Cloud Publications
International Journal of Advanced Remote Sensing and GIS
2016, Volume 5, Issue 1, pp. 1471-1482
ISSN 2320 - 0243, Crossref: 10.23953/cloud.ijarsg.39

Research Article **Open Access**

Soil Erosion and Sediment Yield Analysis Using Prototype & Enhanced SATEEC GIS System Models

Narasayya Kamuju

CWPRS, Pune, Maharashtra, India

Publication Date: 9 January 2016

DOI: https://doi.org/10.23953/cloud.ijarsg.39

Abstract Rapid propagation of soil erosion is a severe worldwide problem because of its economic and environmental impacts. Thus various efforts have been made to evaluate soil erosion and sediment yield spatially and temporarily to develop effective soil erosion best management practices. To effectively estimate soil erosion and to establish soil erosion management plans, many computer models have been developed and used. In the past couple of decades, these soil erosion models have been integrated with Geographic Information System (GIS) for spatiotemporal analysis of generation and transport of soil erosion and sediment. The Revised Universal Soil Loss Equation (RUSLE) has been used in many countries, and input parameter data for RUSLE have been well established over the years. Thus, the GIS-based Sediment Assessment Tool for Effective Erosion Control (SATEEC) was developed to estimate soil loss and sediment yield for any location within a watershed using RUSLE and a spatially distributed sediment delivery ratio. In this paper SATEEC GIS System Ver.1.6 and version 1.8 were used for estimation of soil erosion and sediment yield. Moore & Burch 'LS' factor method and slope based SDR were used for estimation of soil erosion and sediment yield. The simulation results are reveals that SATEEC ver.1.6 exhibits 3 times more in quantity of soil erosion and sediment yield to SATEEC ver. 1.8.
Keywords *SATEEC GIS System; R-Factor; RUSLE; Land Use/Land Cover; DEM*

1. Introduction

Basically, soil erosion is a natural process by which materials are entrained and transported across the surface. As such, soil loss is the amount of material removed from a particular slope due to changes in topography, vegetation, and soil characteristics. Therefore, assessment of sediment yield is necessary to quantify the amount of eroded material that is actually transported from plot, field, channel or watershed [15]. Many soil erosion models like Universal Soil Loss Equation (USLE) [17], Soil and Water Assessment Tool (SWAT) [2], Water Erosion Prediction Project (WEPP) [3], and European Soil Erosion Model (EUROSEM) [9] have been developed to estimate soil erosion. Geographical Information System (GIS) enable users to analyze and manipulate the spatial data easily and it also helps users to identify the spatial locations vulnerable to soil erosion [7]. USLE Model has been widely used because the model is relatively easy to implement and its input data are available in most countries [11]. Therefore USLE model has been integrated with GIS for spatio-temporal analysis of soil erosion by many researchers worldwide [18]. A GIS integrated prototype version of the 'Sediment Assessment Tool for Effective Erosion Control (SATEEC) [6] was developed with GIS interface to estimate soil erosion and sediment yield without additional input parameters other than those for the USLE model. With simple thematic maps as used for USLE, the SATEEC GIS system can estimate soil erosion and sediment yield at any point within the watershed. To reflect precipitation pattern for soil erosion estimate monthly and annual the enhanced SATEEC Ver. 1.8 was utilized. The most useful modification in SATEEC ver. 1.8 is time-variant soil erosion simulation with temporal USLE factors to reflect surface condition of land and precipitation in the form of 'C' and 'R' factors [11]. In the present study soil erosion estimation and sediment yield comparison has been performed using SATEEC GIS System Versions 1.6 and 1.8. For soil erosion calculations Moore & Burch method used for calculation of 'LS' factor for both versions of SATEEC GIS System models. To compare sediment yield slope based module was used for SATEEC GIS System Ver. 1.6 and Ver. 1.8 models.

2. Study Area

The study area is located in the western part of Doon valley, Dehradun district and Uttaranchal state in India. The sub-watershed 'SitlaRao', which is a sub-basin in 'Asan' watershed, is selected to run the erosion model. It belongs to Asan river system, which is tributary of Yamuna River. Geographical location of the study area covers (a total of) an approximately 50 sq km and lies between 77^{o}45'33" and 77^{o}57'46"and 30^{o}24'39" and 30^{o}29'05" as shown in Figure 1. The sub-basin of Sitlarao falls in SOI toposheet map no. 53F/15. The study area falls in western part of the Doon valley of Dehradun district having large area under hilly tract. The climate is humid to sub-tropical varying from valley to the high mountain ranges of Himalayas. During rainy season 1625 mm rainfall is observed in the year 2004. The mean temperature Ranges from 15.8^{o} in winters to 33.3^{o} in summer. The area has a favorable climate for the growth of abundant vegetation due to reasonably good rainfall & elevation Dense & moderate mixed forest, shrubs, agriculture crops. In the study area river terraces are mainly confined to narrow river valley and consisted of alluvium parent material derived from lesser Himalayas & comprises of sedimentary and meta-sedimentary rocks. It composed of gravels, pebbles, cobbles & boulders mainly of quartzite with fine sandy & silty matrix and fragments of shale, slate, phyllite, limestone, sandstone etc. Soils of the study area are found to be derived from alluvium parent material. These were observed, well to excessively drain with low to medium permeability and having texture sandy loam to clay loam with low to medium productivity.

