMSE and deviation (%) of linear and non-linear runoff-sediment yield models, it was observed that all linear and non-linear developed models were found statistically at par. Hence, both linear and non-linear runoff-sediment yield models were declared to be the best-fit (Table 6). However, for a specific storm event, if runoff is zero, the linear models will predict sediment yield based on an ASI. Pyasi and Singh (2001, 2003 and 2004) and Ranjan *et al.* (2011) reported suitability of non-linear dynamic models in their studies.

Model Validation for Runoff-Sediment Yield Process

All the linear and nonlinear models were validated for the daily runoff-sediment yield data series for the years 2001 to 2006. The value of the coefficient of determinations (R^2) for all the linear models was observed to be 1.00. The values of ISE (%), APE (%), CE (%), RMSE and deviation (%) of linear models were found in the range of 1.01×10^{-11} to 5.38×10^{-3}, 0 to 6.04×10^{-3}, 100%, 0 and 3.22×10^{-4} to 6.15×10^{-3} for the micro-watersheds W_1, W_2, W_3, W_4, W_5, W_6, W_8 and W_{AEW}, respectively (Table 7). Values of R^2 for all the non-linear models were observed to be 1.00. The values of ISE, APE, CE, RMSE and deviation (%) of non-linear models were found in the range of 8.44×10^{-5} to 1.42×10^{-2}. 0 to 2.47×10^{-2}, 100%, 0.001 to 0.009 and -1.47×10^{-3} to 2.48 for the micro-watersheds W_1, W_2, W_3, W_4, W_5, W_6, W_8 and W_{AEW}, respectively (Table 7). Validation statistics of all the best- fit linear models for the micro-watersheds W_1, W_2, W_3, W_4, W_5, W_6, W_8 and W_{AEW} were found to satisfy the criteria of a good model (Table 7).

Generalised Model Development for Runoff-Sediment Yield

Both linear and nonlinear dynamic models were developed for the monsoon period. In the developed generalised linear model, predicted sediment yield (S)

Table: 6
Runoff-sediment yield models and their qualitative performance values (during model development 1983-2000)

