Indian Journal of Science and Technology Vol. 4 No. 10 (Oct 2011) ISSN: 0974- 6846

Estimation of soil loss using remote sensing and geographic information system techniques (Case study of Kaliaghai River basin, Purba & Paschim Medinipur District, West Bengal, India)

Babita Pal[1] and Sailesh Samanta[2]

[1]*Department of Remote Sensing and GIS, Vidyasagar University, Paschim Medinipur West Bengal, India.*
[2] *Department of Surveying and Land Studies, PNG UNITECH, Papua New Guinea.*
mundey2@gmail.com, rsgis.sailesh@gmail.com

Abstract

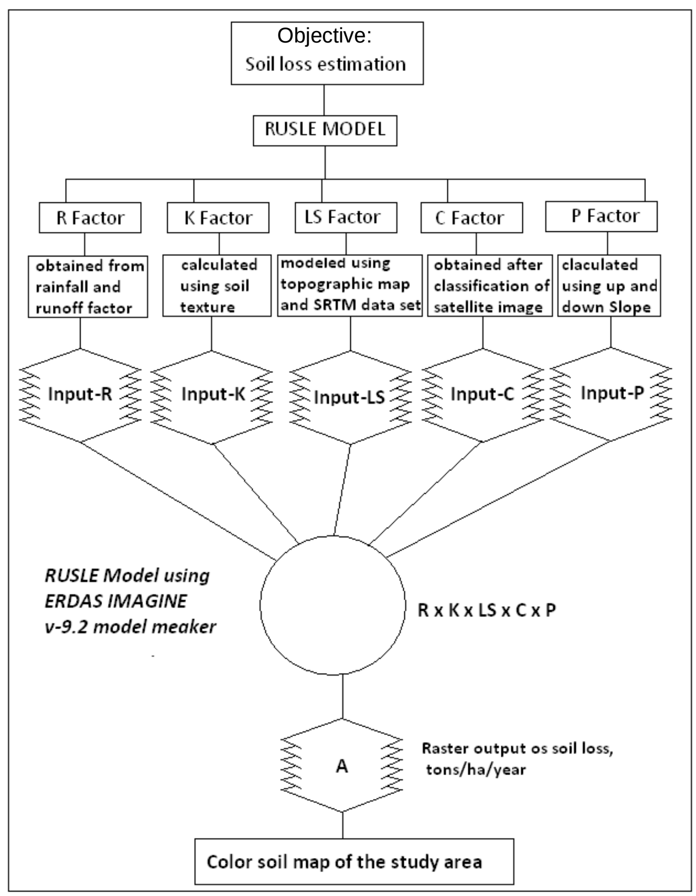
Remote Sensing (RS) and Geographic Information Systems (GIS) are useful tools in hydrological analysis and natural resource management. The application of RS and GIS techniques lends to estimate soil loss based on different parameters. RUSLE (Revised Universal Soil Loss Equation) model is used for soil loss estimation. Different parameters, namely the rainfall and runoff factor (R), soil erodibility factor (K), slope length and steepness factor (LS), crop management factor (C) and conservation practice factor (P), that are the mandatory inputs to RUSLE, have been either derived from remote sensing data or through conventional data collection systems. These parameters are obtained from monthly and annual rainfall data, soil map of the region, Digital Elevation Model (DEM), RS techniques (with use of Normalized Difference Vegetation Index) and land use/land cover map, respectively. This experiential study is carried out on the Kaliaghai river basin under Purbo and Paschim Medinipur district of West Bengal. Soil loss is very high in the river basin area, calculated as 1927779 tons/year using RUSLE model. Thus, the RUSLE model integrated with RS and GIS technologies has great potential for producing accurate and inexpensive erosion and sediment yield assessment map in the Kaliaghai river basin.

