Micro-watershed Treatment for Soil Stabilization

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The sediment yield from micro-watersheds can be minimized with the adoption of effective conservation measures. The effectiveness may be gauged by a defined domain of performance indicators of the watershed activities, influenced by regional meteorology, topography and environmental characteristics. The present paper states the procedure of identification of a set of conservation measures and their performance evaluation with a view to minimize the sediment yield in micro-watersheds. The rainfall pattern and its erosivity was obtained having almost similar intensity and uniform distribution from the small locality over the indicated years. The land degradation in this study, declared as a function of periodic performance of conservation activities in non-arable and arable land of the watershed shows declining trend with a straight fit relation of correlative coefficient ranging from 0.87 to 0.98. The performance indicator scale, measuring the extent of activities, is suitable in the present case, because it has been able to descend the sediment yield in micro-watersheds to the desired level. The model may show different results if the range of performance indicators is changed, when indicators suit to different environment of other localities. The approach may be utilized as a technique to measure and control soil erosion from watersheds for a specific period with the evolution of a performance measuring scale.

Keywords: Micro-watershed; Silt-yield; Performance indicator; Drainage network; Arable/non-arable land

INTRODUCTION

Soil detachment and sediment transport from watershed are phenomena related to rainfall impact, surface runoff and vegetation. Under natural undisturbed condition, an equilibrium is established between the climate of the region and the vegetative cover that protects the soil layer. When land is put under cultivation, the natural balance existing amongst the entities is disturbed and the removal of surface soil by natural agencies takes place at a faster rate than it can be built up by soil forming process. The complexity of physical processes amongst rainfall, overland flows and soil erosion, and also the several man-induced activities, such as, land management and agricultural practices, contribute to make the problem of soil erosion a very difficult one to deal with.

Several regression equations have been developed on the basis of observed sediment yield and basin characteristics, such as, meteorological factors (mostly rainfall and temperature), topographical data, (*eg*, texture, structure and pH). Land use and vegetation are often considered modifying factors. Dendy and Bolton[1] and Weber, *et al*[2] gave elaborate study and statistical analysis on this approach.

Bogardi, *et al*[3] carried out a study on various methods for calculating sediment yield from agriculture watershed and checked the accuracy of the calculation by comparing these with measurement data. The basic characteristics of six watersheds as they selected for their study were : relatively small (24–115 km^2) agricultural catchments, similar ratios of forest to crop land, various soil textures varied from sandy to clay, changing conditions of agricultural production (land use, technology, fertilizer application etc). They concluded that modified Universal Soil Loss Equation (USLE) method with the Soil Conservation Service (SCS) runoff model results in quite accurate estimates. The best method proved to be the USLE with sediment delivery ratio calculated from main channel length. The regression method appears to be more inaccurate, they added.

Julien and Frenette[4] developed a combined stochastic and deterministic method to evaluate soil erosion from overland flow. The exponential distributions from rainfall duration and intensity are combined with rainfall-runoff relationships for discrete stroms. Using sediment delivery ratios, the sediment yield computed from the total soil erosion is in good agreement with the suspended load measured in the river. Earlier, Shen and Li[5] elaborated deterministic model for water routing and sediment from a watershed for a given rainfall hyetograph.

Goswami[6,7,8,9] developed a model to delineate river boundary after meandering, encompassing flood prone watersheds and sediment deposition in flood plain. He visualized the Indian ecological problem due to micro-watersheds crisis leading to soil erosion hazards. Singh and Singh[10] described soil erosion status in hilly regions of India.

If no severe environmental degradation occurs in a region and its adjoining catchments, the rainfall intensity and the distribution pattern is generally observed almost similar or under range of uniformity throughout a period of time Therefore, to minimize soil erosion watersheds, there remains one essential

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This paper (modified) was received on January 3, 2003. Written discussion on the paper will be entertained till August 31, 2004.

approach, *ie,* land management practice. How best the land is utilised, and the conservation measures with drainage line treatment are carried out, is of utmost importance. The objective of the present study is to observe the influence of conservation measures in the regional sediment yield behaviour. A case study of Puthimari watershed of Assam, having three influential micro-watersheds with mild slope topography and flood pain alluvia, is taken up to evaluate regional silt yield characterization under specific conservation grade. The model may, however, show different results having different conservation measure-indicators of other locality.