Micro-watersheds and respective models	Qualitative performance parameters				
	R^2	APE (%)	ISE (%)	RMSE	Deviation (%)
W_1- Fodder based farming system					
$S = 5.774 \times 10^{-10} - 8.288 \times 10^{-10}\ Q + 1 \times ASI$	1.00	6.12×10^{-3}	3.94×10^{-3}	0	2.48
$\ln (S) = 0.001 - 3.052 \times 10^{-5} \ln (Q) + 1 \times \ln (ASI)$	1.00	3.07×10^{-2}	1.78×10^{-2}	0.0009	0
W_2-Forestry based farming system					
$S = 3.584 \times 10^{-11} - 3.09 \times 10^{-11}\ Q + 1 \times ASI$	0.999	6.15×10^{-3}	6.11×10^{-3}	0	2.48
$\ln (S) = 0.001 + 1 \times \ln (ASI)$	0.989	191×10^{-3}	1.35×10^{-3}	0.0001	2.48
W_3-Agroforestry based system					
$S = 4.172 \times 10^{-10} - 2.660 \times 10^{-11}\ Q + 1 \times ASI$	1.00	6.16×10^{-3}	4.53×10^{-3}	0	2.48
$\ln (S) = 7.417 \times 10^{-6} \ln (AQI) + 1 \times \ln (ASI)$	1.00	1.79×10^{-3}	1.23×10^{-3}	0	2.48
W_4-Agriculture(Food Crop) based farming system					
$S = 2.224 \times 10^{-10} - 1.318 \times 10^{-10}\ Q + 1 \times ASI$	0.987	6.13×10^{-3}	3.54×10^{-3}	0	2.48
$\ln (S) = 1.229 \times 10^{-5} \ln (Q) + 1 \times \ln (ASI)$	0.978	1.79×10^{-3}	1.23×10^{-3}	0.0001	2.48
W_5-Agri-Horti-Silvi-Pastoral farming System					
$S = 4.209 \times 10^{-7} - 2.660 \times 10^{-7}\ Q + 1 \times ASI$	1.00	5.81×10^{-3}	3.95×10^{-11}	0	2.48
$\ln (S) = 1.929 \times 10^{-7} + 1.848 \times 10^{-5} \ln (Q) + 1 \times \ln (ASI)$	1.00	3.71×10^{-3}	5.49×10^{-3}	0	2.48
W_6-Horticulture based farming system					
$S = 1.999 \times 10^{-10} - 4.308 \times 10^{-12}\ AQI + 1 \times ASI$	1.00	3.15×10^{-2}	1.61×10^{-2}	0	6.20×10^{-3}
$\ln (S) = 7.774 \times 10^{-5} + 2.048 \times 10^{-6} \ln (AQI) + 1 \times \ln (ASI)$	1.00	7.07×10^{-3}	2.54×10^{-3}	0	6.20×10^{-3}
W_8-Fallow under shifting cultivation					
$S = 2.660 \times 10^{-11} - 8.256 \times 10^{-13}\ AQI + 1 \times 1 \times ASI$	1.00	6.15×10^{-3}	3.64×10^{-3}	0	2.48
$\ln (S) = 9.073 \times 10^{-6} + 1.362 \times 10^{-6} \ln (Q) + \ln (ASI)$	1.00	9.66×10^{-3}	1.63×10^{-3}	0	2.48
W_{AEW}-Pine and natural vegetation based farming system					
$S = -1.983 \times 10^{-10} - 1.260 \times 10^{-11}\ AQI + 1 \times ASI$	1.00	6.15×10^{-3}	4.30×10^{-3}	1.98×10^{-9}	0
$\ln (S) = -2.286 \times 10^{-14} \ln (AQI) + 1 \times \ln (ASI)$	1.00	3.79×10^{-3}	2.19×10^{-3}	5.322×10^{-5}	0

was mainly dependent on runoff (Q), AQI, ASI and CF. The developed generalised models along with qualitative parameters are presented in Table 8. Values of R^2 for the linear model were obtained 1.0. In the case of generalised linear model development, predicted sediment yield (S) was mainly dependent on the runoff (Q), AQI, ASI and CF. The values of ISE (%), APE (%), CE (%), RMSE and deviation (%) of linear model were found 4.49 x 10^{-3}, 6.15 x 10^{-3}, 100, 0.0001 and 6.15 x 10^{-3}, respectively (Table 8).

Values of R^2 for the nonlinear model were also obtained 1.00. In the case of generalised non-linear model development, predicted sediment yield (S) was mainly dependent on runoff (Q), AQI and ASI and CF. The values of ISE (%), APE (%), CE (%), RMSE and deviation (%) of non-linear model were found to be 8.41 x 10^{-7}, 6.04 x 10^{-7}, 100, 0 and -9.77 x 10^{-8}, respectively (Table 8). Statistically, both linear and non-linear models were found to be at par. Both the linear and nonlinear generalised models were considered to be the best-fit.

Validation of Generalised Model for Runoff-Sediment Yield

Both linear and nonlinear models were validated for the daily runoff, sediment data series for the years 2001 to 2006. The value of the coefficient of multiple determinations (R^2) for the linear model was obtained 1.0 during validation. The values of ISE (%), APE (%), CE (%), RMSE and deviation (%) of linear models were found to be 3.46 x 10^{-3}, 6.15 x 10^{-3}, 100, 0.003 and

Table: 7
Validation of runoff-sediment yield models and their qualitative performance values (2001-2006)

