International Journal of Tropical Agriculture
Volume 39, Number (4) • 2021 : pp. 353-364
ISSN: 0254-8755

ESTIMATION OF SEDIMENT YIELD, SEDIMENT DELIVERY RATIO (SDR) AND SEDIMENT TRANSPORT INDEX (STI) IN GODAVARI RIVER BASIN OF ANDHRA PRADESH, INDIA USING REMOTELY SENSED DATA AND SWAT HYDROLOGICAL MODEL

Jatoth Veeranna[1*] , A. K. Mishra [2] D. K. Singh[3], A. Sarangi[4], Indra Mani [5], M. A. Iqebal[6], Arati Marothi Kadam[7], and Man Singh[8]

*[1*7] Ph.D. and M. Tech. Research Scholars; [274] Principal Scientist, Water Technology Centre,*
[3&5] Professor and Head; respectively, Division of Agricultural Engineering, ICAR- Indian Agricultural Research Institute, New Delhi. ICAR- Indian Agricultural Research Institute, New Delhi.
[6]Principal Scientist, ICAR-IASRI, New Delhi
[8]project Director, Water Technology Centre
Correspondence: dranilkumarmishra1@gmail.com

Abstract: Soil Water Assessment Tool (SWAT); a watershed scale model developed to predict the impact of land management practices on runoff water, sediment and agricultural yields with varying soils, land use and management conditions over long periods of time was calibrated and validated. In the Godavari basin of Andhra Pradesh (A.P), India the problem of runoff and sediment were studied using SWAT model. In this model the comprehensive methodologies have been used for modeling the surface runoff which is one of the major causes of erosion of the earth's surface. Hence, the location of high runoff generating areas is very important for making better land management practices. The land use and land cover, soil type, infiltration rate of soil, hydrological group and slope play major role for estimation of runoff, sediment yield. A study was conducted for assessment of surface runoff and sediment yield as affected by the natural recourses such as land use, land cover, soil loss, runoff and sediment yield in sub catchment of Godavari river basin with its outlet in the A.P. The research focused mainly on deriving the parameters required for runoff modeling using the geospatial database and estimate the runoff and sediment yield of the middle portion of the Godavari river basin. The sediment modelling was performed and the model (SWAT) calibration and validation was done. The calibration of SWAT hydrological model gave satisfactory results for surface flow and sediments yield parameter with moderately higher coefficient of determination (R^2) (0.90, 0.83) and Nash Sutcliffe Efficiency (E_{NS}) (0.88, 0.78) for monthly flow calibration. The monthly flow validation values for R^2 and E_{NS} were 0.88, 0.83 and 0.85, 0.76, respectively which were more than calibration. For calibration the average statistical parameters *p*-value and *r*-value were obtained as 0.30, 0.64 and0.38, 0.40 respectively, and for validation the same parameters were observed as *p*-value 0.34, 0.45 and 8.88, 0. 83 respectively. Similarly, the predicted sediment yield calibration and validation values were for R^2 and E_{NS} were 0.88, 0.83 and 0.85, 0.76 respectively. The R^2 was higher in the observed sediment yield as compared to the predicted by the model. The results of this study can be helpful for solving the soil erosion problem of the area through selection of appropriate remedial measures to reduce soil loss and sediment yield.

Keywords: Digital Elevation Model (DEM),Rainfall-Runoff,Sediment Yield and SWAT model; SWAT-CUP (SUFU2).

Article History: Received: 30 September 2021; Revised: 6 October 2021; Accepted: 10 October 2021

INTRODUCTION

Surface runoff is one of the major causes of erosion of the earth's surface and for making better land management practices the location of high runoff generating areas is very important. Also, for determine the sizes of water harvesting structures are hydraulic design of SWCE structure, the knowledge runoff rate essential (Rahaman *et al.*, 2015). Thedeposition of sediment which takes place progressively in timereduces the active capacity of the reservoir (Alemayehu *et al.*, 2014; Purekar and Damgir, 2017). These affect the regulating capability of the reservoir to provide the outflows through the passage of time (Thawait and Chauhan, 2015). Accumulation of sediment at or near the dam may interfere with the future functioning of water intakes and hence affects decisions regarding location and height of various outlets (Alemayehu *et al.,* 2014). It may also result in greater inflow of sediment into the canals/ water problems of the rise in flood levels in the head reaches.However, the modeling of runoff, soil erosion and sediment yield are essential for sustainable development (Arnold *et al.*, 1998; Hafiz and Clemente, 2014).

Further, the reliable estimates of the various hydrological parameters including runoff and sediment yield for remote and inaccessible areas are tedious and time consuming by conventional methods (Hari *et al.*, 2014; Thawait and Chauhan, 2015). Therefore, it is desirable that some suitable methods and techniques are employed for quantifying the hydrological parameters from all parts of the basin. Use of mathematical models for the hydrologic evaluation of watersheds and extraction of watershed parameters using remote sensing and geographical information system is the current trend (GIS) (Arnold *et al.,* 2012; Arnold *et al.,* 2013; Kai *et al.,* 2015). Infiltration excess (runoff) occurs when the rainfall intensities exceed to the soil infiltration rate or all depression storage have been already filled. Soil infiltration rates are controlled by soil characteristics, vegetation cover and land use practices. If one is able to model the infiltration characteristic, the runoff behaviour can also be modelled with high accuracy and precession (Pramanik, 2016).

Rainfall runoff models are classified as probabilistic/stochastic or deterministic, parametric and non-parametric, distributed or lumped, physical or conceptual, empirical or mathematical models (William and Berndt, 1972; Jain and Kothyari, 2000; Khanal and Parajuli, 2014; kumar *et al.,* 2017). Mathematical models are much more popular for runoff assessment as these are less data driven, simpler and cheaper (Kulkarni *et al.,* 2014). Statistical methods such as multivariate regression models artificial neural networks and multivariate time series models are generally used for rainfall runoff analysis (Kumar *et al.,* 2005; Machado *et al.,* 2011). Different types of models have been developed for the purpose of water-resource management and planning. Therefore, to test the capability of the model in determining the runoff of the basin, SWAT 2000 with ArcGIS 10.2(Ha *et al.,* 2017; Arnold *et al.,* 2012) interface was selected for the present study to estimate the soil loss from the Revised Soil Loss Equation (RSLE) (Rao *et al.,* 1994; Jain and Kothyari, 2000; Mitra and Mishra, 2014; Raktim *et al.,* 2014). The study for the delimitation of the zone of high runoff and consequently soil erosion can prove to be of immense value to the decision makers for implementing better land management practices in the area (William and Berndt, 1972; Singh *et al.*, 1981; Van *et al.*, 2000; Samaniego *et al.,* 2010).The main objective of the present study was to derive the parameters required for runoff/sediment modeling using the geospatial database and estimate the runoff and sediment yield of the middle portion of Godavari river basin Andhra Pradesh (Jain and Kothyari, 2000; Vemu *et al.,* 2011).The outlet of study area watershed Mohgaon gauging station has been used for sediment calibration and it was selected as the basin outlet for entire watershed.