THEORETICAL CONSIDERATION

A well established watershed has little environmental crisis and disintegration amongst entities. It has minimum soil degradation and has ample conservation measures. The effectiveness of the watershed is, therefore, measured how best the watershed activities are performed within stipulated time for the desired purpose. It is characterized by pre-defined performance indicators drawn from regional geographical implications.

For micro-watersheds in a region, the rainfall intensity and distribution is found almost similar for indicated years. It is observed that drainage system in the micro-watersheds faces no serious flood hazards or abnormal runoff. The basic principle here is that the sediment yield has a functional relationship with performance of conservation measures adopted in micro-watersheds within specified time, *ie,*

$$S_{yi} = \mathrm{f}\,(p_i) \tag{1}$$

where S_{yi} is the silt yield in *i*th number of micro-watershed; p_i is the indicator point for *i*th number of micro-watershed;

and

$$p_i = \Sigma\,[a_i, b_i, c_i, \ldots\ldots\ldots\ldots]$$

or,

$$\Sigma\,[A_i, B_i, C_i, \ldots\ldots\ldots\ldots];\; i = 1, 2, 3, \ldots\ldots$$

where $a_i, b_i, c_i, \ldots\ldots\ldots\ldots$ are the performance indicators in the micro-watersheds for arable land; $A_i, B_i, C_i, \ldots\ldots$, performance indicators in the micro-watersheds for non-arable land; and *i* is the *i*th number of micro-watershed.

For straight line fit in between S_{yi} and p_i,

$$S_{yi} = \mathrm{a}'p_i + \mathrm{b}' \tag{2}$$

where a′ and b′ are constants.

The correlative coefficient between the cumulative entities,

$$C_R = \frac{n\Sigma S_{yc}\; p_c - \Sigma S_{yc}\; \Sigma\; p_c}{\sqrt{\left[\left\{n\Sigma\,(S_{yc})^2 - (\Sigma S_{yc})^2\right\}\left\{n\Sigma\,(p_c)^2 - (\Sigma\,p_c)^2\right\}\right]}} \tag{3}$$

where, C_R is the correlative coefficient; S_{yc}, cumulative silt yield; p_c, cumulative performance indicator point; and *n* is the number of times.

If

C_R = 0.20 to 0.40 then correlation is low

C_R = 0.50 to 0.70 then correlation is moderate

C_R = 0.80 to 0.99 then correlation is high.

After a careful field investigation in consideration with regional geographical features, the domain of performance indicators is set up. The performance indicators will signify the effectiveness of the activities, and are deciding factors in characterization of regional soil stabilization phenomenon. The p_i will indicate a scale of performance after summing up of all indicator-points.

To proceed for a best fit relation between silt yield in micro-watersheds and the effectiveness of conservation measures, a case study is taken. Puthimari watershed in Assam, namely, having Puthimari river network and three influential micro-watersheds, namely, Morachessa, Katura and Baltijan are shown in Figure 1. Table 1 gives a detail note of flood behaviour and regional silt status for 15 years of Puthimari watershed (PW). The watershed is so chosen that it covers a number of micro-watersheds of which areas generally range from 500 ha to 1000 ha and the soil characterictics are such that there happens soil erosion since long period. The micro-watershed Morachessa (say, mw_1) has arable land 275 ha and non-arable 316 ha. Similarly, Katura and Baltijan (say, mw_2 and mw_3, respectively) have 418 ha and 218 ha arable lands and 264 ha and 336 ha non-arable lands, respectively. In India, a