Keywords: Remote Sensing, Geographical Information System, Soil loss and RUSLE model

Introduction

Soil erosion is a major problem throughout the world. Soil erosion is a complex dynamic process by which productive 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 (Kandrika & Venkataratnam, 2005). Globally, 1964.4 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. The Revised Universal Soil Loss Equation (RUSLE) calculates the long term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, crop system and management practices. RUSLE only predicts the amount of soil loss that results from sheet or rill erosion on a single slope and does not account for additional soil losses that might occur from gully, wind or tillage erosion. Economically, the soil loss results in the decrease of arable land and its quality by depleting the top fertile soil and thereby affecting the land productivity as a whole. It also affects the surface water storage capacity by sedimentation of lakes and reservoirs; and water quality by contaminating the water with suspended soil particles, toxic materials and pesticides. Five major factors are used to calculate the soil loss for Kaliaghai river basin (Flow chart 1).

Chart 1. Methodological flow chart for the preparation of soil loss assessment map

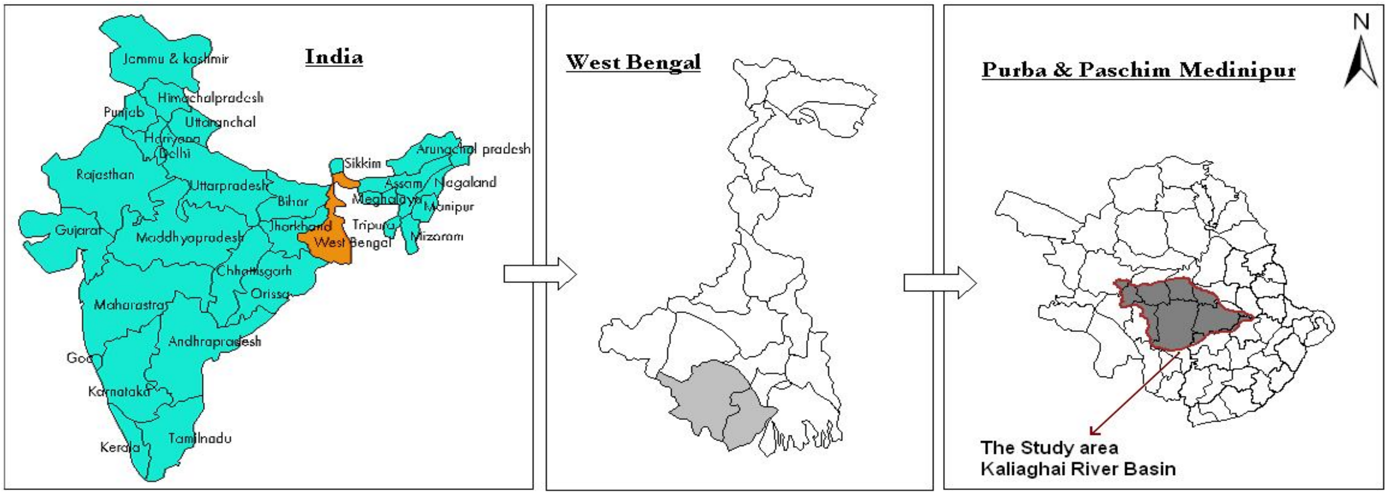


Study area and environmental conditions

The Kaliaghai river basins situated mainly in the Paschim Medinipur district and some parts of its area spread in the Purbo Medinipur district of West Bengal state (Fig.1). In the Paschim Medinipur district part it

Indian Journal of Science and Technology Vol. 4 No. 10 (Oct 2011) ISSN: 0974- 6846

Fig.1. Location map of the study area



covers some blocks *viz*. Kharagpur-I, Kharagpur-II, Pingla, Jhargram, Sankrail, Keshiary, Datan-I, Datan-II, Narayanghar and Sabong and in the Purbo Medinipur district part it covers some blocks *viz*. Pataspur-I, Bhagawanpur-I, Mayna. The area of the river basin is about 1801.40 km^2. The river basin is bounded by 87° 05' 44.83 '' E to 87°47' 43.44 '' E longitude and 21° 59'09.92'' N to 22° 21' 05.54'' N latitude.

A fierce dry heat in hot weather (March to May), a short cold weather (December to February) and a moderate rainfall (June to September) characterize the climate of the area. The average annual rainfall is 1428 mm. The study area faced frequent flood in the monsoon season and the year 2008 was the extreme flood condition in past 100 years.