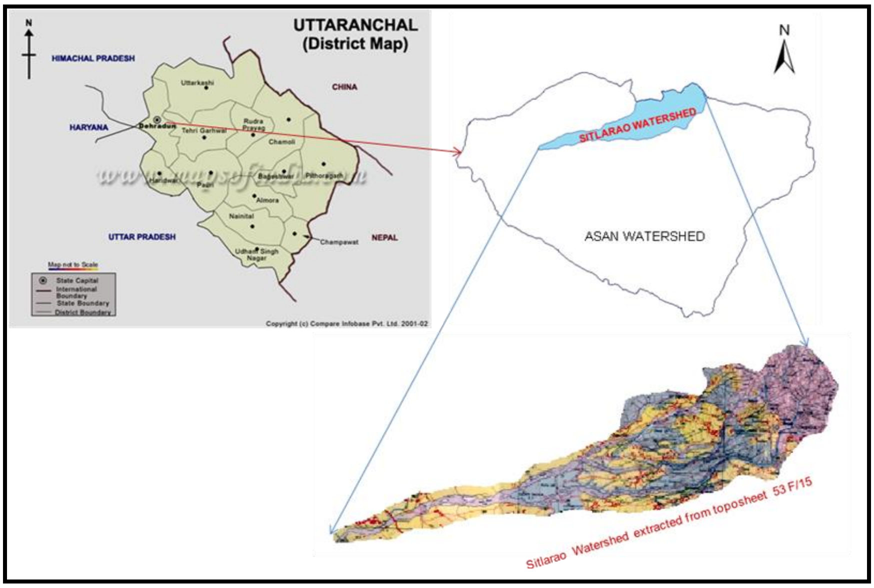

Figure 1: *Location Map of Sitlarao Watershed*

3. Materials

The successful running of the model depends on the preparation of data in the form of thematic layers. Basically SATEEC model required boundary map of the study area, digital elevation model (DEM), Land uses-land cover and soil data. Based on this basic data, thematic layers are prepared in ArcGIS environment and ERDAS imagine software. These thematic layers named as Rain erosivity factor map (R-factor), Soil erodability factor map (K-factor), Crop cover factor map (C-factor), Crop management factor map (P-factor). From DEM the 'LS factor' map derived from Moore & Burch method by SATEEC GIS system itself. All the thematic layers are arranged in Figure 2 as shown.

3.1. Climatic Data

Climatic data prepared from rain gauge stations available in the Sitlarao watershed. In order to prepare Rfactor map, rainfall data available from a Self-recording rain gauges at Langha village [5]. From the average annual rainfall, 'R-factor' is calculated from raster calculator available in spatial analyst tool. The rain gauge available in the watershed is shown in Figure 2a.

3.2. Soil Data

Soil data gathered form textural properties of soils covered in the watershed. A soil thematic layer prepared by using soil data available from Sitlarao watershed. A polygonised soil map prepared based on the types of soils covered in the catchment as shown in Figure 2b. There are 6 verities of soil textural classes are identified from 'Sitlarao' sub-basin. These are Loam, Silt Loam, Sandy Loam, Sandy clay Loam, Gravelly clay loam, Loam to Sandy Clay Loam. The higher portion of the catchment covered with Loamy soils and a least area of soils are covered with loam to sandy clay loam.