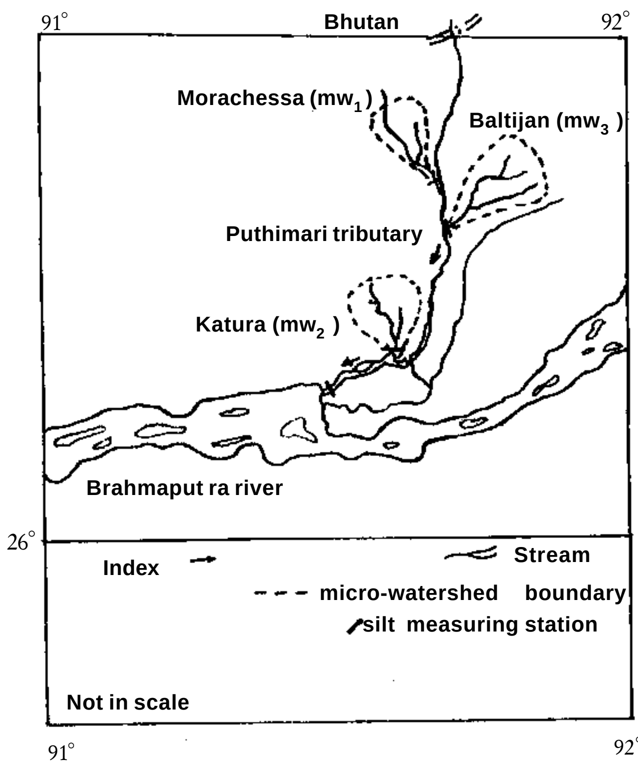

Figure 1 Drainage network of Puthimari watershed

Table 1 Puthimari watershed silt-yield status (before micro-watersheds treatment)

Year	Flood Lift at Gauging River-site, m	Flood Waves, Nos.	Flood Duration Above Danger Level, days	Annual Silt Yield of PW (S_y), ham
1975	3.67	2	7, 1	84.66
1976	4.55	3	6, 8, 1	55.48
1977	3.51	12	2, 10, 1, 2, 1, 10, 1, 2, 1, 8, 8, 1	24.18
1978	4.80	6	2, 6, 1, 2, 1, 1	27.07
1979	4.74	6	5, 3, 10, 1, 1, 2	8.96
1980	4.36	2	2, 6	6.85
1981	3.26	4	1, 6, 1, 2	9.29
1982	3.51	5	1, 4, 9, 2, 7	12.13
1983	4.75	3	1, 2, 6	15.79
1984	3.89	2	5, 1	26.73
1985	2.78	5	1, 5, 1, 1, 7	5.05
1986	2.69	3	1, 1, 2	15.54
1987	5.29	5	1, 6, 3, 4, 1	21.57
1988	5.02	4	1, 6, 2, 4	22.74
1989	5.08	4	3, 9, 7, 2	26.74
1990	6.13	7	1, 6, 4, 1, 3, 1, 4	34.16

huge number of watersheds were undertaken during Ninth Five Year Plan period for treatment with a view to conserving soil and moisture under the programme called National Watershed Development Project in Raindfed Areas (NWDPRA) implemented in Assam by the State Agriculture Department. The Puthimari watershed under that programme has large alluvial flood plain having climatic influence of heavy rainfall during April to September. The middle portion of the Puthimari river is braided and meandering mostly embanked and the bed slope ranges from 1:1100 to 1:6500 approximately.

MATERIALS AND METHODS

To measure silt yield at micro-watersheds, experiments were conducted at the gauging station as shown in Figure 1. For treatment of the micro-watersheds, the drainage network was divided into three reaches, namely, upper reach, middle reach and lower reach. In the arable land, the conservation measures like contour vegetative hedges, repair of gullies, dead furrow cultivation and vegetative filter strips were undertaken. In non-arable land, conservation measures and drainage line treatment were chosen. For conservation measures, live fencing, filter strips and contour hedges were taken. For drainage line treatment, mainly bank stabilization work was done. In upper reaches of the micro-watersheds, live checks, brushwood dams, boulder checks were constructed so that silts would be halted and water would be allowed to filter out. Dug out ponds, sunken structures were constructed in middle and lower reaches of the drainage system according to land

Table 2 Performance indicators (based on regional historic silt behaviour)