Materials used

Different types of data sets are used for the calculation of soil loss within the area. These are (i) Digital Elevation Model (DEM): One of the most widely used DEM data sources is the elevation information provided by the Shuttle Radar Topography Mission (SRTM) (Coltelli *et al*., 1996), As with most other DEM sources, the SRTM data requires significant levels of pre-processing to ensure that there are no spurious artifacts in the data such as pits, spikes and patches of no data (Dowding *et al*., 2004) that would cause problems in later analysis. In the case of the SRTM data, these patches of no data are filled, preferably with auxiliary sources of DEM data, like-topographical maps. Both SRTM data sets and topographical map are used for this study; (ii) West Bengal soils sheet of National Bureau of Soil Survey (NBSS) and soil region map of National Atlas & Thematic Mapping Organization (NATMO) with different group of soil were used to generate soil texture map; (iii) Optical bands with Standard False Color Combination (SFCC) of LANDSAT 7 ETM+ satellite images were used to find out the land use/land cover classes in the study area. All other details of the variables are given in the Table 1.

Physical characteristics of the study area

Land use

Land use/land cover is very important for runoff estimation as well as for soil loss. Maximum likelihood algorithm was used to classify the LANDSAT-7 ETM+ satellite image with their tonal values of different land use/land cover classes using the supervised classification techniques of ERDAS IMAGINE software. We differentiated nine classes within the entire study area. These were water body, dense forest, open forest, natural vegetation, existing agricultural land, agricultural fallow, waste land, home shed land and urban built-up and generate classified map. After field study, we modified the classification by recoding techniques and composing the map and generated final land use land cover map (Fig.2) as an output. The study area contains the following land use /land cover statistics (Table 2).

Table1. Different variables used for this study

Different Variables	Scale/resolution	Year/ Range	Source
Topographical map	1:250000	1960	University of Texas Libraries, Austin
	1:50000	1973-1980	Survey of India, Kolkata
LANDSAT-7, ETM+;	30 m	2000 - 2001	University of Maryland, Institute for Advanced Computer Studies
National Atlas of India, Soil Region	1:2000000	1981	National Atlas & thematic Mapping Organisation, Department of Science and Technology, Govt. of India
Shuttle Radar Topography Mission data	3-arc seconds	2003	*ftp://e0srp01u.ecs.nasa.gv*

Indian Journal of Science and Technology Vol. 4 No. 10 (Oct 2011) ISSN: 0974- 6846

Fig.2. Land use/land cover map of the study area, based on LANDSAT-7 ETM+ image

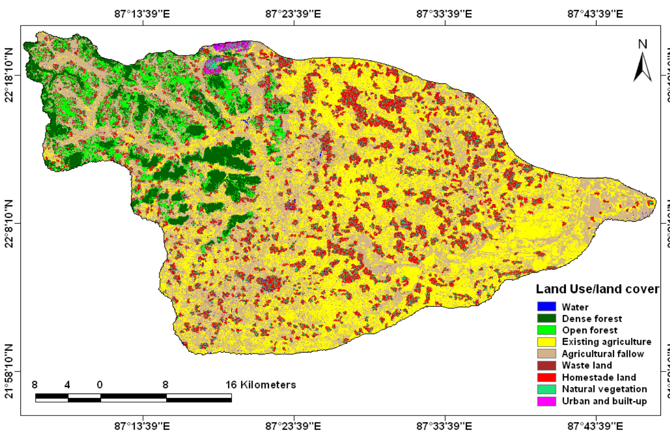


Table 2. Land use/ land cover statistics of the area

Sl No.	Land use/ land cover	Area in sq km	Area in %
1	Water	10.0638	0.6
2	Dense forest	123.7068	6.9
3	Open forest	84.8736	4.7
4	Existing agriculture	586.1619	32.5
5	Agricultural fallow	638.8488	35.5
6	Waste land	83.7945	4.7
7	Home shed land	177.3297	9.8
8	Natural vegetation	92.8008	5.2
9	Urban built-up	3.8214	0.2
Total area		1801.4 sq km	