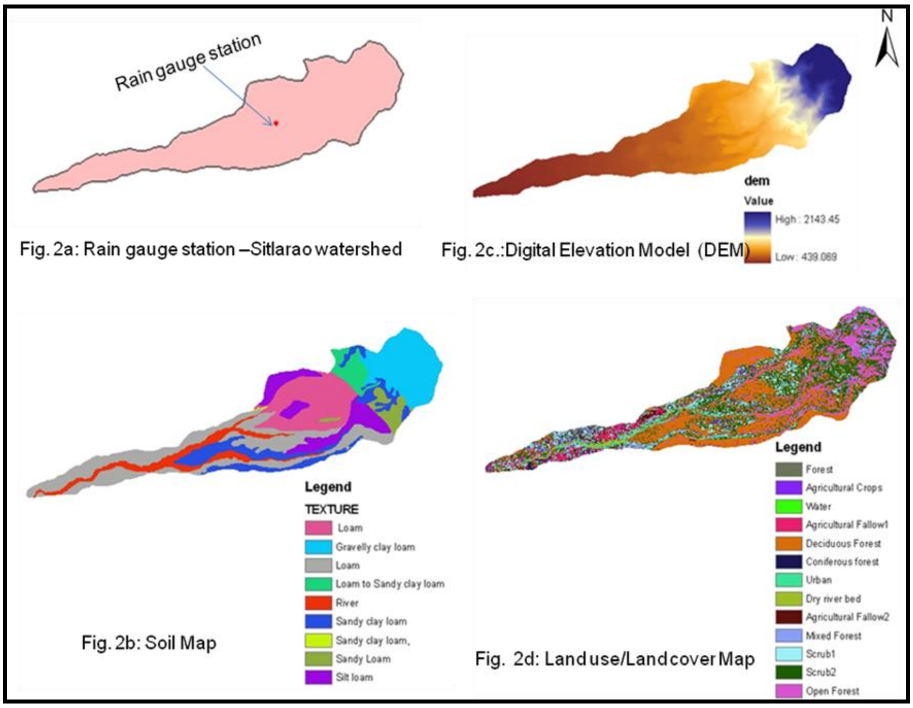

Figure 2: *Input Thematic Layers Prepared for SATEEC GIS System Model*

3.3. Dem

Dem the contour lines having vertical intervals of 20-meters were traced on tracing sheet by visual interpretation method from a toposheet No. 53 F/15 (scale 1:50,000 scale). This manually traced contour map was exported into GIS and digitized to prepare vector layer. Surfacing function in 'Image Interpreter' was used to generate a DEM & to represent as a surface or one-band image file where the value of each pixel was a specific elevation value. A gray scale was used to differentiate variations in terrain as shown in Figure 2c.

3.4. Land Use–Land Cover

Land use classification is prepared using a satellite image of Landsat TM acquired on 14 Nov 2004. There are 7 basic classes are identified under 'supervised classification' with ground truth data in sitlarao watershed as shown in Figure 2d. The basic classes are Agricultural crops, Fallow, Forest, Scrubland, Settlements, dry river bed sand, water and Tea gardens. The Land use-Land cover map is the basis for preparation of Crop cover (C-factor) and Crop Management (P-factor) factor maps.

4. Methodology

Development of effective erosion control plans requires the identification of areas vulnerable to soil erosion and quantification of the amounts of soil erosion from various areas. The RUSLE model does not consider the runoff process explicitly, nor soil detachment, transport, and deposition individually [14]. Eq. (1) shows how the RUSLE computes the average annual soil loss.

Average annual soil loss, $A = R * K * L * S * C * P$ Eq. (1)

Where,
A = average annual soil loss (ton/ha/year)
R = rainfall/runoff erosivity
K soil erodability
LS = slope length and steepness
C = cover management
P = support practice

The R-factor in RUSLE is composed of total storm kinetic energy (E) times the maximum 30 min intensity (I_{30}), and the numerical value of R is the average annual value for storm events for at least 22 years ([15] [17]). Hence, RUSLE cannot be used to estimate soil erosion and sediment yield for a single storm event. Rambabu et al. [13] developed a relationship between EI_{30} and daily and monthly rainfall amounts for Dehradun (India) region as given below:

$EI_{30} = 3.1 + 0.533 * Rd$ (for daily rainfall in mm)
$EI_{30} = 1.9 + 0.640 * R_m$ (for monthly rainfall in mm)

Based on regression equation, R can be determined from Eq. (2)

$R = 22.8 + 0.6400 * Ra$ Eq. (2)

Where,
R = Rainfall erosivity factor (in metric unit), and
Ra = Annual rainfall (mm)

Rain gauges installed at various meteorological observatories give depth of rainfall at that place. This point information can be converted to spatial distribution by IDW method in GIS environment. Once this IDW map is derived then by above formula, R factor map can be drawn and shown in Figure 3a.

RUSLE K factor indicating soil erodibility index (g / J) is the weight of soil detached from the soil mass per unit of rainfall energy. It is integrated effect of the processes that regulate rainfall acceptance and the resistance of the soil to particle detachment and subsequent transport. These processes are influenced by soil particle, of which soil texture is an important factor that influences erodibility. In this study soil erodibility factor are taken from [1].