Activities and Performance Indicators	Scale	Indicator -point, p_i
Arable Land		
a_i — Contour vegetation hedge, ha	$a_i < 5$	0.5
	$15 > a_i \geq 5$	1.0
	$25 > a_i \geq 15$	2.0
	$35 > a_i \geq 25$	3.0
	and so on	. . . . . .
b_i — Repair of gullies, number	$b_i < 1$	0.5
	$4 > b_i \geq 1$	1.0
	$8 > b_i \geq 4$	2.0
	$12 > b_i \geq 8$	3.0
	$16 > b_i \geq 12$	4.0
	and so on	. . . . . .
c_i — Dead furrow cultivation, ha	$c_i < 20$	0.5
	$50 > c_i \geq 20$	1.0
	$80 > c_i \geq 50$	2.0
	and so on	. . . . . .
d_i — Vegetative filter strips, rmt	$d_i < 50$	0.5
	$100 > d_i \geq 50$	1.0
	$150 > d_i \geq 100$	2.0
	$200 > d_i \geq 150$	3.0
	and so on	. . . . . .
Non-arable Land		
A_i — Live fencing, rmt	$100 > A_i > 0$	1.0
	$200 > A_i \geq 100$	2.0
	$300 > A_i \geq 200$	3.0
	and so on	. . . . . .
B_i — Vegetative filter strips, rmt	$B_i < 50$	0.5
	$100 > B_i \geq 50$	1.0
	$150 > B_i \geq 100$	2.0
	$200 > B_i \geq 150$	3.0
	and so on	. . . . . .
C_i — Contour hedge, ha	$C_i < 5$	0.5
	$15 > C_i \geq 5$	1.0
	$25 > C_i \geq 15$	2.0
	$35 > C_i \geq 25$	3.0
	and so on	. . . . . .
D_i — Bank stabilization, rmt	$150 > D_i > 0$	1.0
	$300 > D_i \geq 150$	2.0
	$450 > D_i \geq 300$	3.0
	and so on	. . . . . .
E_i — Live checks, brushwood dams, boulder checks, dug out ponds, sunken structure etc (number)	$200 > E_i > 0$	1.0
	$400 > E_i \geq 200$	2.0
	$600 > E_i \geq 400$	3.0
	and so on	. . . . . .

suitability. Additional silt deposition in the checks and ponds was measured on volumetric basis.

The conservation measure structures are small in size and those may vary in shape according to local site condition. Here, mainly the procedure is shown how the performance of the activities will influence the silt stabilization behaviour. Depending upon the regional soil characteristics and soil degradation history, the scale of conservation performance will be fixed.

For each year, since 1991 to 1997, the achievement of selected conservation activities in the micro-watersheds was recorded and their scale of performance was measured from Table 2. The silt accumulation in the checks and ponds and that of drainage system measured in the gauging stations were recorded for every year. Tables 3 and 4 give the detail of treatments in micro-watersheds and yearly silt yield. No treatment was taken up for years 1998 to 2000 and the silt yield for that period was also observed.

A set of conservation measures was taken for treating the arable land and the non-arable land of each micro-watershed. The basis of selecting the unit and location of the conservation activities was the topography, the drainage network and the previous sediment yield of the watershed. The field experience of the individual would dictate the selection accuracy. A range of conservation measures for the region was therefore pre-defined and then the performance indicators scale was determined.

Table 2 gives the regional performance indicators of the conservation activities. Here, if the activity like the contour vegetation hedge in hectare be denoted as a_i for the ith micro-watershed and is taken into consideration for implementation up to a limit of 5 ha land, then let us give a point value, say 0.5. Then for next 5 ha to 15 ha contour vegetative hedge activity, the comparative point value be given as 1.0 and the procedure is adopted likewise. Some technical person may give the first point value as 0.1, but the next increment in point value must have a comparative increment in relation with activity performance.

However, this experiment of fixing the scale value may differ in other locality where these activities will bear different status of location suiting to environment, topography and drainage network.

In Tables 3 and 4, a detail report of data evaluation is given. Say in Table 3, for arable land development in micro-watershed mw_1, the activity a_1 will indicate contour vegetative hedge in hectare; b_1, repair of gullies in number; c_1, dead furrow cultivation in hectare and d_1 is vegetative filter strips in running metre. For the set of conservation activities undertaken, the performance indicator point p_1, where will be $p_{a1} + p_{b1} + p_{c1} + p_{d1}$ is calculated. Here for the year 1991, p_1 is 5 and correspondingly total silt yield S_{y1} from mw_1 is 6.72 ha m drawn from field measuring station. The cumulative performance indicator p_c for all micro-watersheds mw_1, mw_2 and mw_3, ($p_c = p_1 + p_2 + p_3$) and cumulative silt yield ($S_{yc} = S_{y1} + S_{y2} + S_{y3}$) are calculated as shown in the Tables 3 and 4.