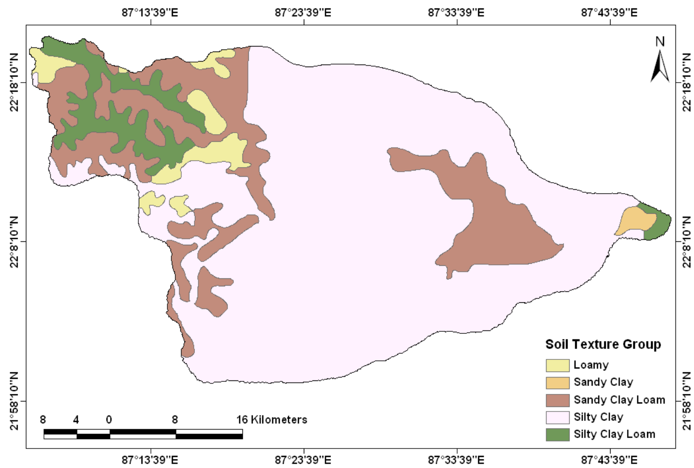
Soil type

Soil texture is very important for hydrologic soil group determination. Soil textures were classified by the fractions of each soil separate (sand, silt, and clay) present in a soil. Classifications were typically named for the primary constituent particle size or a combination of the most abundant particles sizes. In the United States, twelve soil texture classifications are defined by the USDA i.e. (i) sand (ii) loamy sand (iii) sandy Loam (iv) silt loam (v) loam (vi) sandy clay loam (vii) silt clay loam (viii) clay loam (ix) clay (x) sandy clay(xi) silt clay and (xii) silt . First we collect NBBS soil map then geo-reference this map using ground control point by the process of single image/map rectification in ERDAS IMAGINE and Arc View software. Then a polygon vector layer was created and digitized the entire soil group according to their characteristics. Different soil texture name are introduced into the attribute table of vector layer and created thematic soil texture map .The study area contained five type of soil (Fig.3). These are loamy, sandy clay loam, sandy clay, silt clay loam and silt clay. Silt clay soil coved 54% of entire study area.

Drainage

It can be noted from the prepared drainage map that flow direction of the river is from north-west to

Fig.3. Soil texture map of the study area, based on West Bengal soil sheet of NBSS

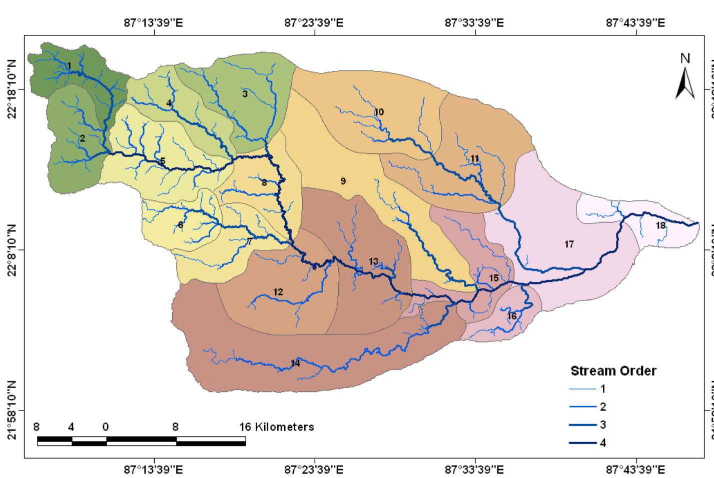


south-east. The source of water of this river is rain water. The river basin is divided into 18 sub-basins (Fig.4). The area of each sub-basin is around l00 km^2. The total area of the river basin is 1801.4 km^2 and the length of the Kaliaghai river is around 118.4km. The Panch khal and Kapaleshwari nadi are the most prominent tributaries of the Kaliaghai river meets with it. On the basis of physiographic, river gradient is found to be very gentle. So sand bars appear beside the river bank and some time it appears in between the river channels. The maximum stream order of the river is four which appear in lower part of the basin.