MATERIALS AND METHODS

Study area

The study area was the sub catchment of middle portion of Godavari river basin which starst entering into the A.P. It is located between latitude $19^0 46'34.68''$ N - $18^0 45'19.14''$ N and longitude $75^0 09'35.62''$ E - $76^0 44'16.23''$ E covering geographic area 11060 Km^2. Elevation in the study area varies from minimum 356 m to maximum of 873 m. The terrain parameters like slope and slope length, and stream network characteristics, length and width of the selected study area were derived from the digital elevation model (DEM) (Fig.1).For runoff, sediment yield and calibration of SWAT model, the hydrological response units (HRU) were defined as a unique combination of soil, land use types and slope along with climatic parameters. Runoff was predicted separately for each HRU and routed to obtain the total runoff for the watershed. The input data included topography, weather, land use, soil and management practice adopted. Data from four stations, which were within and around the study area, were obtained from station records between 2000 and 2014 (Kulkarni *et al.,* 2014).

The digital elevation model (DEM) of the study area was extracted from the Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER), the flagship satellite of NASA's Earth Observing System, TERRA with a spatial resolution of 30 m and topo-sheet of the study area of scale 1:50000 was collected from Survey of India (SoI). The WGS 1984 UTM Zone 43-N projection system was adopted to extract the required study area. The DEM and the pour point were the two main input parameters required for the extraction purpose (Fig. 1). The fill and sink operationswere done by using hydrology processing tools in Arc-GIS 10.2. Flow direction (creates a raster of flow direction from each cell to its steepest downslope) and flow accumulation (creates a raster of accumulated flow into each cell) were done with the same tool and the file was converted to stream features for analyzing the stream order and flow direction by Strahler method. Two pour points were selected to delineate basin of river network. The flow length of the streams, perimeter and area of basin was calculated by use of GIS software. Slope of the study area was also calculated from DEM file. The different sources and the purpose of all parameters were presented in the Table 1.

Land use and land cover

The land use and land cover(LULC) map was prepared by extracting the data from Global Cover map for the study area. In the study area8 different types of land use and land cover were found(Fig.2).The land use and land cover classification was done using ERDAS Imagine version 10.3 software and the different area covered under different LULC were presented in Table 2.

Soil loss and sediment yield estimation

In this study, the Universal Soil Loss Equation (USLE) was used to assess soil erosion (Singh *et al.*, 1981; Vemu *et al.*, 2011; Thawait and Chauhan, 2015; Rahman *et al.* 2015) which is as follows (equation 1).

$$A = R\ K\ L\ S\ C\ P \tag{1}$$

Where A (t $ha^{-1}yr^{-1}$) is the average soil loss of the study area, R (MJ mm $ha^{-1}h^{-1}yr^{-1}$) is the rainfall-runoff erosivity factor, K (t ha yr $ha^{-1}MJ^{-1}mm^{-1}$) is the soil erodibility factor, LS (dimensionless) is the slope length and slope steepness factor, C (dimensionless) is the cover and management practice factor, and P (dimensionless) is the support practice factor. The L, S, C, and P values are dimensionless. These factors (R, K, L, S, C, P) were combined in a GIS environment for soil erosion prediction (Jaiswal, *et al;* 2015 and 2014; Pramanik, 2016; Rahaman *et al.,* 2015). For sediment analysis, an empirical model was used (Rahaman *et al.,* 2015) and the soil loss were presented in Table 3.

Rainfall erosivity factor (R)

The rainfall erosivity factor indicates the potential ability to remove the soil surface and which is mainly depends on rainfall intensity. The erosivity factor R for the study area was calculated by using following an empirical equation (2) (Morgan and Davidson, 1991; Kumar*et al.,* 2005; Purekar and Damgir. 2017).

$$R = P * 0.5 \tag{2}$$

where, P = mean annual rainfall in mm and R = rainfall erosivity factor in MJ/ha.mm/h.

Soil erodibility factor (K)

The soil erodibility factor (K) characterizes both susceptibility of soil to erosion and the amount and rate of runoff of a particular area (Fistikoglu and Harmanicoglu, 2002). The soil map was prepared from Soil map from National

Bureau of Soil Survey and Land use Planning, Nagpur India. K factor were observed 0.4 to 0.9 respectively.

Slope steepness factor (LS)

The slope of the basin is major factor directly affecting the runoff, erosion and sediment accumulation in the rivers. The slope map of study area was prepared by extraction from ASTER-DEM (Fig. 4), and the slope map was reclassified using ArcGIS 10.2 software to understand the terrain morphology of the basin. The slope has been reclassified into 4 classes' ranges from 20 to 80 as shown in the Table 3. For slope length longer than 4 m, the slope steepness factor is derived using the following equations (3 and 4)(McCool *et al.*, 1987; Jain and Kothyari, 2000; Kai *et al.,* 2015):

S = 10.8 sin θ + 0.03 (for slope gradient < 9 %) (3)

S = 16.8 sin θ − 0.05 (for slope gradient ≥ 9 %) (4)

where, S = slope steepness factor (dimensionless) and θ = slope angle in degree.

Land cover/Conservation factor (C) and Management practices (P) factor

The C and P factors indicate the crop, management, cultivation and conservation practice of a particular area. In the present work P factor value was taken as 0.85. (Vemu and Bhaskar, 2011) The C factors were calculated from Normalized Difference Vegetation Index (NDVI), obtained from LANDSAT satellite images downloaded (Table 4). NDVI is positively correlated with the amount of green biomass, it represent a differences in green vegetation coverage. The NDVI was calculated by following equation (5) developed by European Soil Bureau (Samaniego *et al.,* 2010; Vemu *et al.,* 2011; Yalew *et al.,* 2016).

$$C = e^{-\alpha\left(\frac{NDVI}{\beta - NDVI}\right)} \quad (5)$$

where, α, β are the parameters that determine the shape of the NDVI-C curve. A α value of 2 and a β value of 1 have been assumed and the NDVI presented in the equation 6 (Van der Knijff *et al.,* 2000).

where,

$$NDVI - \frac{NIR - R}{NIR + R} \quad (6)$$

NDVI is normalization of Ratio Vegetation Index (RVI) is calculated using the formula (7):

$$RVI = \frac{NIR}{R} \quad (7)$$

where, NIR and R is the spectral responses in the near infra-red and red band respectively. The Ravinder *et al.*, 2017 reported that the value of RVI close to 1 for bare soil and NDVI value varies from -1 to +1.