Table 3 Treatment in micro-watersheds and silt yield (arable land)

Activities	Year	mw_1			mw_2			mw_3			Cumulative	
		a_1, b_1, c_1, d_1	p_1	S_{y1}, ha m	a_2, b_2, c_2, d_2	p_2	S_{y2}, ha m	a_3, b_3, c_3, d_3	p_3	S_{y3}, ha m	p_c	S_{yc}, ha m
Conservation: Measures	1991	10, 2, 20, 102	5 (1 + 1 + 1 + 2)	6.72	15, 6, 21, 152	8 (2 + 2 + 1 + 3)	3.29	5, 2, 0. 50	3 (1 + 1 + 0 + 1)	5.00	16	15.01
Contour vegetative hedge, ha	1992	12, 3, 50, 80	5 (1 + 1 + 2 + 1)	4.09	6, 9, 53, 106	8 (1 + 3 + 2 + 2)	6.11	10, 4, 20, 51	5 (1 + 2 + 1 + 1)	4.30	18	14.50
Repair of gullies, no	1993	23, 6, 30, 115	7 (2 + 2 + 1 + 2)	4.66	17, 6, 53, 150	9 (2 + 2 + 2 + 3)	3.90	15, 5, 22, 53	5 (2 + 1 + 1 +1)	5.34	21	13.90
Dead furrows cultivation, ha	1994	16, 6, 24, 150	8 (2 + 2 + 1 + 3)	4.01	25, 7, 22, 102	8 (3 + 2 + 1 + 2)	4.30	5, 6, 50, 52	6 (1 + 2 + 2 + 1)	4.69	22	13.00
Vegetative filter strips, rmt	1995	15, 8, 56, 103	9 (2 + 3 + 2 + 2)	3.90	25, 6, 81, 150	11 (3 + 2 + 3 + 3)	3.08	6, 3, 0, 100	4 (1+1 + 0 + 2)	5.22	24	12.20
	1996	6, 8, 80, 100	9 (1 + 3 + 3 +2)	3.85	15, 8, 50, 104	9 (2 + 3 + 2 + 2)	4.17	15, 4, 21, 150	8 (2 + 2 + 1 + 3)	3.74	26	11.76
	1997	15, 3, 59, 156	8 (2 + 1 + 2 + 3)	4.23	25, 12, 81, 151	13 (3 + 4 + 3 + 3)	2.99	17, 6, 23, 53	6 (2 + 2 + 1 + 1)	4.27	27	11.49
No treatment,	1998	—	Nil	3.96	—	—	2.58	—	—	3.06	—	9.60
only silt yield	1999	—	—	3.59	—	—	2.41	—	—	3.00	—	9.00
observation	2000	—	—	3.53	—	—	2.36	—	—	3.00	—	8.89