Digital elevation model

As with most DEM data sources, the SRTM data requires significant levels of pre-processing to ensure that there are no spurious artifacts in the data that would cause problems in later analysis such as pits, spikes and patches of no data (Dowding *et al.* 2004; Gamache, 2004; Chaplot, *et al.* 2006; Fisher and Tate, 2006). In the case of d SRTM data, these patches of no data are pervasive and filled with auxiliary sources of DEM data, like

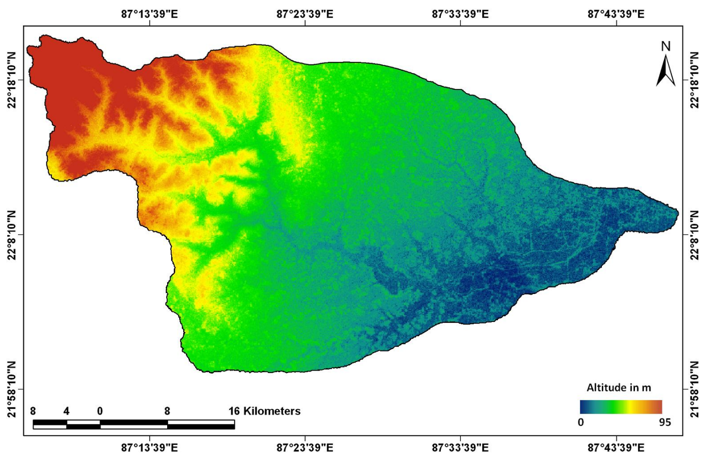
Fig.4. Drainage order and sub-basin (1-18) map of the study area



Indian Journal of Science and Technology Vol. 4 No. 10 (Oct 2011) ISSN: 0974- 6846

topographical maps. Slope length gradient factor, which is an important function for soil loss estimation, is also dependent on elevation. The study area recorded a maximum elevation of 95 meter which is observed at the North-West part of basin area (Fig.5).

Fig.5. Digital elevation of the study area, generated from SRTM data and topographical maps



Slope

The slope tool calculates the maximum rate of change of elevation between each cell and its neighbors. The lower slope value indicates relatively flat terrain and the higher the slope value steeper is the terrain. The output slope raster can be calculated as percent of slope or degree of slope. When the slope angle equals 45 degrees, the rise is equal to the horizontal run and expressed as the 100 percent slope. As the slope approaches vertical (90 degrees), the percentage slope approaches infinity. The study area has maximum of 4.5 percent slope, found in 1st, 2nd and 4th sub-basin. Entire river basin had an average slope of 1.75 percent.

Methodology

The geo-referencing method with second order polynomial equation 2 was used to rectify satellite image in the ERDAS IMAGINE software. Unsupervised (ISO data) classification technique was applied to find out different land use/ land cover classes in the study area. Overall accuracy was 96%, achieved after the accuracy assessment.

Hydrologic calculation of soil loss for Kaliaghai basin is performed using simple equations. By using universal soil loss equation (Renard, 1997) we measured the total soil loss of Kaliaghai basin. Revised Universal soil loss equation (RUSLE) is-

$$A = R \times K \times LS \times C \times P \quad \ldots\ldots\ldots\ldots (1)$$

Where, A is the potential long term average annual soil loss in tons per acre per year. This is the amount, which is compared to the "tolera
ble soil loss" limits. R is the rainfall and runoff factor by

Table 3. LS factor data

Sub-basin	Slope (%)	Length in m	Constant	NN	LS Factor
1	2.10	13616	22.1	0.5	6.39
2	2.05	12629	22.1	0.5	5.14
3	1.87	11152	22.1	0.5	3.67
4	2.02	13472	22.1	0.5	4.36
5	1.87	13841	22.1	0.5	3.10
6	1.81	8827	22.1	0.5	3.87
7	1.70	12267	22.1	0.5	2.17
8	1.74	11581	22.1	0.5	2.35
9	1.61	28773	22.1	0.5	1.90
10	1.72	17677	22.1	0.5	3.08
11	1.78	16362	22.1	0.5	2.95
12	1.69	12344	22.1	0.5	2.11
13	1.73	18218	22.1	0.5	2.39
14	1.75	34280	22.1	0.5	2.85
15	1.75	12563	22.1	0.5	2.47
16	1.77	9779	22.1	0.5	2.42
17	1.80	1832	22.1	0.5	2.95
18	1.89	13580	22.1	0.5	5.24

geographic location. K is the soil erodibility factor. LS is the slope length-gradient factor. C is the crop/vegetation and management factor. P is the support practice factor. The following equation (Robert, 2000) was used to calculate the slope length-gradient factor.