Sediment yield

According to the RSLE model (Pourghasemi *et al.*, 2012; Jaiswal *et al.*, 2015; Rahaman *et al.*, 2015; Pramanik, 2016; Kumar *et al.*, 2016)the sediment yield (SY) can be expressed in the following equation (8):

$$SY = 1.067 \times 10^{-3} R^{1.384} A^{1.292} D_d^{0.392} S^{0.129} F^{2.51} \quad (8)$$

where, SY is the annual sediment yield (Mm^3/year), R is the annual precipitation (cm), A is the sub-watershed area (km^2), D_d is the drainage density (km/km^2), S is the average slope and F is the vegetative cover factor can be expressed in the following equation (9).

$$F = \frac{0.21F_1 + 0.2F_2 + 0.6F_3 + 0.8F_4 + F_5}{\Sigma_{i=1}^{5} F_i} \quad (9)$$

where, F_1 is the area under reserved and protected forest, F_2 is the unclassified forest area, F_3 is the cultivated area, F_4 is the grass and pasture land and F_5 is the wasteland.For the calauclation of sediment delivery ratio (SDR) an empirical equation has been chosen and it was expressed as follows in the equation (10) (Williams and Berndt's, 1972):

$$SDR = 0.627.SLP^{0.403} \quad (10)$$

where, SLP = % slope of main stream channel, and

$$(SY) = A.SDR \quad (11)$$

where, SY= Sediment yield, (Mm^3/year)

The maximum and minimum of sediment transport indices (STIs) (Table 4) for different sub-watersheds were estimated by the following equation (12) as done by many other researchers (Jaiswal *et al.,* 2015; Yalew *et al.*, 2016; Yang *et al.*, 2013):

$$STI = \left[\frac{A}{22.13}\right]\left[\frac{\sin(\beta)}{0.0896}\right]^{1.3} \quad (12)$$

where, A is the upstream catchment area and β is the slope steepness in degree.

The different thematic maps and layers were prepared by ArcGIS 10.2 and SWAT model were over imposed and the sediment yield were estimated (Fig. 5)

Prioritization of sub watersheds

The Godavari basin was divided into 4 sub-watersheds for the soil loss estimation and prioritization purpose (Arnold *et al.*, 2013). The average soil loss values in t/ha/yr for each sub-watershed were calculated by the SWAT and ArcGIS 10.2 model (Table 3) using aggregation option of Integrated Land and Water Information Systems (ILWIS). Prioritization of sub-watershed (PSW) has been done on the basis of average annual soil loss. The PSW1 is the first priority category followed by PWS2, PW3, PW4, PW5 and PW6 (Table 3) and the pairwise comparison matrix of soil erosion parameters also were presented in the Table (4).

Calibration and validation of SWAT model for estimation of sediment yield by SWAT-CUP (SUFI2)

The *p*-value, *r*-value, coefficient of determination (R^2), Nash-Sutcliffe Efficiency (N_{SE}) are fourstatistical parameters that are used to evaluate the performance of model results. The N_{ES} is a normalized dimensionless statistic parameters which determines the relative magnitude of the residual variance and ranges from -∞ to 1 (Nash and Sutcliffe 1970; Arnold, 2013 *et al., 2013;* Kumar *et al.*, 2017). The $N_{ES}$was selected for calibration and validation of sediment yield bu using following equation (13):

$$E_{NS} = 1 - \frac{\Sigma_{i=1}^{n}(O_i - P_i)^2}{\Sigma_{i=1}^{n}(O_i - P_i)^2} \quad (13)$$

where, P_i is the model simulated value, O_i is the observed data and i = 1, 2, ..., n, where n is the total number of pairs of simulated and observed data. E_{NS} indicates how well the plot of the observed value versus the simulated value fits the 1:1 line, and ranges from −∞ to 1.The recorded values of sediments at the outlet of watershed Mohgaon gauging station was used for sediment calibration and it was selected as the basin outlet for the entire watershed as well.The SUFI2-SWAT CUP model (Arnold *et al.*, 2012) was used for calibration of monthly observed sediment yield and runoff calculations.

RESULTS AND DISCUSSION

The Godavari basin is the main cultivable area for agricultural production throughout the year due to continuous availability of water in the region. In this study area the basic soil hydrological group D was observed with available soil type clay and clay loam, silty clay loam, sandy clay and silty clay soil due to high deposition of sand and silt (Fig. 3). These types of soils are very useful for agricultural production. Theaverage bulk density of the soil in the region was found to varying from 1.5 to 1.6 Mg/m^3 (Binhanu, 2009). DEM of the study area revealed that 42% of area was between altitudes from 450m to 720m. The mean slope length factor was varied from 0.2 to 530. The larger areas (74% of the catchment area) were covered with the slope ranging from 0 and 5; the 10 % of the catchment area had greater slopes than 5-10, the next 8% of the watershed had a slope 10-15 % while the rest 16 % area observed steeper slope > 15%. The high slope was one of the major causative factor for higher rate of soil erosion observed in the region. The land cover (C)factors in the study area varied from 0.1 to 0.3. The major land use and land cover were presented in Table 2. In the present study area the maximum area was found under irrigated crop land (41.26%) flowed by the water body (25.73%). The smallest area under shrubs and mixed vegetation were 1.52%, 4.47% respectively (Table 2). The K-factor was varied from 0.4 to 0.9 respectively (Binhanu, 2009; Kumar *et al.,* 2014).

During model calibration the average *p*-value and the *r*-value were obtained as 0.30, 0.64 and 0.38, 0.40 respectively, (Table 5), and in model validation the same were obtained as 0.32, 0.63 and 0.34, 0.45 respectively (Table 6) (Kumar *et al.,* 2012).The fourerosion classes had been identified varying from slight erosion to very severe erosion (Table 3 and Fig. 6). The results indicated that the maximum soil loss(9.24

Table 1: The source of spatial database used in soil erosion estimation analysis

S No.	Data used	Parameters	Source	Purpose
	Soil map	Soil Texture, Hydrological soil group, Soil type	Soil map from National Bureau of Soil Survey and Land use Planning, Nagpur (India)	K-factor map in RUSLE model,
	Sentinel – 2, satellite image high-resolution optical imaging	LULC	Earth explore	Land use map, C, P-factor, maps in RUSLE model and Drainage update
	Survey of India (SOI) Toposheet no. 61 L/1, 61 L/2, 61 L/3, 61 L/5, 61 L/6, 61 L/7	Drainage, contour, update, watershed, Sub-watershed	Survey of India, Andhra Pradesh, (India)	Contours, drainage, sub-watershed boundaries, slope, sediment transport index (STI) map and geomorphological parameters
	Metrological data	Rainfall	Water Resource Department, Raipur Andhra Pradesh.	R-factor map in RUSLE model,
	Topography/Elevation data	DEM, Slope	Earth explore: SRTM DEM 1 Arc second,	LS-factor map in RUSLE model,