Table 4 **Treatment in micro-watersheds and silt yield (non-arable land)**

Activities	Year	mw_1			mw_2			mw_3			Cumulative	
		A_1, B_1, C_1, D_1	p_1	S_{y1}, ha m	A_2, B_2, C_2, D_2	p_2	S_{y2}, ha m	A_3, B_3, C_3, D_3	p_3	S_{y3}, ha m	p_c	S_{yc}, ha m
Conservation Measures and Drainage Line Treatment:	1991	112, 0, 0, 150, 26	4 (2 + 0 +0 + 1 + 1)	4.59	200, 50, 0, 51, 201	7 (3 + 1 + 0 + 1 + 2)	3.82	75, 59, 0, 0, 65	3 (1 + 1 + 0 + 0 + 1)	5.34	14	13.75
Live fencing, rmt	1992	131, 0, 0, 143, 201	4 (1 + 0 + 0 + 1 + 2)	2.71	106, 111, 0, 150, 206	8 (2 + 2 + 0 + 2 + 2)	4.61	81, 64, 0, 150, 40	5 (1 + 1 + 0 + 2 + 1)	4.19	17	11.51
Vegetative filter, Strips, rmt;	1993	129, 52, 9, 136, 28	6 (2 + 1 + 1 + 1 + 1)	1.95	151, 156, 7, 160, 209	10 (2 + 3 – 1 + 2 + 2)	2.01	100, 50, 6, 65, 39	6 (2 + 1 + 1 + 1 + 1)	3.02	22	6.98
Contour hedges, ha; Bank stabilization, rmt	1994	108, 54, 10, 101, 201	7 (2 + 1 + 1 + 1 + 2)	0.75	109, 150, 0, 150, 200	9 (2 + 3 – 0 + 2 + 2)	1.96	106, 54, 6, 75, 202	7 (2 + 1 + 1 + 1 + 2)	1.23	23	3.94
Live check Brushwood dams	1995	102, 51, 0, 50, 200	6 (2 + 1 + 0 + 1 + 2)	1.12	200, 150, 10, 302, 400	13 (3 + 3 + 1 + 3 + 3)	1.50	100, 106, 10, 75, 100	7 (2 + 2 + 1 + 1 + 1)	1.54	26	4.16
Boulder checks Dug out ponds	1996	106, 51, 6, 75, 206	8 (3 + 1 + 1 + 1 + 2)	0.98	206, 150, 15, 300, 402	14 (3 + 3 + 2 + 3 + 3)	1.46	64, 50, 9, 94, 68	5 (1 + 1 + 1 + 1 + 1)	1.89	27	4.33
Sunken structure, no	1997	175, 106, 7, 69, 201	8 (2 + 2 + 1 + 1 + 2)	1.73	300, 206, 15, 306, 402	16 (4 + 4 + 2 + 3 + 3)	2.06	56, 78, 5, 163, 209	7 (1 + 1 + 1 + 2 + 2)	1.23	31	5.02
No treatment, only silt yield observation	1998	—	—	1.03	—	—	1.96	—	—	1.17	—	4.16
	1999	—	—	1.03	—	—	1.83	—	—	1.15	—	4.01
	2000	—	—	1.02	—	—	1.99	—	—	1.20	—	4.21

Figure 2 shows the year-wise silt yield behaviour for all micro-watersheds.

RESULTS AND DISCUSSIONS

There is a descending trend of silt yield from micro-watersheds (Figure 2), which is because of adoption of right choice of conservation measures and drainage line treatment. The measures were taken up to 1997 and after that year, no treatment was taken for three years and sediment yield was observed. The experiment shows uniform trend of sediment yield at low level in the fag end of last there years.

The desired level of silt yield in the said micro-watersheds was pre-considered to be one hectare metre, a safe value in the region. Since, the prefixed set of conversation measures has been able to derive the nearby desired level of silt yield in the micro-watersheds, the set may be considered befitting for soil stabilization in the said Puthimari watershed.

Figure 3 shows the soil stabilization curve, *ie,* the straight line fit in between cumulative silt yield and cumulative conservation performance with a correlation coefficient ranging from 0.87 to 0.98. The relations as obtained in the present study are

$$S_{yc} = 0.34\ p_c + 20.66$$

$$[\text{for arable land,} \quad C_R = 0.98, \theta = 18.78^\circ] \tag{4}$$

$$S_{yc} = 0.59\ p_c + 20.58$$

$$[\text{for non-arable land,} \quad C_R = 0.87, \theta = 30.54^\circ] \tag{5}$$

Since, the correlation coefficient C_R, for silt yield and performance indicators shows the best fit relation, the relations obtained will underline the regional silt yield status. For other set of conservation measures, the performance indicators may be determined from Table 2, and from equations (4) and (5) (in accordance with arable land and non-arable land), the yearly silt yield from the micro-watersheds in that region may be determined.

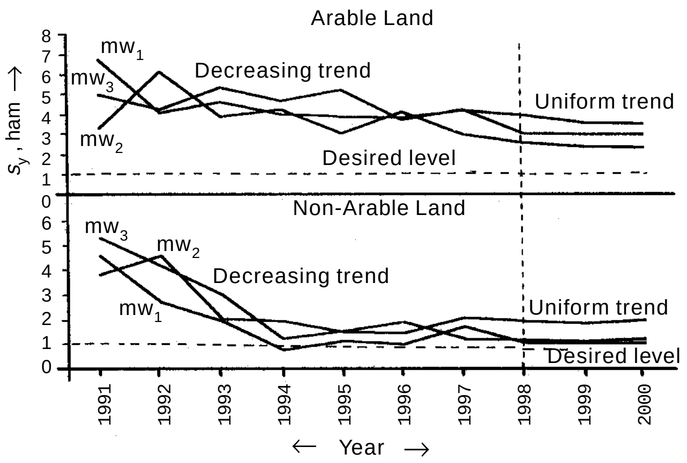

Figure 2 Silt yield in micro-watersheds (after treatment)