$$LS = [0.065 + 0.0456(slope) + 0.006541(slope)^2] x (slope\text{-}length \div const)^{NN} \quad \ldots\ldots\ldots\ldots (2)$$

Where, slope is the percent of steepness (%), slope length is length of slope (m), constant is 22.1 and - NN is 0.5 as slope is more than 1%. The slope length gradient factor of every sub-basin is shown in Table 3. K was flexible factor as sub-basin contained different type of soil (Robert, 2000), is shown in the Table 4. C factor was obtained multiplying crop type factor and the tillage method factor shown in the Table 5. R factor was

Table 4. K factor data (Robert, 2000)

Textural class	Organic matter content		
	Average	< 2 %	> 2 %
Clay	0.22	0.24	0.21
Clay Loam	0.30	0.33	0.28
Coarse Sandy Loam	0.07	0.07	0.07
Fine Sand	0.08	0.09	0.06
Fine Sandy Loam	0.18	0.22	0.17
Heavy Clay	0.17	0.19	0.15
Loam	0.30	0.34	0.26
Loamy Fine Sand	0.11	0.15	0.09
Loamy Sand	0.04	0.05	0.04
Loamy Very Fine Sand	0.39	0.44	0.25
Sand	0.02	0.03	0.01
Sandy Clay Loam	0.20	0.20	0.20
Sandy Loam	0.13	0.14	0.12
Silt Loam	0.38	0.41	0.37
Silty Clay	0.26	0.27	0.26
Silty Clay Loam	0.32	0.35	0.30
Very Fine Sand	0.43	0.46	0.37
Very Fine Sandy Loam	0.35	0.41	0.33

Indian Journal of Science and Technology Vol. 4 No. 10 (Oct 2011) ISSN: 0974- 6846

Fig.6. Calculated soil loss of the Kaliaghai river basin based on soil texture, satellite image, DEM using RUSLE model

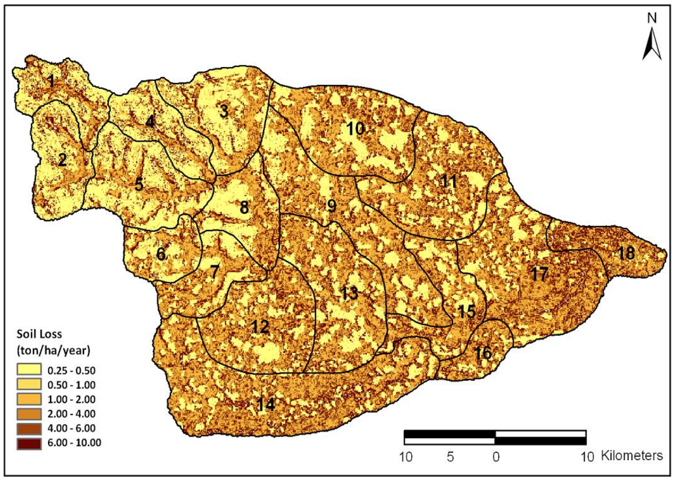


Table 5. C factor data

Crop type factor		Tillage method factor	
Crop Type	Factor	Tillage Method	Factor
Grain Corn	0.4	Fall Plow	1
Silage Corn, Beans & Canola	0.5	Spring Plow	0.9
Cereals (Spring & Winter)	0.35	Mulch Tillage	0.6
Seasonal Horticultural Crops	0.5	Ridge Tillage	0.35
Fruit Trees	0.1	Zone Tillage	0.25
Hay and Pasture	0.02	No-Till	0.25

considered as 100 for India and P factor as 0.50 for contour farming (Robert, 2000), is shown in the Table 6. All the values are put in the universal soil loss equation and total soil loss of the study area was calculated as shown in the Table 7.

