



A SPATIALLY DISTRIBUTED EVENT-BASED MODEL TO PREDICT SEDIMENT YIELD[#]

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ABSTRACT

A study has been conducted in three sub-watersheds to model the spatial distribution of runoff and sediment yield. The basic structure of the model includes generation of runoff using SCS curve number (CN) method and soil detachment by RUSLE, MUSS and MUST equations, which is in turn delimited by Kirkby's transport capacity equation. The input parameter grids – cover, practice and soil erodibility grids were generated from satellite data with adequate field check. Routing of runoff and sediment was done in ARC/INFO's GRID module. Predicted results were validated with field-measured values. Results show that the runoff from CN method was better estimated after accounting for depression storage. Results from two hilly watersheds show that the standard error of sediment yield prediction of RUSLE < MUSS < MUST equations. In a relatively flat watershed, sediment yields were underestimated, due to underestimation of transport capacity. Hence, there is a need to address the transport capacity in plains and moderately sloping areas.

Keywords: *Runoff, sediment yield, GIS, remote sensing, watershed, event-based.*

INTRODUCTION

Soil erosion is a complex dynamic process by which productive soil surface soil is detached, transported and accumulated at a distant place resulting in exposure of subsurface soil and siltation in reservoirs and natural streams elsewhere. Economically, the soil loss results in the decrease of arable land and its quality by depleting the top fertile soil and affecting the land productivity. It also affects the surface water storage capacity and by sedimentation of lakes and reservoirs; and water quality by contaminating the water with suspended soil particles, toxic materials and pesticides. Though the soil erosion is said to be the natural process, it could be detained or accelerated by human intervention. Surface mining, deforestation, improper land husbandry, etc. could aggravate the problem.

Soil erosion is problem *per se* though out the world. Globally, 1,964.4 M ha of land is affected by human-induced degradation (UNEP, 1997). Of this, 1,903 M ha are subject to soil erosion by water and 548.3 M ha by wind erosion. In India about 5334 MT of soil is eroded annually though the total river carrying capacity is 2052 MT (Narayana and Rambabu, 1983). As per the Ministry of Agriculture (1985) about 113.3 M ha of land is subjected to soil erosion by water.

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Since the inception of understanding the gravity of soil erosion problem, several studies were carried out to understand the relationship between erosion and the causative facts. Subsequently this work has led to development of erosion prediction models for the purpose of conservation planning, evaluation of what it scenarios, predicting the soil loss in inhospitable terrains, etc. These erosion models could be grouped into empirical, physically-based and mixed models. However, they are developed under off-Indian conditions and evaluation of these models is required before directly using them for our conditions.

India for demarcation of priority watersheds for taking up soil conservation measures a Sediment Yield Index (SYI) method (Bali and Karale, 1977) has been developed and implemented. The SYI method gives only an index of sediment yield whose prediction has high subjectivity in assigning the weightage values. Besides it does not consider the actual rainfall and is solely dependent on the soil, topography and land cover. Besides, most of the quantitative erosion studies in India culminated in developing simple empirical relationships, which do not explain the erosion process spatially and cannot be used in other areas with same level of confidence. Hence there is strong requirement for evaluation of quantitative and spatially distributed soil erosion models and suitably modifying them for domestic conditions.

One of the major problems in testing these models is the generation of input data, that too spatially. The conventional methods proved to be too costly and time consuming for generating this input data. With the advent of remote sensing technology, deriving the spatial information on input parameters has become more handy and cost-effective. Besides with the powerful spatial processing capabilities of Geographic Information System (GIS) and its compatibility with remote sensing data, the soil erosion modeling approaches have become more comprehensive and robust. Thus, in the recent years, several studies were carried out using GIS to model soil erosion spatially (Heidtke and Auer, 1993; Savabi et al., 1996; de Roo et. al., 1996 and Huang et al, 1999).

In order to realize the potential of remote sensing and GIS to model soil erosion, the present study was carried out in three typical watersheds, with an objective to develop an event-based soil erosion model for quantitative estimation of sediment yield by integrating remote sensing and spatial analytical techniques.

STUDY AREAS

The current study has been taken up in three watersheds covering three different agro-climatic regions with varying rainfall intensities and distribution patterns. The location of test sites was given as Fig-1.

Mynaly watershed is located in Udagamandalam district of Tamil Nadu state. Geographically the watershed extends between $11^{\circ} 21' 32''$ to $11^{\circ} 24' 37''$ N latitude and $76^{\circ} 44' 14''$ to $76^{\circ} 48' 05''$ E longitude. The climate of the area can be classified as sub-humid and sub-tropical. The annual average temperature of the study area is 17° C. The study area is composed of steep to very steeply sloping hills and valleys. Lithologically the area is composed of crystalline rocks formed during Archean period known as Charnokites.

Karso watershed is located in Hazaribagh district of Jarkhand state. Geographically the watershed extends between $24^{\circ} 12' 25''$ to $24^{\circ} 16' 45''$ N latitude and $85^{\circ} 24' 30''$ to $85^{\circ} 28' 00''$ E longitude and is spread over an area of 2570 ha. The climate of the area can be classified as sub-humid and tropical. The annual average temperature is around 23.7° C. The general elevation of the area ranges from 390 m to 670 m above mean sea level (MSL). Lithologically the area is composed of Barakar sandstones and shales.