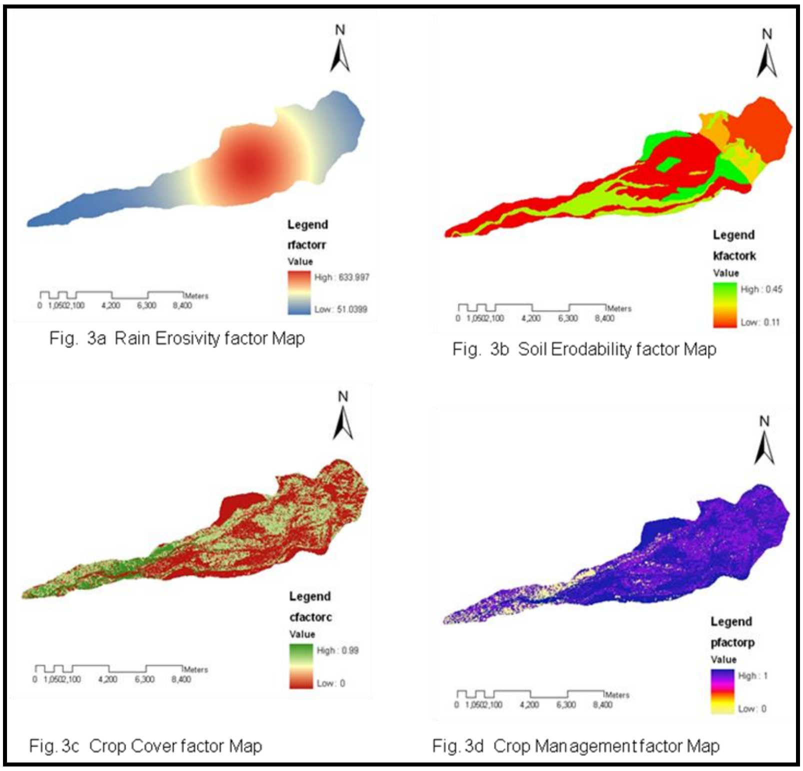

Figure 3: *RUSLE Factor Maps*

SATEEC computed the LS factor map based on DEM and the method suggested by Moore and Burch 1986 [8]. In this study Moore and Burch LS factor is used for the entire computations both in versions of SATEEC GIS system. The length of hill slope in the USLE experimental plots ranged from 10.7 m (35ft) to 91.4 m (300 ft), thus, it was recommended to use of slope lengths less than 122 m (400 ft) because overland flow becomes concentrated into the rills in less than 122 m (400 ft) under natural condition. The equation 3 (Eq. 3) utilized in this study [4].

$$LS = \left(\frac{A}{22.13}\right)^{0.6} \times \left(\frac{\sin\theta}{22.13}\right)^{1.3} \qquad \text{Eq. (3)}$$

Then the RUSLE crop cover management (C-factor) reflects the effects on soil erosion of surface condition of watershed, rainfall drop impact and flow velocity are affected by the surface condition of watershed in real field. It has the range 0 to 1 as a fraction lower value indicates that the surface is covered well so that less soil erosion occurs, while higher value indicates that the surface is covered roughly which has higher possibility of much soil erosion. The prepared C-factor map is shown in Figure 3c. The overall methodology applied is drawn in flow chart and shown in Figure 4.

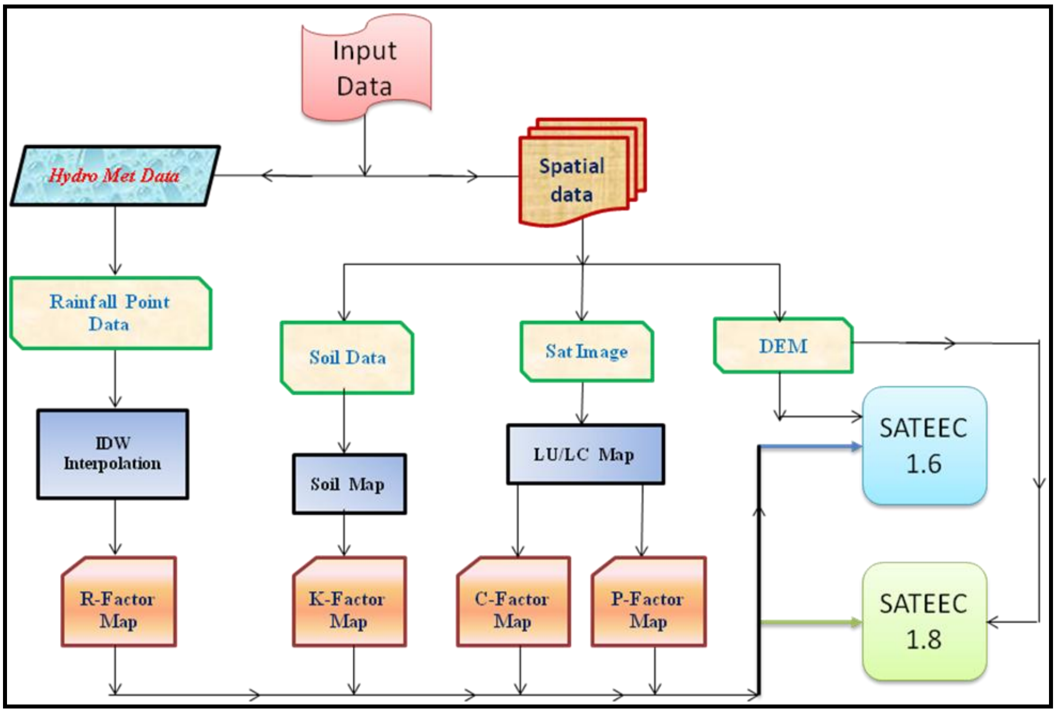

Figure 4: *Flow Chart of Methodology*

Conservation practice factor (P-factor) in the RUSLE model expresses the effect of conservation practices that reduce the amount and rate of water runoff, which reduce erosion. A "P factor" map was derived from the land use/land cover map, and each value of P was assigned to each land use/cover type and slope [1]. The attribute table in ArcGIS was used to reclassify the land use/cover according to its 'P' value. P-factor map which was prepared similar to 'C' factor map. The spatial distribution of P-factor map is shown in Figure 3d.

4.1. SDR

RUSLE is a field scale model, thus it cannot be directly used to estimate the amount of sediment reaching downstream areas because some portion of the eroded soil may be deposited while traveling to the watershed outlet, or the downstream point of interest. To account for these processes, the Sediment Delivery Ratio (SDR) for a given watershed should be used to estimate the total sediment transported to the watershed outlet. The SDR can be expressed from equation 4 as follows

$$SDR = \frac{SY}{E} \qquad \text{Eq. (4)}$$

Where,
SDR = Sediment Delivery Ratio,
SY = Sediment Yield,
E = Gross Erosion for Entire Watershed.