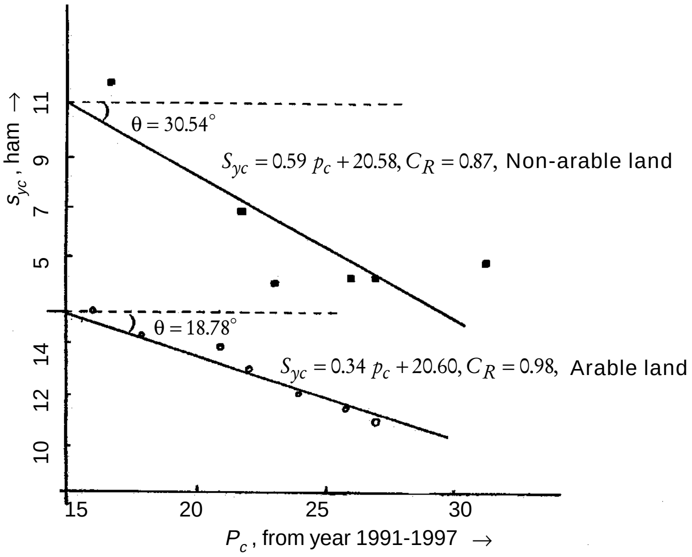

Figure 3 Soil stabilization curve (line of best fit for Puthimari watershed)

CONCLUSION

The present study determines a set of conservation measures suitable for soil stabilization for the region. This is one procedure to fix the conservation activities in micro-watersheds to bring the soil erosion for arable and non-arable lands to a desired level. The performance indicators attributed under the identified range of watershed activities may vary depending upon the topography and drainage network of the region, but its correlative influence on sediment yield will be of uniform nature provided the selection of the set of conservation activities is in accordance with soil characteristics. In the present study, the soil erosion level is attained almost up to 1 ha m for each micro-watershed, which is the safe value for the region. The model will show good result if the selection of the conservation measures is in the desired domain.

REFERENCES

1. R E Dendy and G C Bolton 'Sediment Yield—Runoff Drainage Area Relationships in the United States.' *Journal of Soil and Water Conservation,* vol 31, no 6, 1976, p 264.

2. J Weber, M Fogel and L Duckstein. 'The use of Multiple Regression Model in Predicting Sediment Yield.' *Water Resources Bulletin,* vol12, no 1, 1976, p l.

3. I Bogardi, A Bordossy, M Fogel and L Duckstein. 'Sediment Yield from Agricultural Watersheds.' *Journal of Hydraulic Engineering, American Society of Civil Engineers,* vol 112, no 1, 1986, p 64.

4. P Y Julien and M Frenette. 'Modelling of Rainfall Erosion.' *Journal of Hydraulic Engineering, American Society of Civil Engineers,* vol 111, no 10, 1985, p 1344.

5. H W Shen and R M Li. 'Watershed Sediment Yield Model.' *Stochastic Application to Water Resources, H W Shen Ed, Water Resource Publication, Fort Collins, Colo,* 1976, p 68.

6. M D Goswami. 'Sinusoidal Behaviour in Meandering Alluvial Channel.' *Ph D Thesis to the Department of Civil Engineering, Gauhati University,* Assam, India, July 2001, p 66.

7. M D Goswami. 'Manders in Tributaries and a Biological Catchment.' *The Employment News, Ministry of Information and Broadcasting, Government of India,* vol 26, no 12, 2001, p 1.

8. M D Goswami and M M Das. 'Sinusoidal Channel Development in Alluvial Flood Plain.' *Journal of Indian Water Resources Society,* IIT Roorkee, vol 22, no 2, 2002, p 57.

9. M D Goswami. 'Treat Watershed, Be Eco-friendly.' *The Assam Tribune, Tribune Publication, Assam,* India, January 3, 2004, p 4.

10. A Singh and M D Singh. 'Soil Erosion Hazards in North Eastern Hill Region.' *Research Bulletin No 10, ICAR Research Complex for NEH Region,* India, 1981, p 19.