Harsul watershed is located in Nasik district of Maharashtra state. Geographically the watershed extends between $20^{\circ} 04' 13''$ to $20^{\circ} 07' 03''$ N latitude and $73^{\circ} 26' 00''$ to $73^{\circ} 28' 05''$ E longitude and is spread over an area of 885 ha. The climate of the area can be classified as semi-arid

and tropical. The annual average temperature is around 24.5° C. The general elevation of the area ranges from 360 m to 743 m above mean sea level (MSL). Lithologically the area is composed of Quartzites.

MODEL FORMULATION

In order to formulate a model for predicting the soil loss, a literature survey has been carried out to understand the potentials and limitations of various models keeping the data availability and applicability under India scenario. Based on the availability of meteorological data from most of the observatories, it was felt that an event-based model could do a good job. The following model has been formulated, which is similar to erosion sub-component of EPIC model with a modification in soil erodibility parameter estimation and delimiting the sediment detachment with transport capacity.

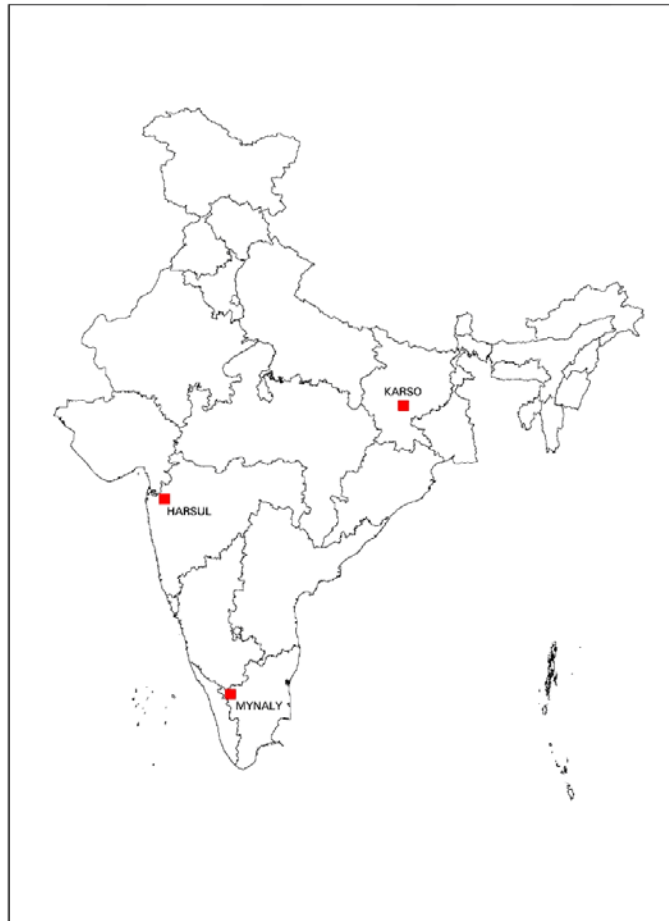


Fig-1. Location map of study areas.

RUNOFF

Owing to simplicity and compatibility with remote sensing and GIS, the runoff component was estimated using SCS curve number method (Maidment, 1992) as follows:

$$Q' = \frac{(P - 0.2 * S)^2}{2.5} \quad \text{if } P > (0.2 * S)$$

$$(P + 0.8 * S)$$

$$Q' = 0 \quad \text{if } P < (0.2 * S)$$

where,

Q' = Runoff (mm)

P = Precipitation (mm)

S = (25400 / CN) - 254

where,

CN = Curve number

The curve numbers could be derived from the information on land use / land cover and hydrological soil groups. The curve numbers are provided for moderate antecedent soil moisture conditions (ASM-II), to convert into ASM-I and ASM-III conditions, regression equations are developed from the data available in the Hand book of Hydrology using Curve fit software.

$$CN-I = 0.3358 * 1.009^{CN-II} * CN-II^{1.038} \quad r^2 = 0.9998$$

$$CN-III = 3.5610 * 0.9961^{CN-II} * CN-II^{0.8101} \quad r^2 = 0.9999$$

where, CN-I, -II, -III represents curve numbers for antecedent moisture condition I, II and III respectively.

To compute the total runoff over the grid cell, in cubic meters,

$$Q = (Q' / 1000) * \text{grid cell area (in m}^2\text{)}$$

Peak runoff rate :

The peak runoff rate (Q_p) can be computed as suggested in EPIC model:

$$Q_p = 3.97 * A^{0.7} * S^{0.16} * (Q / 25.4)^{0.903} * A^{0.017} * LW^{-0.19}$$

where,

A = Area of the cell (km^2)

S = Length of the cell along slope (m/km)

Q = Runoff depth (mm)

LW = Length to width ratio of the cell

All the grid cells in the present study are square cells having length to width ratio of 1.0.