The total soil loss for a given area is not the same as the sediment yield measured at a point of interest, such as a watershed outlet. To explain the possible deposition of eroded materials while they travel to the channel networks and eventually to the watershed outlet, the spatially distributed SDR is computed in the SATEEC GIS system. The SDR is related with physical characteristics of the watershed, such as size and shape of watershed, rainfall patterns, direct runoff, peak runoff, land use, cover crop, slope, particle size, and channel density [10]. Area-based SDR module provides convenience to estimate SDR with limited data collection for a given watershed. The SDR in the watershed is affected by various geomorphologic properties such as average channel slope than watershed area. Thus, slope-based SDR module was incorporated into the SATEEC system to supplement limitation of area-based SDR module. The equation 5 for SDR based on slope of the watershed is given by [16]

$$SDR = 0.627 \ X \ S^{0.403} \qquad \text{Eq. (5)}$$

Where, S is slope of watershed.

However, the SDRs by slope-based SDR module were from 0.553 to 0.999 with varying slope from 0.73 % to 3.17 %. It indicates that the SDR is one of watershed-specific conditions, thus, better ways to estimate SDR needs to be developed based on various characteristics of watershed and measured data, not just based on single parameter such as only area or only slope. Three area based methods are used in SATEEC to compute the spatially distributed SDR map and it is out of scope study to discuss in details. In this study channel slope based-SDR values are utilized for both versions of SATEEC GIS system modules.

5. Application of SATEEC GIS System

The SATEEC GIS system acts as an extension for ArcView GIS 3.2a, with easy to use commands. The SATEEC GIS system estimates annual average soil loss by multiplying all USLE input parameter maps (e.g. R, K, LS, C, and P maps). The two erosion modules consist of SATEEC Soil Loss. All the procedures are fully automated with Avenue, CGI, and database programming; thus the enhanced SATEEC system does not require experienced GIS users to operate the system.

5.1. SATEEC ver. 1.6

The prototype version of the SATEEC GIS system was developed by ‘Kyoung Jae Lim and Bernard A. Engel’ Purdue university to provide an easy to use sediment assessment tool for soil erosion decision makers with Avenue programming within the ArcView GIS software. Thus, with several clicks of the mouse button with SATEEC menus, users can estimate the sediment yield for every cell within a watershed [6]. An overview of the prototype version of the SATEEC GIS system shown in Figure 5. Soil loss is estimated with RUSLE, and a spatially distributed sediment yield map is generated with RUSLE estimated soil loss multiplied by the spatially distributed sediment delivery ratio map.

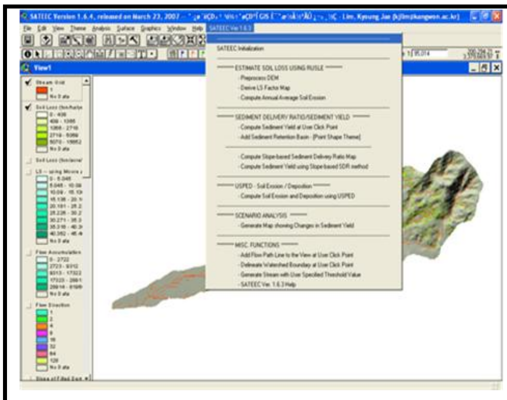

Figure 5: Over view of SATEEC GIS System ver. 1.6

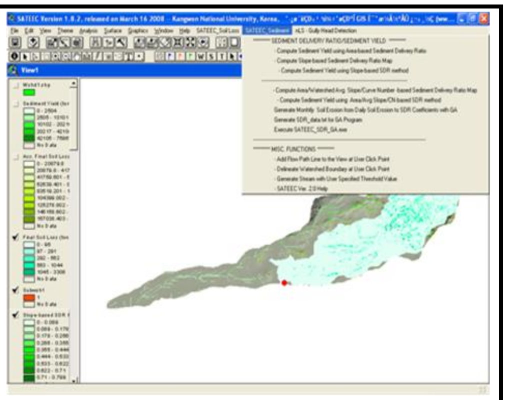

Figure 7: Over view of SATEEC GIS System ver. 1.8

Figure 6: Spatial distribution of Sediment yield map - SATEEC ver. 1.6

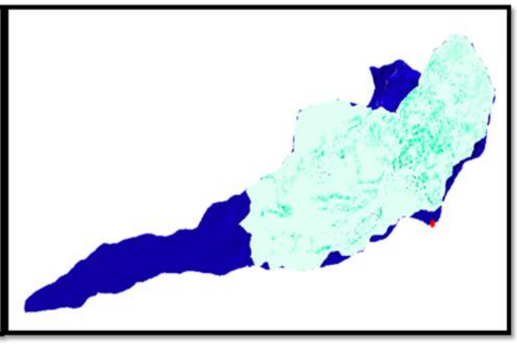

Fig 8: Spatial distribution of Sediment yield map - SATEEC ver. 1.8

The total soil loss for a given area is not the same as the sediment yield measured at a point of interest, such as a watershed outlet. To explain the possible deposition of eroded materials while they travel to the channel networks and eventually to the watershed outlet, the spatially distributed SDR is computed in the SATEEC GIS system. In this study slope based SDR value has been used to compute and thus sediment yield estimated. The result map of sediment yield as shown in Figure 6.