Micro-watersheds and respective models	R^2	APE (%)	ISE (%)	CE (%)	RMSE	Deviation (%)
W_1- Fodder based farming system						
$S = 5.774 \times 10^{-10} - 8.288 \times 10^{-10} Q + 1 \times ASI$	1.00	6.15x10^{-3}	4.64x10^{-3}	100	0	6.15x10^{-03}
$\ln(S) = 0.001 - 3.052 \times 10^{-5} \ln(Q) + 1 \times \ln(ASI)$	1.00	2.47x10^{-2}	1.42x10^{-2}	100	0.0009	2.47x10^{-02}
W_2-Forestry based farming system						
$S = 3.584 \times 10^{-11} - 3.09 \times 10^{-11} Q + 1 \times ASI$	1.00	6.13x10^{-3}	3.75x10^{-3}	100	0	6.15x10^{-03}
$\ln(S) = 0.001 + 1 \times \ln(ASI)$	1.00	1.89x10^{-3}	9.46x10^{-4}	100	0.0001	-1.89x10^{-03}
W_3-Agroforestry based system						
$S = 4.172 \times 10^{-10} - 2.660 \times 10^{-11} Q + 1 \times ASI$	1.00	6.15x10^{-3}	3.69x10^{-3}	100	0	6.15x10^{-03}
$\ln(S) = 7.417 \times 10^{-6} \ln(AQI) + 1 \times \ln(ASI)$	1.00	0	8.71x10^{-4}	100	0	-1.47x10^{-03}
W_4-Agriculture(Food Crop) based farming system						
$S = 2.224 \times 10^{-10} - 1.318 \times 10^{-10} Q + 1 \times ASI$	1.00	6.14x10^{-3}	3.24x10^{-3}	100	0	6.14x10^{-03}
$\ln(S) = 1.229 \times 10^{-5} \ln(Q) + 1 \times \ln(ASI)$	1.00	2.14x10^{-3}	1.09x10^{-3}	100	0.0001	-2.14x10^{-03}
W_5-Agri-Horti-Silvi-Pastoral farming System						
$S = 4.209 \times 10^{-7} - 2.660 \times 10^{-7} Q + 1 \times ASI$	1.00	6.04x10^{-3}	1.01x10^{-11}	100	0	6.04x10^{-03}
$\ln(S) = 1.929 \times 10^{-7} + 1.848 \times 10^{-5} \ln(Q) + 1 \times \ln(ASI)$	1.00	2.06x10^{-3}	1.01x10^{-3}	100	0	2.48
W_6-Horticulture based farming system						
$S = 1.999 \times 10^{-10} - 4.308 \times 10^{-12} AQI + 1 \times ASI$	1.00	6.11x10^{-3}	5.38x10^{-3}	100	0	3.22x10^{-04}
$\ln(S) = 7.774 \times 10^{-5} + 2.048 \times 10^{-6} \ln(AQI) + 1 \times \ln(ASI)$	1.00	3.22x10^{-4}	8.44x10^{-5}	100	0.0001	6.15x10^{-03}
W_8-Fallow under shifting cultivation						
$S = 2.660 \times 10^{-11} - 8.256 \times 10^{-13} AQI + 1 \times 1 \times ASI$	1.00	6.18x10^{-3}	4.03x10^{-3}	100	0	6.15x10^{-03}
$\ln(S) = 9.073 \times 10^{-6} + 1.362 \times 10^{-6} \ln(Q) + \ln(ASI)$	1.00	3.68x10^{-3}	1.65x10^{-3}	100	0	2.48
W_{AEW}-Pine and natural vegetation based farming system						
$S = -1.983 \times 10^{-10} - 1.260 \times 10^{-11} AQI + 1 \times ASI$	1.00	0	4.32x10^{-3}	100	0	6.15x10^{-03}
$\ln(S) = -2.286 \times 10^{-14} \ln(AQI) + 1 \times \ln(ASI)$	1.00	2.46x10^{-3}	1.42x10^{-3}	100	0.0009	2.47x10^{-02}

Table: 8
Generalised models for runoff-sediment yield and their qualitative performance values during model development (1983-2000)