Table 2: Land use and Land cover classification of the Godavari basin

S.No	Land use and land cover	Area (ha)	% of area
1	Crop/Grass land	179394	13.77
2	Irrigated crop land	537532	41.26
3	Dense forest	43587	3.35
4	Barren or Sparely vegetated land	78352	6.01
5	Shrubs land	19763	1.52
6	Water body	335262	25.73
7	Mixed vegetation	45263	3.47
8	Habitats	63726	4.89

Table 3: Soil Loss categories according to average annual soil loss and prioritization of sub-watersheds (PSW) and soil loss and sediment yield parameters based on soil erosion classes

Priority Class	Slope	Class	Area	% Area	Soil loss (Million tons)	Soil loss (%)	Observed SY	Predicted SY
PSW1	> 80	Very severe	22543	10.3	9.24	39.1	30.8	33.6
PSW2	40 – 80	Severe	54362	24.8	7.34	31.0	27.4	25.1
PSW3	20 – 40	Moderate	63421	28.9	4.53	19.1	24.4	21.9
PSW4	< 20	Slight	78452	35.8	2.53	10.7	17.4	19.4

Table 4: Pairwise comparison matrix of soil erosion parameters

	SL	SY	STI	Slope	NDVI	DD	Rp
SL	1.000	0.167	0.189	0.250	0.222	0.500	0.667
SY	6.000	1.000	1.000	1.200	1.100	0.300	1.000
STI	5.300	1.000	2.000	0.400	0.417	0.769	0.455
Slope	4.000	0.833	2.500	1.000	1.200	0.500	1.000
NDVI	4.500	0.909	2.400	0.833	1.000	0.294	0.714
DD	2.000	3.333	1.300	2.000	3.400	1.000	0.588
Rp	1.500	1.000	2.200	1.000	1.400	1.700	1.000

SL = sediment loss, SY = sediment yield, STI = sediment transport index, S=Slope, NDVI= Normalized Difference Vegetation Index, D_d= Drainage Density, Rp=Runoff Potential million tons) was found in the subwatershed-1 (PSW1) followed by subwatershed-2 (as 7.32) and like wise.An average soil loss (5.91 million tone $ha^{-1}yr^{-1}$)was estimated from entire watershed.The SWAT model quantitatively simulated the monthly sediment yield and matched with the observed data. The observed sediment loss was found to vary from30.8 to 17.4 million tone $ha^{-1}yr^{-1}$ while the predicted sediment yield was found to have been vary varying between 33.6 to19.4 million tone $ha^{-1}yr^{-1}$ (Table 3). The results concluded that there was an immediate action required to be taken for erosion control (Pourghasemi *et al.,* 2012; Jaiswal *et al.,* 2015; Pramanik 2016; Rahaman *et al.,* 2015) in the Godavari river catchment. The sediment transport index obtained from the equation (12) for different sub-watersheds was found to be in the range of 0.1-2.5. The sub-watersheds in the downstream side were observed to have relatively higher slopes as compared to sub-watersheds existing in the upper region of the basin as results the more concertation of runoff and erosion and sediment deposition in river beds.

The SWAT-CUP was used for calibration and validation of sediment yield analysis. The model was calibrated using six years data (2000-2006) and validation done by using eight years data (2007-2014) with SUFI2 on monthly time scale (Nash and Sutcliff, 1970; Arnold *et al.,* 2013). The results of observed sediments yield showed that R^2=0.90, 0.83 and E_{NS} coefficient = 0.88, 0.78 respectively, for calibration and validation (Table.5).Similarly for the predicted sediment yield values were for R^2 and E_{NS} were 0.88, 0.83 and 0.85, 0.76respectively, forcalibration and validation (Table 6). Observed and simulated sediment yield values in graphical plot for the whole validation period shown in the figure 7 and figure 8.Therefore, it can be confidently concluded that the SWAT model was found to have satisfactorily estimated the soil loss, sediment yield and transport index.

CONCLUSIONS

ArcGIS and SWAT are one of the best river basin models that can be used for understanding the hydrology as well as soil loss productivity. It is also proved that the model can be employed under changing climate scenarios as well as in different management practices. The land use and land cover, soil type, infiltration rate of soil, hydrological group and slope play major role for estimation of runoff and sediment yield analysis. In the present study area i.e. The Godavari basin, the maximum area was found under irrigated crop land (41.26%) followed by the water body (25.73%). The smallest area under shrubs (1.52%) and mixed vegetation (4.47%). The calibration of sediments yield with SWAT-CUP was found satisfactory with R^2=0.90, 0.83 and E_{NS} coefficient = 0.88, 0.78 respectively for observed data. Similarly, the predicted sediment yield calibration and validation values were for R^2 and E_{NS} were 0.88, 0.83 and 0.85, 0.76 respectively.

Table 5: Average calibration and validation results of observed sediment yield on monthly basis (SWAT-CUP, SUFI2)

Sediment flow Calibration results on monthly basis				
Variables	*p*-factor	*r*- factor	R^2	E_{NS}
Sediment out	0.30	0.38	0.90	0.88
Sediment flow validation results on monthly basis				
Variables	*p*-factor	*r*- factor	R^2	E_{NS}
Sediment out	0.64	0.40	0.83	0.78

Table 6: Average calibration and validation results of predicted sediment yield on monthly basis (SWAT-CUP, SUFI2)

Sediment flow Calibration results on monthly basis				
Variables	*p*-factor	*r*- factor	R^2	E_{NS}
Sediment out	0.32	0.34	0.88	0.85
Sediment flow validation results on monthly basis				
Variables	*p*-factor	*r*- factor	R^2	E_{NS}
Sediment out	0.63	0.45	0.83	0.76