5.2. SATEEC ver. 1.8

In similar way, SATEEC Ver. 1.8 is used for estimation of soil erosion and sediment yield for entire watershed by using Moore & Burch LS factor and channel-slope based SDR. The enhanced version of the SATEEC GIS system provides an overview as shown in Figure 7. The SATEEC estimated soil loss can be used to identify spatial locations vulnerable to soil erosion within the study area. This study carried with slope based SDR value to estimate sediment yield of the sitlarao watershed by dividing the entire basin into 20 sub-basins. The resultant spatially distributed sediment yield map is generated with RUSLE as shown in Figure 8.

6. Results and Discussions

The study aims to evaluate the applicability of an erosion model in mountainous terrain of Sitlarao watershed. In addition, it aims to determine spatial distribution of soil loss and sediment yield to analyze the utilization of different versions of ATEEC GIS system. The soil erosion obtained from SATEEC Ver. 1.6 a maximized value of 11,76,936 (ton/yr) and a lower value of 4,76,328 (ton/yr) soil erosion obtained from SATEEC ver. 1.8. The entire basin is divided into 20 sub-basins. The overall results are summarized and arranged in tabular format shown in Table 1.

Table 1: *Summary of Results from both versions of SATEEC GIS System*

Sub-	Area	SATEEC 1.6			SATEEC 1.8		
Basins	sq. km	SDR	Soil Loss	Sediment Yield	SDR	Soil Loss	Sediment Yield
		slope-based	(ton/yr)	(ton/yr)	slope-based	(ton/yr)	(ton/yr)
1	27.1095	0.9611	911947	361231	0.39611	369399	146323
2	8.9323	0.276256	118205	32654.8	0.276256	47833.8	13214.3
3	9.50371	0.184922	20254.4	3745.48	0.184932	8206.68	1517.76
4	1.61823	0.468864	103664	48604.1	0.468864	41940.1	19664.2
5	0.012642	0.181522	1455.84	264.266	0.181522	589.651	107.034
6	0.279062	0.426928	4538.21	1937.49	0.426816	1836.36	783.788
7	0.23388	0.160657	39.6999	6.37806	0.14811	16.7769	2.48484
8	0.09	0.115591	17.9065	2.06983	0.115591	7.07621	0.81795
9	0.152155	0.17966	51.859	9.31696	0.17966	21.1954	3.80796
10	0.112289	0.106506	64.7158	6.8926	0.106506	25.6139	2.72803
11	0.21129	0.158134	46.9754	7.42839	0.158134	19.2021	3.0365
12	0.206639	0.148857	46.0784	6.8591	0.148857	21.3283	3.17487
13	0.151823	0.0898823	12.7903	1.14962	0.0898823	2.65773	0.238883
14	0.192353	0.124513	37.5737	4.67842	0.124513	14.983	1.86558
15	0.154813	0.18082	37.4408	6.77003	0.18082	15.5145	2.80533
16	0.145179	0.106552	44.3841	4.72924	0.106552	17.736	1.89382
17	0.164115	0.189607	167.072	31.678	0.189607	67.008	12.7052
18	0.112621	0.452129	7757.29	3507.29	0.442986	2835.7	1256.18
19	0.199994	0.402586	8478.03	3413.14	0.402586	3429.93	1380.84
20	0.094682	0.214496	70.2305	15.0641	0.214496	28.1055	6.02851

The highest sub-basin area of 27.10 sq.km contains a soil loss of 911947 (ton/yr) with SATEEC ver. 1.6 and for the same area of sub-basin delivered a soil loss of 369399 (ton/yr). The results obtained from both these SATEEC versions reveals that Prototype of SATEEC ver. 1.6 gives higher values as shown in Figure 9.

In this article slope based sediment delivery ratio value is used to estimate sediment yield at outlet point of the basin. The total sediment yield delivered at outlet of sitlarao basin is 455460 from SATEEC ver.1.6 and comparatively a lower value of 1,84,288 (ton/yr) obtained from SATEEC ver. 1.8. For the higher area of sub-basin, the sediment yield obtained 3,61,231 (ton/yr) from SATEEC ver. 1.6 and for the same area of sub-basin a value of 1,46,323 (ton/yr) from SATEEC ver.1.8. The comparison graph of sediment yield drawn in logarithmic scale for better discrimination visually between these two versions of SATEEC GIS system as shown in Figure 10.