EROSION

The erosion component was divided into detachment, transport capacity and net detachment. Details are given here under:

Detachment (D):

To compute detachment of soil particles Universal Soil Loss Equation (USLE) or its variants were often used with a modification in energy component. We have assumed that the surface runoff is the major component that governs the soil detachment and its transport. Hence we retained the basic structure of Revised Universal Soil Loss Equation (RUSLE) as:

$$D = \lambda * K * LS * C * P$$

Where,

D = Soil loss
 λ = Erosive energy component
K = Soil erodibility factor
LS = Slope length factor
C = Cover factor
P = Erosion control practice factor

The λ component could be explained by modifications as suggested by various authors as (from Erosion Productivity Impact Calculator (EPIC) model documentation):

$$\lambda = 11.8 * (Q * Q_p)^{0.56} \quad \text{For MUSLE (Modified Universal Soil Loss Equation)}$$

$$\lambda = 2.5 * (Q * Q_p)^{0.5} \quad \text{For MUST (Theoretically derived version of MUSLE)}$$

$$\lambda = 0.79 * (Q * Q_p)^{0.65} * A^{0.009} \quad \text{For MUSS (Small watershed version of MUSLE)}$$

Where,

Q = Storm runoff volume (m³)
Q_p = Peak runoff rate (m³/sec)
A = Area of the grid cell (ha)

The other parameters like C, LS, P factors were computed as defined in the RUSLE manual using RUSLE software. In the EPIC model documentation, the soil erodibility was determined through RUSLE equations. However, de Roo (1993), from his experiments, found that the soil erodibility factor could be better explained by the equation suggested by Martin (1988), since it accounts for cation composition responsible for sediment suspension and stoniness of the soil.

$$K = [0.0006 * \gamma * (1.0 + 0.0015 * \alpha * \beta) * (12 - \mu) + 0.021 * (k + na)] * e^{-0.05 * \tau}$$

where,

γ = Silt content (%)
 β = Clay content (%)
 α = Sand content (%)
 μ = Organic matter content (%)
 τ = Stone cover (%)
k = Exchangeable Potassium (%)
na = Exchangeable Sodium (%)

Since the influence of stone cover is accounted in the K-factor estimation, it was not included in the cover factor. Hence only, surface cover influence has been considered while computing C-factor.

Transport Capacity (T):

It is well known phenomenon that all the detached sediment will not be transported till the end of watershed. It depends on the transport capacity of the flow. Two equations are available in the literature to explain the transport capacity of the flow– one given by Yalin (1963) and the other one developed by Kirkby (1985). In the present study, the transport capacity equation given by Kirkby (1985) was used as it accounts for surface cover variations.

$$T = Q^d * C * \sin(S) * 10^{-6} * A$$

Where,

T = Transport capacity of the flow (tons)

Q = Runoff (mm)

C = Cover factor (dimensionless)

S = Slope of the land element (%)

A = Area of the cell (m²)

Net Detachment (N):

It is true that all the sediment detached will not be transported down the stream. The transport capacity of the cell limits the net detachment and the detachment excess of transport capacity will be deposited in the cell under consideration. As the transportation of sediment detached (D) is limited to the transporting capacity, the net detachment (N) from the cell will be:

$$\begin{array}{ll} N = D & \text{if } (D \leq T) \\ N = T & \text{if } (D > T) \end{array}$$

Flow routing:

For simplicity of computation we have adopted steepest descent method for routing the flow, where the steepest cell receives the entire flow. The flow and the sediment will be accumulated at the end of the watershed to give the net estimate of sediment and runoff.

GENERATION OF INPUT DATA

In the present study, multi-spectral remote sensing data was used to derive the information of land use / cover and spatial distribution of soil types. The digital elevation model (DEM) of various watersheds was generated by interpolating the contours provided in Survey of India topomaps. For Mynaly watershed, Landsat-TM data of 1st November, 1999 covered by path-144 and row-52 was procured in the form of digital data. For Karso watershed, Landsat-TM data of 11-10-1996 covered by path-140 and row-43 was used. Whereas, the IRS-1C LISS-III data covered by path-94 and row-58, acquired on 23-October-97 was the satellite data set for Harsul watershed. Due to cloud cover problem, the data during July and August months could not be procured.

The rainfall, runoff and sediment concentration data forms the hydrological data used in the study, which was provided by the Indo-German Bilateral Project office, New Delhi. The rainfall, runoff volume and sediment data was collected at 30 minutes to one hour frequency at respective silt monitoring stations. For computing runoff volume and sediment yield of an event the observed values were summed up over the event duration.

In the present study, ERDAS Imagine 8.4 software was used for geometric registration of satellite data, maps and for visual interpretation of satellite data. For overlaying of thematic maps, DEM generation and hydrological modeling, GRID module of ARC/INFO 7.3 is used since the estimation of sediment yield involves cell-by-cell processing and flow routing. For geometric registration of the raw satellite data and digitization of contours, Calcomp Drawing board-II (A0 size)

digitizer was used. Magellan's Promark-X GPS was used for recording the precise location of ground observation points and location of silt monitoring stations.

To begin with, the satellite data corresponding to the silt monitoring events has been geometrically corrected by selecting tie-points between Survey of India (SOI) topomaps and uncorrected satellite data. A second order polynomial function was fitted on thus collected tie points and the uncorrected satellite data was resampled using nearest neighbor algorithm. To maintain uniformity between IRS-1C LISS-III (24m spatial resolution) and that of Landsat-TM (30m), a common spatial resolution of 30 meters has been selected. Besides, the contour information and drainage network provided in topomaps were used in digital form after labeling them appropriately.