Runoff-sediment yield-conservation factor model	Qualitative performance parameters					
	R^2	APE (%)	ISE (%)	CE (%)	RMSE	Deviation (%)
$S = 1.797 \times 10^{-10} - 6.144 \times 10^{-11} Q + 5.022 \times 10^{-12} AQI + 1 \times ASI - 6.33 \times 10^{-13}$ CF	1.00	6.15x10^{-3}	4.49x10^{-3}	100	0.0001	6.15x10^{-3}
$\ln(S) = -6.146 \times 10^{-5} - 1.85 \times 10^{-16} \ln(Q) + 4.931 \times 10^{-17} \ln(AQI) + 1 \times \ln(ASI) - 1.626 \times 10^{-16} \ln(CF)$	1.00	6.04x10^{-7}	8.41x10^{-7}	100	0	-9.771x10^{-8}

6.15×10^{-3}, respectively (Table 9). Values R^2 for the non-linear was obtained 1.0 during validation. The values of ISE (%), APE (%), CE (%), RMSE and deviation (%) were found to be 3.15×10^{-8}, 9.71×10^{-8}, 100, 0 and -9.71×10^{-8}, respectively satisfying the criteria of a good model (Table 9).

Statistically, both linear and non-linear models satisfy the condition of a good model during validation. Using the developed generalised models of rainfall-runoff and runoff-sediment yield; runoff and sediment yield of similar behaviour, micro-watershed of a hilly area of the region can be predicted. Table 6 represent runoff-sediment yield models for nine micro-watersheds separately. Whereas Table 8 represents generalised runoff-sediment yield models when land use, soil conservation measure and human/biotic activity are denoted by a CF. In this case, all watersheds input data were pooled while developing the model. Generalised models are having an advantage over other individual models of runoff-sediment yield of different micro watersheds, because they include one more important input variable *i.e.* CF. Overall, there are very limited studies available ondynamic modelling of runoff-sediment yield under different land uses of a hilly watershed of NE India to the best of author's knowledge. Such studies need to explore in similar types of watersheds for further confirmation of findings.

4. CONCLUSIONS

In this study, an attempt has been made to develop the runoff-sediment yield dynamic models by introducing input parameters like runoff (Q), sediment (S) and also including four more different indices, *i.e.* antecedent precipitation index (API), AQI and ASI and CF. Both the linear and non- linear dynamic models were developed for rainfall-runoff-sediment yield process for nine micro watersheds having different land generally uses in practice in Meghalaya, India. For runoff-sediment yield process, all linear and non-linear models developed were performed satisfactorily for all the micro-watersheds except W_7. Hence, both linear and non-linear runoff-sediment yield models were declared to be the best-fit. Generalised models runoff-sediment yield were developed using CF as one of the independent variables. For runoff-sediment yield process, both the linear and non-linear generalised models were found the best-fit. Using generalised models of rainfall-runoff and runoff-sediment yield; runoff and sediment yield of similar behaviour, micro-watershed of a hilly area of the region can be predicted.

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Table: 9
Generalised models for runoff-sediment yield and their qualitative performance values during model validation (2001-2006)

Runoff-sediment yield-conservation factor model	Qualitative performance parameters					
	R^2	APE (%)	ISE (%)	CE (%)	RMSE	Deviation (%)
$S = 1.797 \times 10^{-10} - 6.144 \times 10^{-11} Q + 5.022 \times 10^{-12} AQI + 1 \times ASI - 6.33 \times 10^{-13} CF$	1.00	6.15×10^{-3}	3.46×10^{-3}	100	0.003	6.15×10^{-3}
$\ln(S) = -6.146 \times 10^{-5} - 1.85 \times 10^{-16} \ln(Q) + 4.931 \times 10^{-17} \ln(AQI) + 1 \times \ln(ASI) - 1.626 \times 10^{-16} \ln(CF)$	1.00	9.71×10^{-8}	3.15×10^{-8}	100	0	-9.71×10^{-8}

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