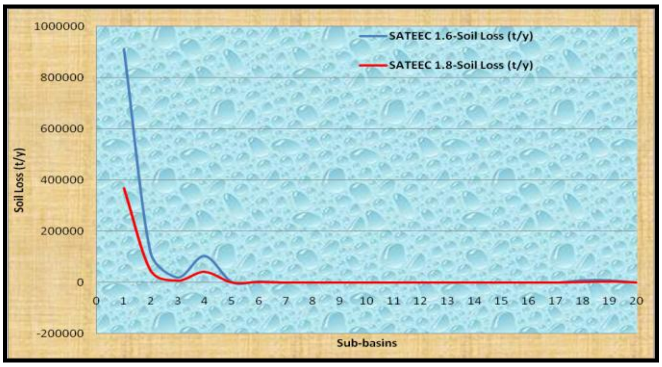

Figure 9: *Soil Erosion Graph - SATEEC ver. 1.6 Vs SATEEC ver. 1.8*

In all 20 sub-basins of sitlarao, SATEEC ver. 1.6 values of sediment yield is higher than SATEEC ver. 1.8.The higher sediment yield occur for higher SDR for SATEEC ver. 1.6. In case of SATEEC ver. 1.8 the highest sediment yield not occurred with highest SDR value. As per the basic equation of SDR, sediment yield is directly proportional to sediment delivery ratio.

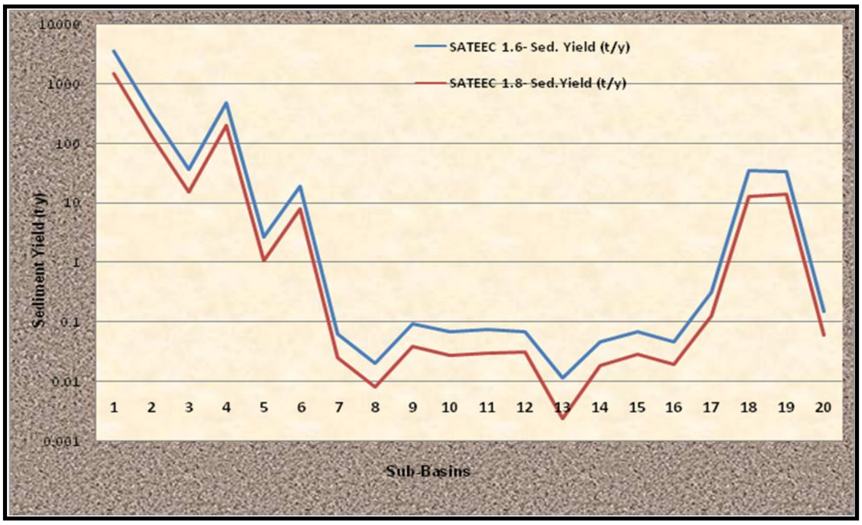

Figure 10: *Sediment Yield Graph - SATEEC Ver. 16 Vs SATEEC ver. 1.8*

As such, a comparative sediment delivery ratio (SDR) graph drawn between SATEEC ver. 1.6 and SATEEC ver. 1.8 as shown in Figure 11. The graph shows that prototype SATEEC version gives higher values at first two sub-basins. And these SDR values are slightly higher values than SATEEC ver. 1.8. A tremendous variation shown in SDR value at first sub-basin as 0.9611 in SATEEC ver. 1.6 and 0.3961 for SATEEC ver. 1.8

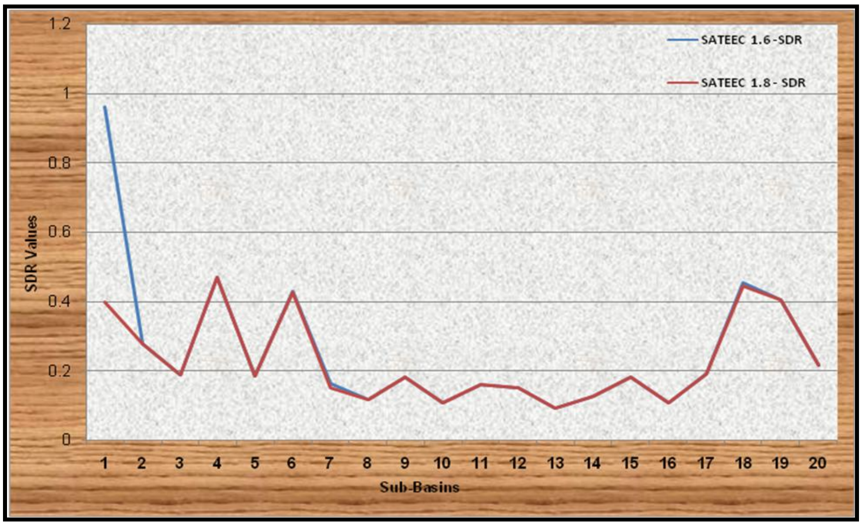

Figure 11: *SDR Graph - SATEEC ver. 1.6 Vs SATEEC ver. 1.8*

7. Conclusions

The Sitlarao watershed which is a sub-watershed of ASAN basin is taken to study for soil erosion and sediment yield using SATEEC GIS systems of versions 1.6 and 1.8. The average annual soil erosion from RUSLE equation obtained nearly 59.52% higher erosion takes place from SATEEC ver.1.6 than SATEEC ver. 1.8. Interestingly, 59.53% more sediment yield obtained than SATEEC ver. 1.8. The overall results reveal that SATEEC ver. 1.6 gives higher values in terms of Average Annual Soil erosion and Sediment yield. The manual calculation of soil erosion and sediment yield using RUSLE for large areas or many sub-basins could be cumbersome and time consuming process, therefore an advanced GIS tool such as SATEEC GIS system is an appropriate application. However, soil erosion decision makers can be used to estimate soil loss and sediment yield, to identify areas vulnerable to soil loss, and to establish efficient erosion control plans with a fully automated menu driven system available in advanced GIS based geospatial tools of SATEEC ver. 1.6 & SATEEC ver. 1.8.