Subsequently, contours and drainage network digitized from topomaps were interpolated using *topogrid* command (ARC/INFO) and DEM of the study area was generated. This DEM was subsequently used to generate slope and slope length (LS) factor. To generate the spatial distribution of the other input parameters namely, curve numbers, cover factor, soil erodibility factor and management factor, the satellite remote sensing data was used. Initially, geometrically corrected satellite data was interpreted employing monoscopic visual interpretation techniques. Subsequently, the random strips were selected and a detailed ground information on land use / land cover was collected from these random strips. Geographic location of ground truth points has been recorded with the help of GPS as well as topographic maps. To map the spatial distribution of soil properties, the inherent relationship between physiography, lithology, land use / cover information was exploited. The physiographic boundaries were delineated using remote sensing data and topographical maps in conjunction. Subsequently, the land use information was also incorporated and final soilscape unit were delineated. Random sample strips were selected to cover all the possible variations, for further field verification. Information of surface stoniness was also collected along with information of morphological soil characteristics. Soil samples were collected from the representative locations and were labeled appropriately for further analysis in the laboratory. Besides, a detailed account on field conditions, dates of sowing, package of practices, crop type and duration, conservation practices adopted, etc. was also collected. The soil samples collected in the field were analysed for particle separates, organic carbon and other chemical properties like exchangeable sodium and potassium using standard analytical procedures.

After correlating the ground truth information with respect to land cover / use classes, training sets were defined in ERDAS Imagine 8.4 and spectral signatures were generated for various land use / land cover classes. Subsequently, the satellite data was classified using per-pixel Gaussian maximum likelihood classifier into various land use / cover categories. For preparing the soil map, lithology, physiography, soil physical and chemical properties were correlated and final soil mapping units were delineated. The associated soil properties like percentage of particle separates, organic matter, exchangeable sodium and potassium etc., were appended as attributes to the polygon attribute table (PAT). The soil erodibility was computed as another attribute using the erodibility prediction equation given above. This polygon layer with erodibility was converted into grid using *polygrid* command.

Hydrological grouping of soils is important to assign the curve numbers to various land use / cover classes. Based on soil texture information, the soil properties map has been converted into hydrological soil group grid. Then the land use / cover grid was overlaid on hydrological soil group grid to derive curve numbers through a rule-based approach taking into consideration the crop growth stage and field surface conditions. The curve number grid thus generated was used to predict the runoff.

The land use / cover grid was used to derive information of cover factor considering the stage and type of crop. To generate the management practice factor grid, the land use / cover information and ground observations were logically combined. The slope length factor grid is generated from DEM by developing a programme in Arc Macro Language (AML).

RESULTS AND DISCUSSION

The results obtained in the present study were presented and discussed hereunder:

LAND USE / LAND COVER

The spatial information on the land use / land cover forms an important input for the subsequent analysis and generation of derivative information like curve numbers and cover factor and practice factor. Mynaly watershed is predominantly under agriculture (42.8 % of total area) followed by Tea plantations (24.4 %) and grasslands (16.9 %). Dense forests (6.9 %), Eucalyptus (3.6 %) and dense scrubland (5.4 %) are other land cover classes in this area (Table-1). In Harsul watershed, various types of forests occupy 47.2% area. Scrublands (9.7 %) and grasslands (7.9 %) are other major land cover classes. About 4.7% is under thin grass cover. Paddy crop (7.6%), Maize (3.6%) and small grains (18.9%) are the various crops under agriculture. Whereas in Karso watershed forests (16.7%), scrub lands (18.5 %) and croplands (52.1 %) are the major land use / cover categories. Valley bottom is under paddy crop (26.6 %); and uplands under Maize (11.9 %) and small grains like Fox millet and finger millet (13.6%). About 3.3 % area is under gullied land.

Table- 1a. Spatial extent of various land use / cover classes in Mynaly watershed.

SL. NO.	LAND USE / COVER	AREA (HA)	% TOTAL AREA
1	Crop land (vegetables)	580	28.7
2	Fallow land	284	14.1
3	Tea gardens	493	24.4
4	Grassland	342	16.9
5	Forest	140	6.9
6	Eucalyptus	73	3.6
7	Dense scrub	110	5.4
	TOTAL AREA	2022	100.0

Table- 1b. Spatial extent of various land use / cover classes in Harsul watershed.

SL. NO.	LAND USE / COVER	AREA (HA)	% TOTAL AREA
1	Paddy	90	7.6
2	Maize	43	3.6
3	Small grains	223	18.9
4	Thin grassland	56	4.7
5	Grassland	93	7.9
6	Degraded forest	191	16.2
7	Scrub	114	9.7
8	Dense forest	10	0.9
9	Moderately dense forest	355	30.1
10	Settlement	5	0.4
	TOTAL AREA	1179	100.0

Table- 1c. Spatial extent of various land use / cover classes in Karso watershed.

SL. NO.	LAND USE / COVER	AREA (HA)	% TOTAL AREA
1	Water	59	2.3
2	Paddy	686	26.6
3	Dense Forest	429	16.7
4	Scrub	476	18.5
5	Settlement	87	3.4
6	Small grains	349	13.6
7	Poor scrub	96	3.7
8	Maize	305	11.9
9	Gullied land	84	3.3
	TOTAL AREA	2571	100.0

SOIL PROPERTIES

The soil map prepared in this study exploits the strong relationship between soil properties and physiography, climate and land cover. To delineate the lithology, physiography and land cover, the multi-spectral satellite data was found to be of immense use. Especially delineation of physiography and land cover information is much clearer on satellite data. The range in soil properties of all the three watersheds is provided in Table-2. The soils of Harsul watershed are more sandy and have more rock fragments owing to their origin from quartzite parent material. Though we have used the Martin's equation for estimating the soil erodibility which incorporates cation concentration, the lower cation concentrations in soils of all the three watersheds don't warrant for using this equation. Nevertheless, its usage could be justified for its applicability in watersheds with salt-affected soils, that too those with high sodium content, which is a common problem in India. Furthermore the soils of all the three watersheds are poor in organic matter content, except for their counterparts in forest regions.