:veerucae023@gmail.com

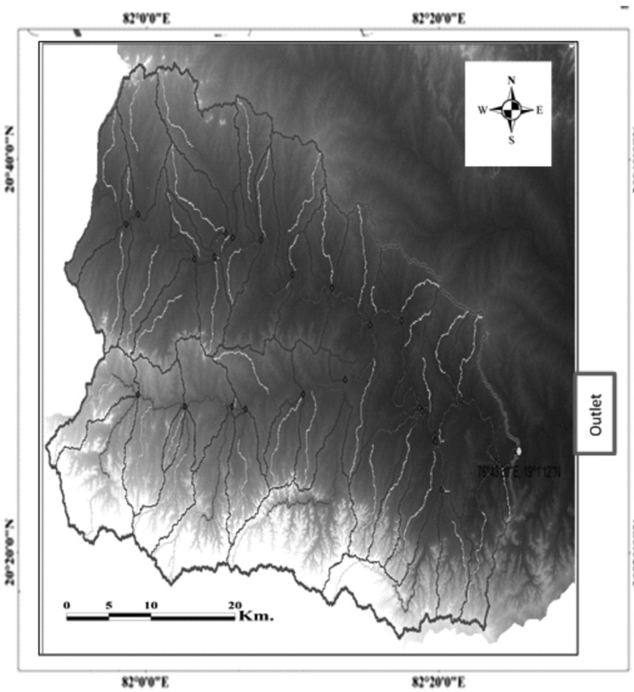

Figure 1: DEM (ASTER 30 meter resolution) and sub watershed delineation of the Godavari basin