References

[1] Pandey, V.M. Chowdary and B.C. Mal. *Identification of Critical Erosion Prone Areas in the Small Agricultural Watershed Using USLE, GIS and Remote Sensing*. Water Resources Management. 2007. 21. 729-746.

[2] Arnold, J.G., Srinivasan, R., Muttiah, R.S., and Williams, J.R. *Large Area Hydrologic Modeling and Assessment Part I: Model Development.* Journal of American Water Resources Association. 1998 34 (1) 73-89.

[3] Flanagan, D.C., and Nearing, M.A. 1995: *USDA Water Erosion Prediction Project: Hill Slope Profile and Watershed Model Documentation.* NSERL Report No. 10. USDA-ARS National Soil Erosion Research Laboratory, West Lafayette, IN 47907-1194.

[4] Foster, G.R., Renard, K.G., Yoder, D.C., McCool, D.K. and Weesies, G.A., 1996: *RUSLE User's Guide*. Soil and Water Cons. Soc.

[5] Kalpana O. Bhaware, 2006: *Soil Erosion Risk Modelling and Current Erosion damage Assessment using Remote Sensing and GIS Techniques.* M.Tech Thesis. Andhra University, T. 130.

[6] Lim, K.J., Choi, J., Kim, K., Sagong, M., and Engel, B.A. *Development of Sediment Assessment Tool for Effective Erosion Control (Sateec) in Small Scale Watershed*. Transactions of the Korean Society of Agricultural Engineers. 2003. 45 (5) 85-96.

[7] Lufafa, A., Tenywa, M.M., Isabirye, M., Majaliwa, M.J.G., and Woomer, P.L. *Prediction of Soil Erosion in a Lake Victoria Basin Catchment using a GIS-based Universal Soil Loss Model.* Agricultural Systems. 2003. 76; 883-894.

[8] Moore, I. and Burch, G. *Physical Basis of the Length-Slope Factor in the Universal Soil Loss Equation.* Soil Science Society of America Journal. 1986. 50; 1294-1298.

[9] Morgan, R.P.C., Quinton, J.N., Smith, R.E., Govers, G., Poesen, J.W.A., Auerswald, K., Chisci, G., Torri, D., and Styczen, M.E. *The European Soil Erosion Model (EUROSEM): A Dynamic Approach for Predicting Sediment Transport from Fields and Small Catchments.* Earth Surface Processes and Landforms. 1998. 23; 527-544.

[10] Ouyang, D., and Bartholic, J., 1997: *Predicting Sediment Delivery Ratio in Saginaw Bay Watershed.* Proceedings of the 22nd National Association of Environmental Professionals Conference. May 19-23, 1997, Orlando, FL. 659-671.

[11] Ouyang, D., and Bartholic, J., 2001: *Web-Based GIS Application for Soil Erosion Prediction.* Proceedings of an International Symposium—Soil Erosion Research for the 21st Century Honolulu, HI. Jan. 3-5.

[12] Park, Y.S., Kim, J., Kim, N., Kim, K.S., Choi, J., and Lim, K.J. *Analysis of Sediment Yields at Watershed Scale using Area/Slope-Based Sediment Delivery Ratio in SATEEC.* Journal of Korean Society on Water Quality. 2007. 23 (5) 650-658 [in Korean].

[13] Rambabu, Tejwani, K.K., Agrawal, M.C. and Bhusan, L.S., 1979: *Rainfall Intensity Duration-Return Equation and Nomographs of India*. CSWCRTI, ICAR, Dehradun, India.

[14] Renard, K.G., Foster, G.R., Yoder, D.C., and McCool, D.K. *RUSLE Revisited: Status, Questions, Answers, and the Future.* Journal of Soil Water Conservation. 1994. 49; 213-220.

[15] Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., and Yoder, D.C., 1997: *Predicting Soil Erosion by Water: A Guide to Conservation Planning With the Revised Soil Loss Equation (RUSLE).* U.S. Dept. of Agriculture, Agric. Handbook No. 703.

[16] Williams, J.R., and Berndt, H.D. *Sediment Yield Prediction Based on Watershed Hydrology,* Trans. of the ASAE. 1977. 20; 1100-1104.

[17] Wischmeier, W.H., and Smith, D.D. 1978: *Predicting Rainfall Erosion Losses. A Guide to Conservation Planning.* The USDA Agricultural Handbook No. 537.

[18] Yitayew, M., Pokrzywka, S.J., and Renard, K.G. *Using GIS for Facilitating Erosion Estimation.* Applied Engineering in Agriculture. 1999. 15 (4) 295-301.