Table-2. Range of soil properties.

SL. NO.	SOIL PROPERTY	MYNALY	HARSUL	KARSO
1	Sand (%)	28.5 – 81.5	30.5 – 88.9	44.8 – 76.6
2	Silt (%)	12.5 – 46.2	11.5 – 21.2	8.2 – 28.1
3	Clay (%)	6.0 - 30.4	3.8 – 26.7	5.4 – 35.4
4	Texture class	Loamy sand – sandy clay loam	Loamy sand – Sandy clay loam	Loamy sand to clay loam
5	Organic matter (%)	0.95 – 3.86	0.20 – 2.15	0.28 – 3.05
6	Exchangeable sodium (%)	0.12 – 0.24	0.05 – 0.45	0.08 – 0.38
7	Exchangeable potassium (%)	0.08 – 0.25	0.04 – 0.30	0.07 – 0.35
8	Rock fragments (%)	0.0 – 10.0	0.0 – 25.0	0.0 – 8.0
9	Erodibility Factor	0.14 – 0.72	0.19 – 0.69	0.26 – 0.62

TERRAIN PROPERTIES

The terrain properties were assessed from area statistics of slope (Table-3). Mynaly watershed has slope ranging from 0.05 per cent to 84.7 per cent with a mean of 29.0 per cent. The Harsul watershed has slope ranging from 0.04 per cent to 77.8 per cent with a mean of 21.1 per cent, whereas in Karso watershed, the slope ranges from 0.05 per cent to 80.9 per cent with a mean of 7.8 per cent. A comparison of above statistics speaks that Karso watershed is relatively flat compared when to other two watersheds. Mynely watershed has relatively larger area under steeply sloping areas.

Table – 3a. Area under various slope categories in Mynaly watershed.

SL. NO	SLOPE CLASS	AREA (HA)	PER CENT TOTAL AREA
1	0 - 3 %	29.34	1.45
2	3 - 5 %	38.97	1.93
3	5 – 10 %	119.16	5.89
4	10 – 15 %	153.18	7.57
5	15 – 25 %	477.99	23.63
6	25 – 33 %	450.27	22.27
7	33 – 50 %	604.71	29.91
8	> 50 %	148.77	7.36

Table – 3b. Area under various slope categories in Harsul watershed.

SL. NO	SLOPE CLASS	AREA (HA)	PER CENT TOTAL AREA
1	0 - 3 %	106.29	9.01
2	3 - 5 %	84.87	7.19
3	5 – 10 %	140.94	11.94
4	10 – 15 %	118.53	10.04
5	15 – 25 %	261.45	22.16
6	25 – 33 %	222.30	18.84
7	33 – 50 %	218.43	18.51
8	> 50 %	27.27	2.30

Table – 3c. Area under various slope categories in Karso watershed.

SL. NO	SLOPE CLASS	AREA (HA)	PER CENT TOTAL AREA
1	0 - 3 %	1111.77	43.24
2	3 - 5 %	552.33	21.48
3	5 – 10 %	438.75	17.07
4	10 – 15 %	106.02	4.12
5	15 – 25 %	132.12	5.14
6	25 – 33 %	76.05	2.96
7	33 – 50 %	112.32	4.37
8	> 50 %	41.67	1.62

RUNOFF ESTIMATION

The runoff computed from SCS - curve number method was compared with the *in situ* measurements (Table-4 and Fig-2a). In general, the runoff as computed from SCS curve number method resulted into over estimation, in majority of the cases. It was also observed that the runoff computed from curve number method is highly influenced by the antecedent moisture conditions, since it greatly influences the curve number selection. A further analysis of these deviations revealed that the deviations are of very small magnitude when the field conditions are smooth and large deviations were observed when the field conditions are rough / ploughed. This is probably due to the limitation of the parameterization of surface roughness in the SCS curve number method. In order to circumvent the problem of over estimation of runoff from the rough fields, a random surface parameter was introduced as provided in LISEM model (de Roo *et al*, 1996). Thus the runoff can be computed as:

$$Q' = \frac{(P - 0.2 * S)^2}{(P + 0.8 * S)} - \Phi \quad \text{if } P > (0.2 S - \Phi)$$

$$Q' = 0 \quad \text{if } P < (0.2 S - \Phi)$$

where,

Q' = Runoff (mm)
P = Precipitation (mm)
 Φ = Depression storage (mm)
S = (25400 / CN) - 254
CN = Curve number

$$\Phi = 0.112 * R + 0.031 * R^2 - 0.012 * R * s$$

where,

R = Random roughness (cm)
s = Slope gradient (%)