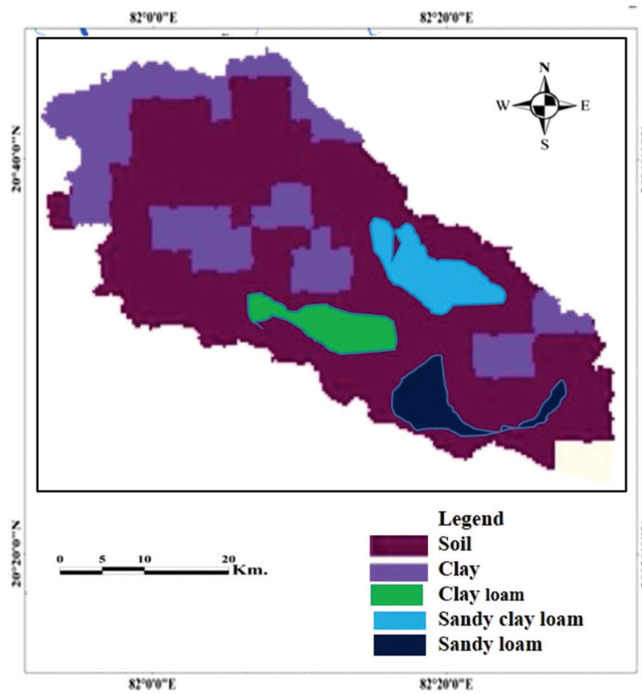

Figure 3: Soil map of sub watershed of the Godavari basin

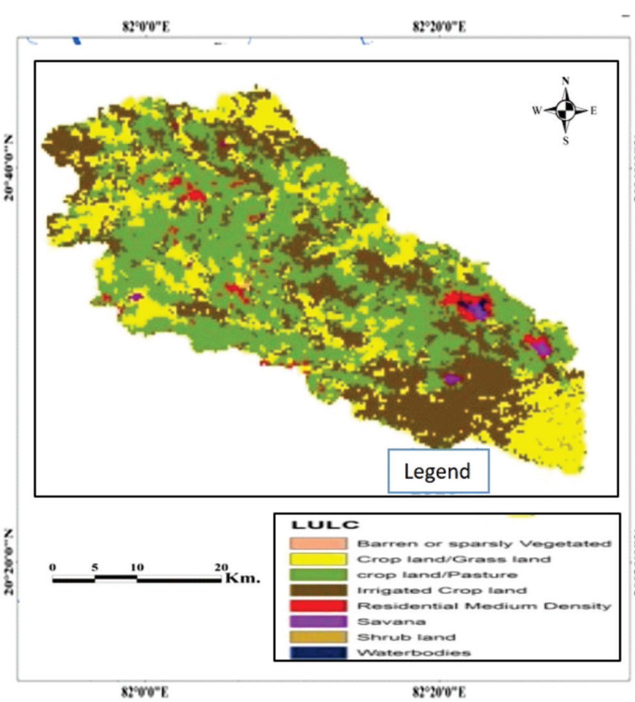

Fig. 2. Land use and land cover of sub watersheds of the Godavari basin

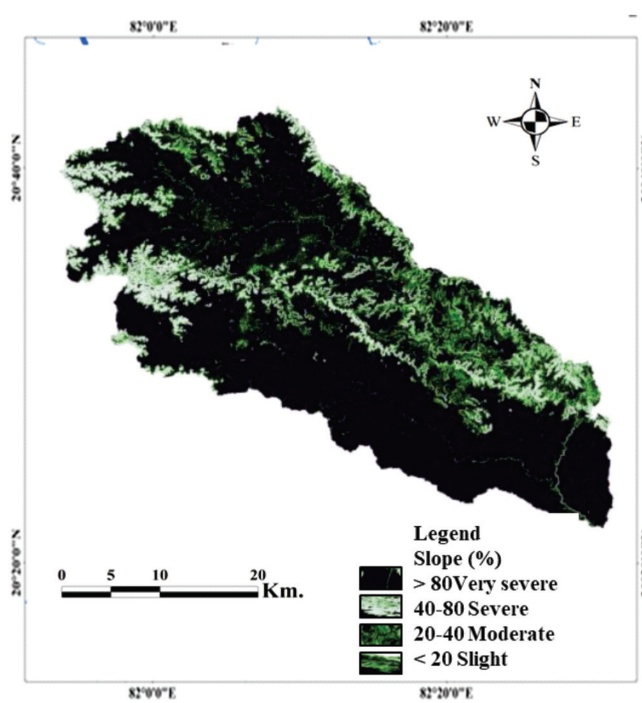

Figure 4: Slope map of sub watershed of the Godavari basin

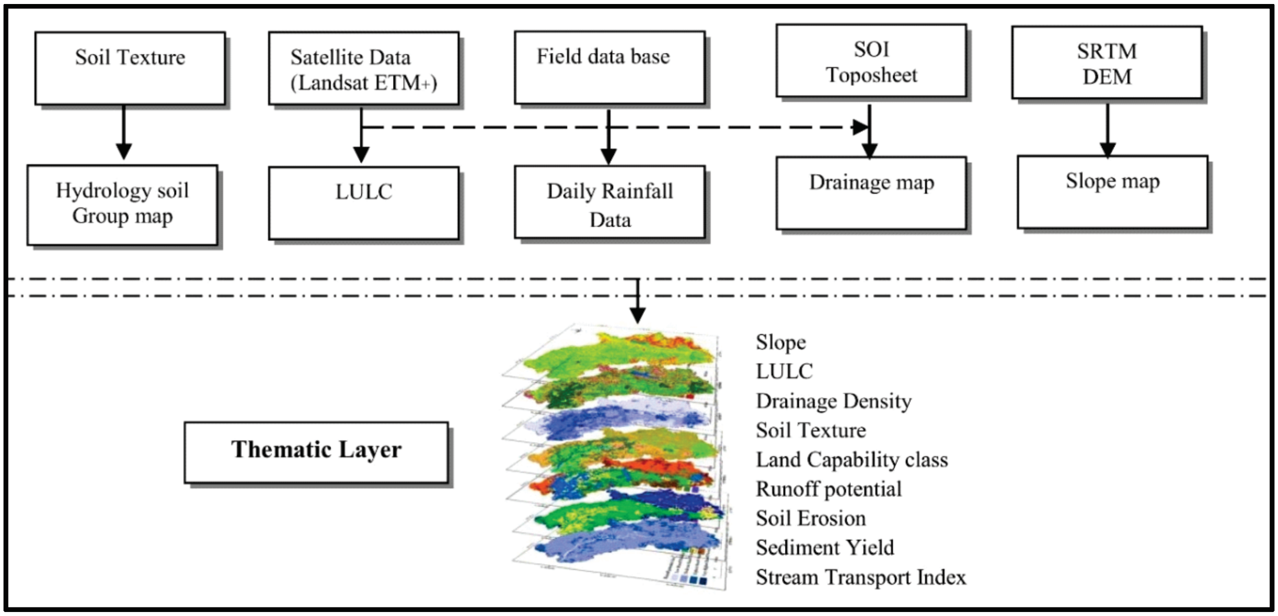

Figure 5: Flow chart of calculation methodology for sediment yield and sediment transportation index of the Godavari basin

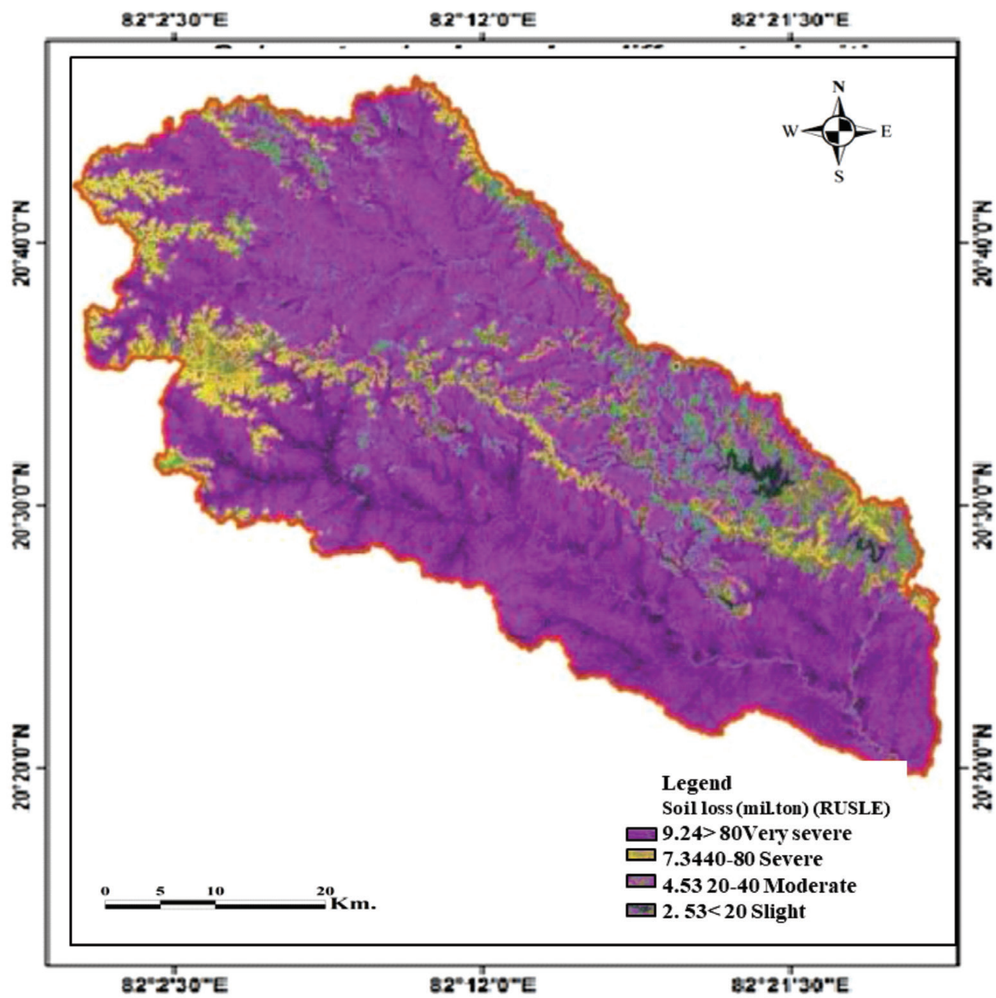

Figure 6: Soil erosion classes map of sub watershed of the Godavari basin

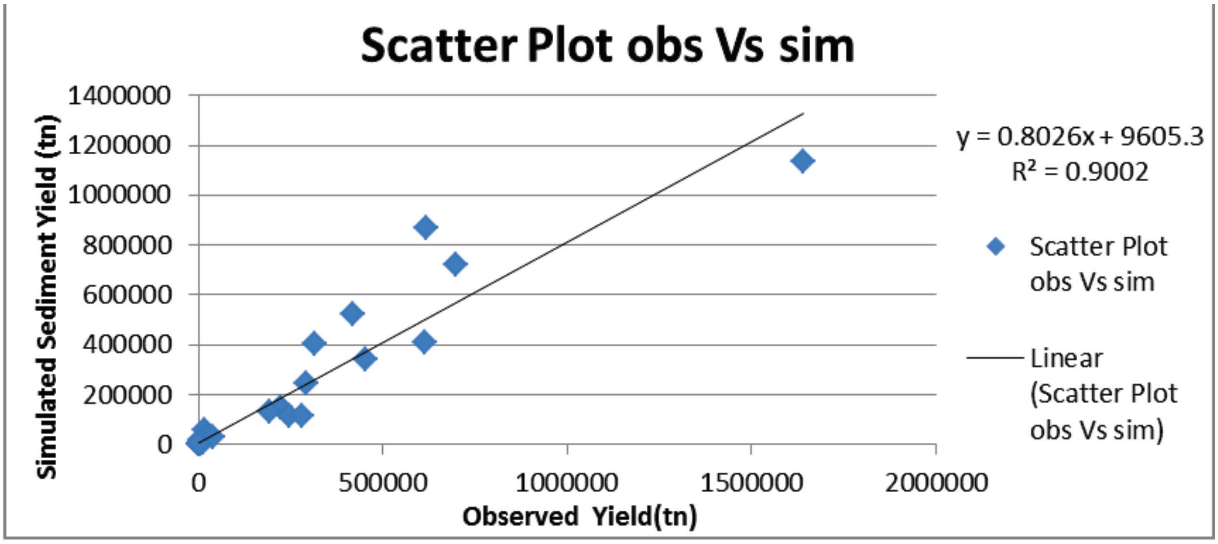

Figure 7: Simulated scatter plot of sediment yield of sub watershed of the Godavari basin