Table-4. Runoff prediction using original curve number method

EVENT NO.	EVENT	RAINFALL (MM)	5-DAY ANTECEDENT RAINFALL (MM)	MEASURED RUNOFF (M ³)	PREDICTED RUNOFF (M ³)	ABSOLUTE DEVIATION FROM MEASURED
	MYNALY					
1	13-21 Oct., 1999	103.3	24.5	162,238	402,031	239793
2	23-26 Oct., 1999	76.6	23.2	109,103	193,393	84290
3	29-30 Nov., 1999	76.0	30.1	97,492	189,435	91943
4	22-24 Dec., 1999	44.0	0.0	52,824	98,038	45214
	HARSUL					
5	04-09 Aug., 1997	68.6	302.5	49,408	53,633	4225
6	13-18 Aug., 1997	59.1	19.1	5,632	37,306	31674
7	19-28 Aug., 1997	324.3	46.8	1,227,292	1,532,895	305603
	KARSO					
8	16-19 July, 1995	16.5	19.2	23,234	23,647	413
9	20-26 July, 1995	53.5	16.5	26,221	251,592	225371
10	29-31 July, 1995	17.2	12.6	2,011	26,151	24140
11	01-02 Aug., 1995	32.4	17.2	54,430	100,226	45796
12	03-08 Aug., 1995	78.8	49.6	351,458	492,362	140904
13	21-25 July, 1996	81.0	28.8	541,223	515,883	-25340
14	07-11 Aug., 1996	109.5	154.3	736,058	848,530	112472

The results after accounting for surface depression storage are presented as Table-5 and Figure-2b, which showed a significant reduction in the predicted runoff and are in good agreement with the observed runoff. The standard error of runoff estimate was also reduced from 89,999 m³ of the original CN method to 9,231 m³ in the modified CN method after incorporation of surface depression storage parameter. The major problem encountered is in assigning the random roughness spatially. However, in the present study the random roughness was assigned as per the guidelines provided in RUSLE manual by taking into account the soil conditions, general package of practices of the area coupled with ground survey. It would have been more precise to derive the random roughness from an active radar data. Nevertheless, the above methodology has also yielded satisfactory results, since the cultivation practices are almost same with in a small watershed area, especially under rainfed agriculture.

Table-5. Predicted runoff after accounting for surface roughness conditions

EVENT NO.	EVENT	MEASURED RUNOFF (M ³)	PREDICTED RUNOFF (M ³) [ORIGINAL CN METHOD]	ABSOLUTE DEVIATION FROM MEASURED	PREDICTED RUNOFF (M ³) [AFTER ACCOUNTING ROUGHNESS]	ABSOLUTE DEVIATION FROM MEASURED
	MYNALY					
1	13-21 Oct., 1999	162,238	402,031	239793	165,448	3210
2	23-26 Oct., 1999	109,103	193,393	84290	111,414	2311
3	29-30 Nov., 1999	97,492	189,435	91943	98,336	844
4	22-24 Dec., 1999	52,824	98,038	45214	56,919	4095
	HARSUL					
5	04-09 Aug., 1997	49,408	53,633	4225	53,633	4225
6	13-18 Aug., 1997	5,632	37,306	31674	4,696	-936
7	19-28 Aug., 1997	1,227,292	1,532,895	305603	1,194,674	-32618
	KARSO					
8	16-19 July, 1995	23,234	23,647	413	23,647	413
9	20-26 July, 1995	26,221	251,592	225371	26,627	406
10	29-31 July, 1995	2,011	26,151	24140	3,448	1437
11	01-02 Aug., 1995	54,430	100,226	45796	53,823	-607
12	03-08 Aug., 1995	351,458	492,362	140904	357,742	6284
13	21-25 July, 1996	541,223	515,883	-25340	515,883	-25340
14	07-11 Aug., 1996	736,058	848,530	112472	745,253	9195

The runoff thus computed for each cell was stored in the form of ARC/INFO grid and was subsequently used as input to compute detachment as well as transport capacity.

SEDIMENT YIELD ESTIMATION

The detachment computed from all the three equations showed a positive relationship to the measured sediment yield in Mynaly watershed (Event-1 to 4). However, the computed detachment was highest in magnitude for RUSLE followed by MUST and MUSS. This is due to the variation in the modulating factors of detachment used in the three equations. The transport capacity is computed from Kirkby's equation. Combining the detachment and transport capacity logically, as mentioned in the methodology, led to the computation of the sediment yield (Table-6). A comparison of the thus obtained sediment yield (Fig-3) reveals that the best results were obtained with RUSLE equation followed by MUST and MUSS, indicating that the modulating detachment factors are more appropriate to account for the variations in the predictions of the sediment yield in the hilly watershed. In case of Harsul watershed all the three equations comparably predicted the sediment yields (event-5 to 7) indicating the validity modulating detachment factors in all the three equations. This is due to the reason that the watershed covers both hilly as well as plain portions almost in equal proportions. Where as in case of Karso watershed (event-8 to 14), the predicted sediment yield from all the three equations was unsatisfactory because the predicted transport capacity is too low since this watershed is mostly a gently to moderately sloping terrain.