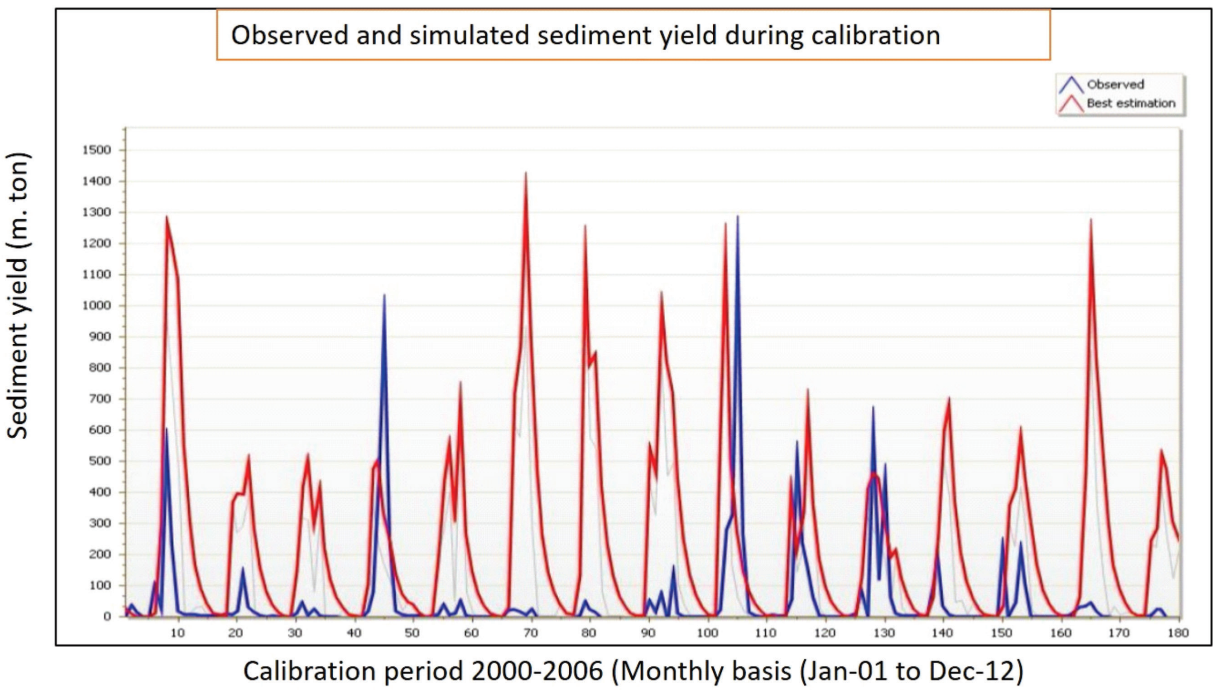

Figure 8: Observed and simulated monthly sediment yield during calibration of the Godavari basinusing the SWAT-CUP (SUFI2) model

The R^2 was higher in the observed sediment yield as compared to the predicted by the model. The results of this study can be helpful for solving the soil erosion problem of the area through selection of appropriate remedial measures to reduce soil loss and sediment yield.

Acknowledgments

This work was supervised and done under the guidance of Dr. M. Srinivasan, the developer, SWAT model in the 10 days 14-12-2015 to 23-12-2015 training programme on SWAT model under his guidance and supervision at Indian Institute of Technology, Hyderabad.Authors want to express their hearty thanks the authority of IARI for providing all the facilities to undertake this research. The first author wants to express his sincere thanks to authorities of the State Ground Water Board and Irrigation Department, Krishna and Guntur districts of Andhra Pradesh. He also thanks to DistrictCollector, Hyderabad for providing the necessary information and data for completion of this research work. Thanks are due to Er. P.K. Sundarm, Scientist, Agricultural Engineering, (ICAR- Research

Complex Patna) for giving his inputs and suggestion about this work.Our thanks also extended to the Head and Professor, Division of Agricultural Engineering, for their support and valuable guidance for completion of work.

References

Alemayehu, D., Srinivasan, R. and Daggupati, P. 2014. Application of Soil and Water Assessment Tool Model to Estimate Sediment Yield in Kaw Lake. *American Journal of Environmental Sciences*, **10**(6):530-545

Arnold, J. G., Moriasi, D. N., Gassman, P. W., Abbaspour, K. C., White, M. J., Srinivasan, R. and Kannan, N. 2012. SWAT: Model use, calibration, and validation. *Transactions of the ASABE*, **55**(4):1491-1508.

Arnold, J. G., Moriasi, D. N., Gassman, P. W., Abbaspour, K. C., White, M. J., Srinivasan, R., Santhi, C., Harmel, R, D., Van, Griensven, A., Van, Liew, M. W., Kannan, N. and Jha, M. K. 2013. SWAT: Model use, calibration, and validation. T. *ASABE*., **55**:1491-1508, doi:10.13031/2013.42256.

Arnold, J. G., Srinivasan, R., Muttiah, R., S. and Williams, J. R. 1998. Large area hydrologic modeling and assessment: Part I. Model development, *J. Am. Water Resour. Assoc*., **34**:73–89, doi:10.1111/j.1752-1688.1998.tb05961.20 8.

Binhanu, Z. B. 2009. Hydrological modeling of the Kihansi river catchment in South Central Tanzania using SWAT model. *International Journal of Water Resources and Environmental Engineering*.**1**(1):1-10.

Fistikoglu, O. and Harmancioglu, N. B. 2002. Integration of GIS with USLE in assessment of soil erosion. *Water Resour Manag*, **16**:447–467.

Ha, L. T., Bastiaanssen, W. G., van Griensven, A., van Dijk, A. I., and Senay, G. B. 2017. SWAT-CUP for Calibration of Spatially Distributed Hydrological Processes and Ecosystem Services in a Vietnamese River Basin Using Remote Sensing.*Hydrol. Earth Syst. Sc*i.1-35.

Hafiz, Qaisar, Yasin. and Roberto, Clemente. 2014. Application of SWAT model for hydrologic and water quality modeling in Thachin river basin, Thailand. **Arab J Sci. Eng**. **39**:1671–1684.

Hari, Krishna, B., Mani, A., Uma, Devi, M. and Ramulu. 2014. Modelling of water resources for sustainable water use in Upper Manair Catchment, Andhra Pradesh. *Int. J. Pure App. Biosci*. **2**(1):23-34.

Jain, M. K. and Kothyari, U. C. 2000. Estimation of soil erosion and sediment yield using GIS. *Hydrol Sci J*,**45**(5):771–786.

Jaiswal, R. K., Narayan, C. G., Lohani, A. K. and Thomas, T. 2015. Fuzzy AHP Based Multi Crteria Decision Support for Watershed Prioritization. *Water Resources Management*, **29**(12):4205–27. (http://link.springer.com/10.1007/s11269-015-1054-3).

Kai, Xu., Huiqing, Peng., De, Ge,JiRi, Fu., Ruixin, Zhang., Hao, Xiao. and Qian, Shi. 2015. Sediment yield simulation using SWAT model for water environmental protection in an agricultural watershed. *Applied Mechanics and Materials*. 713-715.

Khanal, S. and Parajuli, P. B. 2014. Sensitivity Analysis and Evaluation of Forest Biomass Production Potential Using SWAT Model. *Journal of Sustainable Bioenergy Systems*, **4**:136-147.

Kulkarni, B. D., Deshpande, N. R., Patwardhan, S. K. and Bansod, S. D. 2014. Assessing Hydrological Response to Changing Climate in the Krishna Basin of India. *Earth Sci. Clim. Change*, **5**:211-219.

Kumar, A. R. S., Sudheer, K. P., Jain, S. K. and Agarwal, P. K. 2005. Rainfall runoff modeling using artificial neural networks: Comparison of network types. *Hydrol. Process* **19**:1277–1291.

Kumar, N., Singh, S. K., Srivastava, P. K. and Narsimlu, B. 2017. SWAT Model calibration and uncertainty analysis for streamflow prediction of the Tons River Basin, India, using Sequential Uncertainty Fitting (SUFI-2) Algorithm. *Modeling Earth Systems and Environment*, **3**(1):30.

Kumar, T., Gautam, A. K. and Jhariya, D. C. 2016. Multi criteria decision analysis for planning and management of groundwater resources in Balod District, India, *Environ Earth Sci*,**75**:649, DOI 10.1007/s12665-016-5462-3.

Machado, F., Mine, M., Kaviski, E. and Fill, H. 2011. Monthly rainfall runoff modeling using artificial neural networks. *Hydrol. Sci. J*.**56**(10):349–361.

McCool, D. K., Foster, G. R., Mutchler, C. K., Meyer, L. D. 1987. Revised slope steepness factor for the universal soil loss equation. *Trans ASAE***30**(5):1387–1396.

Mitra, S. and Mishra, A. 2014. Hydrologic Response to Climatic Change in the Baitarni River Basi. *Journal of Indian Water Resources Society*, **34**(1):24-33.

Morgan, R. P. C. and Davidson, D. A. 1991. Soil erosion and conservation. Longman Group, UK.

Nash, J. E., Sutcliffe, J. 1970. River flow forecasting through conceptual models: part I-a discussion of principles. *J Hydrol*, 10:282–290.

Pourghasemi, H. R., Pradhan, B. and Gokceoglu, C. 2012. Application of Fuzzy Logic and Analytical Hierarchy Process (AHP) to Landslide

Susceptibility Mapping at Haraz Watershed, *Iran. Natural Hazards,***63**(2):965–996.

Pramanik, M. K. 2016. Site Suitability Analysis for Agricultural Land Use of Darjeeling District Using AHP and GIS Techniques. *Modeling Earth Systems and Environment***2**(2):1-22. Retrieved (http://dx.doi.org/10.1007/s40808-016-0116-8).

Purekar, A. and Damgir, R. M. 2017. Sediment Yield Evaluation by Using QSWAT. *International Journal of Scientific Engineering and Technology*, **6**(7):231-234.

Rahaman, S. A., Ajeez, S. A., Aruchamy, S. and Jegankumar, R. 2015. Prioritization of Sub Watershed Based on Morphometric Characteristics Using Fuzzy Analytical Hierarchy Process and Geographical Information System , A Study of Kallar Watershed, Tamil Nadu. *Aquatic Procedia*, **4**(1):1322-1330

Raktim, Haldar., Shivika, Singla., Rumani, Singla., Rudraksh, Rajeev. and Rakesh, Khosa. 2014. Hydrologic Modeling for the Gandak Basin Using SWAT with Sensitivity Consideration. *Int. J. Earth science and Engineering*, 7:448-455.

Rao, V. V., Chakravarty, A. K., Sharma, U. 1994. Watershed prioritization based on sediment yield modeling and IRS-1A LISS data. *Asia Pac Remote Sens J*.**6**(2):59–65.

Samaniego, L., Kumar, R. and Attinger, S. 2010. Multiscale parameter regionalization of a grid-based hydrologic model at the mesoscale. *Water Resources Research*, **46**(5):55-61.

Singh, G., Babu, R., Narain, P., Bhusan, L. S, Abrol, I. P. 1992. Soil erosion rates in Indian. *J Soil water Conserv*.**47**(1):97–99.

Singh, Gurmel., Babu, Ram. and Chandra, Subash. 1981. Soil loss prediction research in India, Bulletin No. T-12/ D-9. Central Soil and Water Conservation Research and Training Institute, Dehra Dun.

Thawait, A. K. and Chauhan, M. S. 2015. Sediment Yield Modelling of Mohgaon watershed of Narmada river basin using SWAT model. *Int. Journal of Engineering and Technical Research.***3**(2):321-331.

Van, Der, Knijff, J. M., Jones, R. J. A. and Montanarella, L. 2000. Soil erosion risk assessment in Italy, European Soil Bureau, EUR 19044 EN.

Vemu, Sreenivasulu. and Udaya, Bhaskar, Pinnamaneni. 2011. Estimation of spatial patterns of soil erosion using remote sensing and GIS: A case study of Indravati catchment. *Natural Hazards,* **59**(3):1299-1315.

Williams, J. R. and Berndt, H. D. 1972. Sediment yield computed with universal equation. *J Hydrol Div ASCE*, **98**(12):2087–2098.

Yalew, Seleshi, G., Griensven, A. V., Mul, Marlous, L. and Zaag, P. V. D. 2016. Land Suitability Analysis for Agriculture in the Abbay Basin Using Remote Sensing, GIS and AHP Techniques. *Modeling Earth Systems and Environment*,**2**(2):1–14.

Yang, X. Ling., Jie, Hua, D. and Hui, H. 2013. Application of a Triangular Fuzzy AHP Approach for Flood Risk Evaluation and Response Measures Analysis. *Natural Hazards,* **68**(2):657–74.