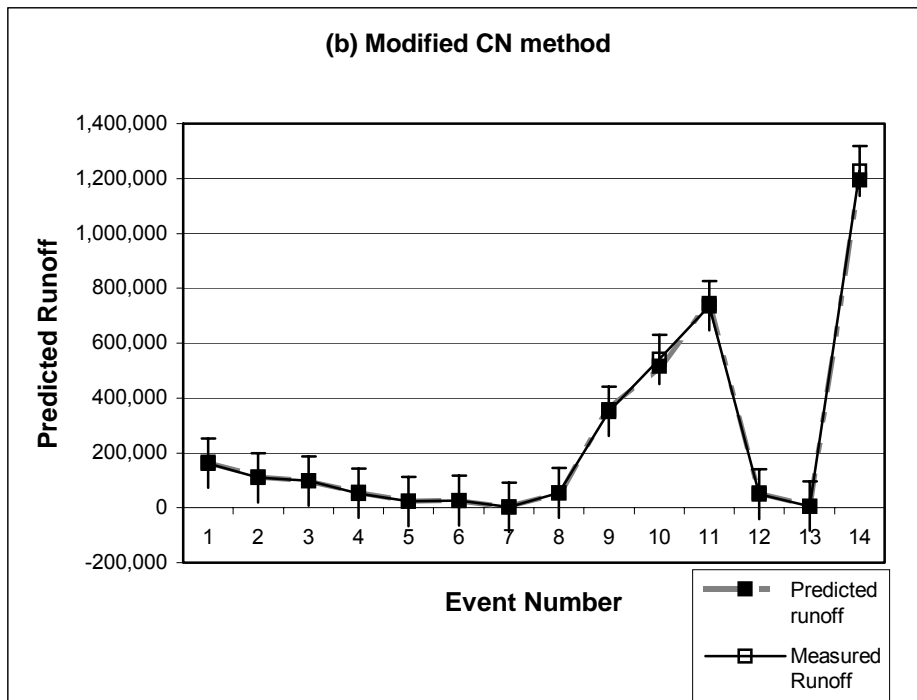
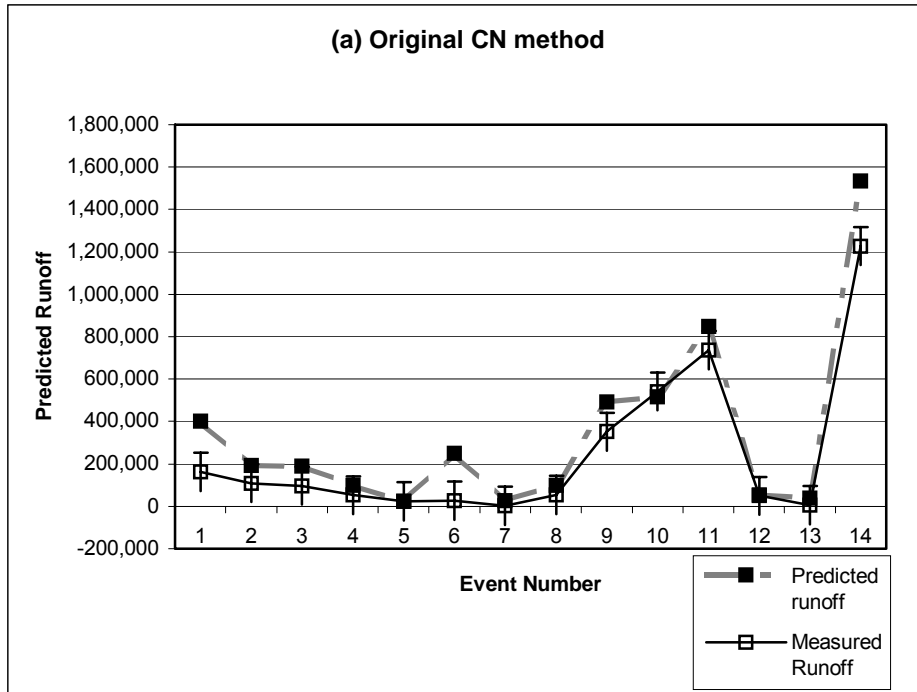


Fig-2. Runoff predicted from original SCS curve number method and modified curve number method.

Among the three equations used, RUSLE was able to provide better predictions when the sediment loss is of moderate quantities coupled with high runoff. Under conditions of low to moderate runoff states, all the three equations poorly performed in computation of sediment yield. Under these

conditions the transport capacity of the sediment was also very less. This implies that the current transport capacity as well as the runoff has to exceed a critical threshold for these equations to predict the sediment yield. The observed results indicate that the RUSLE equation is able to predict the sediment yields in a better way, as its modulating factors are more appropriate to address these conditions.

The standard error of sediment yield estimate of Mynaly watershed alone is 24 tons using RUSLE, 31 tons using MUSS and for MUST it is 40 tons; whereas for Harsul watershed, the values are 1, 8 and 2 tons, respectively. In Karso watershed, the SEE values are 145, 69 and 119 tons for RUSLE, MUSS and MUST, respectively. From this analysis, it is clear that the sediment yield predictions from RUSLE equation are consistently low. A flow chart depicting the proposed methodology is appended as Fig-4.

SENSITIVITY ANALYSIS

Sensitivity analysis is performed for one event for all the influencing parameters that are used in the above model. The predicted sediment yield for the event considered for sensitivity analysis is 175 tons. The parameter values under grid cell were uniformly altered by –20 per cent to + 20 per cent. It was assumed that the variations in the estimation of these parameters would vary uniformly. The sensitivity analysis shows that the runoff, cover factor and slope are influencing both detachment as well as transport capacity whereas, soil erodibility, practice parameters influence only detachment. The peak rate of runoff will influence only detachment. Out of all the parameters, the runoff parameter is most sensitive parameter and could cause variations in the sediment yield to the tune of 36% negative change, if it varied by –20% and a positive change to the tune of 43%, if it is varied by +20%. The cover factor could bring 20% negative change and 19% positive change, when it is varied from –20% to +20%, respectively. The slope factor could bring out 19% positive change and 18% negative change for the same set of variations. The soil erodibility and practice factor have not brought any change in the final output. This analysis has shown that sufficient caution needs to be exercised while estimating the sensitive runoff parameters i.e., curve number and depression storage.

SUMMARY AND CONCLUSIONS

A study has been conducted to synergistically exploit the merits of remote sensing and GIS techniques to model soil erosion along with collateral data in three typical watersheds characterized by varying topographic and cover conditions. Soil and land use / land cover maps as derived from multispectral satellite data were used for generation of parameter grids required to run the model.

From the results it was observed that the runoff, which was estimated using Curve Number (CN) method, was over estimated especially under ploughed filed conditions. Hence, surface depression storage parameter was introduced into curve number method, which resulted in significant improvement in runoff prediction. The detachment was computed from the three equations namely, RUSLE, MUSS and MUST and transport capacity from Kirkby's equation. In case of Mynaly and Harsul watersheds, which are hilly, the sediment yield predictions were in agreement with the observed sediment yields. However, in Karso watershed higher deviations were observed. This is attributed to the plain topography of the watershed, where Kirkby's transport capacity equation could not explain the sediment transport completely. Of the three equations – RUSLE, MUSS and MUST used, RUSLE has performed the best by consistently yielding lower standard error of estimates in all the three watersheds. The sensitivity analysis carried out indicated that the runoff is a very sensitive parameter followed by slope.

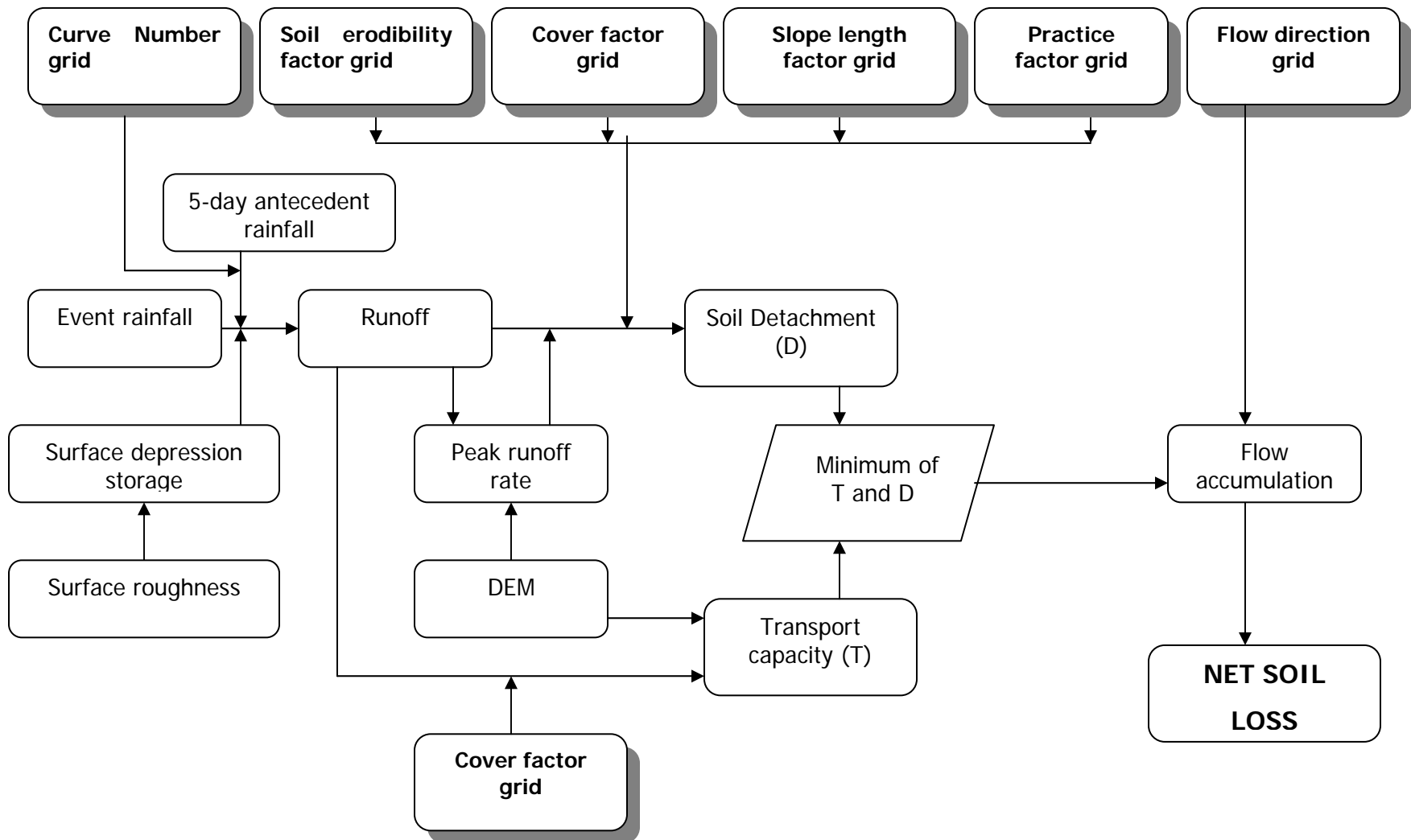


Fig-4. Flow chart for the proposed methodology.

In the present study DEM was generated from contours of 20m interval. Though it was found to be useful, the precise estimation of slope parameter calls for high quality DEMs. With the developments in the space technology it is expected to generate meter and sub-meter level accurate DEMs, which would enable in retrieval of slope parameter more precisely, with corresponding improvement in sediment yield prediction.

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