Results

Rainfall and runoff factor (R), soil erodibility factor (K), slope length and steepness factor (LS), crop management factor (C) and conservation practice factor (P) are used to calculate the soil erosion in the river basin area. Monthly and annual rainfall data, soil map of the region, Digital Elevation Model (DEM), Remote Sensing (RS) techniques (with use of Normalized Difference Vegetation Index) and land use/land cover map are used to obtain the above parameters. Soil loss is estimated for each sub basin. Total soil loss is 1927778.968 tons/year calculated for the Kalaighai river basin. Soil loss characteristics of the basin are shown in Fig.6. Brown color pixels are indicating high rate of soil erosion in the basin area. The figure indicates maximum rate of soil loss in the middle and lower basin area because crop management factor, high rainfall and runoff factor and soil erodibility factor. It is found that crop management factor, rainfall and runoff factor and soil erodibility factor of the RUSLE model are the most significant factors contributing to soil loss in the study area.

Table 6. P factor data

Support Practice	P Factor
Up & Down Slope	1.0
Cross Slope	0.75
Contour farming	0.50
Strip cropping, cross slope	0.37
Strip cropping, contour	0.25

Conclusion

The study area is characterized with high soil loss capacity. In the upper basin area relative relief, average slope, drainage density and drainage frequency are more. These are the cause of erosion in the upper basin

Table 7. Estimation of total soil loss of Kaliaghai Basin

Sub-water-shed	LS factor	R factor	K factor	P factor	C factor			Soil Loss (tons /year)		
					Crop	Vegetation	Others	Vegetation	Others	Crop
1	6.39	100	0.35	0.5	0.4	0.025	0.005	6800.16	403.83	124076.10
2	5.14	100	0.2	0.5	0.4	0.025	0.005	4282.40	209.72	58380.12
3	3.67	100	0.2	0.5	0.4	0.025	0.005	2772.29	328.45	66850.08
4	4.36	100	0.2	0.5	0.4	0.025	0.005	3274.68	168.58	45631.41
5	3.10	100	0.34	0.5	0.4	0.025	0.005	6278.31	331.11	96434.68
6	3.87	100	0.27	0.5	0.4	0.025	0.005	2153.19	137.11	58000.73
7	2.17	100	0.27	0.5	0.4	0.025	0.005	1159.75	84.19	48457.68
8	2.35	100	0.27	0.5	0.4	0.025	0.005	2036.08	75.98	49645.94
9	1.90	100	0.27	0.5	0.4	0.025	0.005	955.72	307.54	109048.00
10	3.08	100	0.27	0.5	0.4	0.025	0.005	953.14	644.05	148831.78
11	2.95	100	0.27	0.5	0.4	0.025	0.005	970.97	528.37	161155.05
12	2.11	100	0.27	0.5	0.4	0.025	0.005	535.03	267.94	103924.22
13	2.39	100	0.27	0.5	0.4	0.025	0.005	767.78	428.67	125110.63
14	2.85	100	0.27	0.5	0.4	0.025	0.005	1098.99	524.40	282283.38
15	2.47	100	0.27	0.5	0.4	0.025	0.005	426.45	229.37	74334.81
16	2.42	100	0.27	0.5	0.4	0.025	0.005	142.97	57.78	36477.36
17	2.95	100	0.27	0.5	0.4	0.025	0.005	814.07	437.48	229938.24
18	5.24	100	0.14	0.5	0.4	0.025	0.005	45.97	39.94	68526.31
Total soil loss of Kaliaghai basin (tons/year)								1927778.968		

area. Rill and gully erosion are found in the upper basin area. The eroded material is transferred to the lower basin where the geographical slope is very low. Also the channel depth is decreasing every year due to excessive sedimentation. As a result the channel cannot carry excess water during the rainy season due to heavy rainfall in the upper basin area that causes flooding in the lower basin with delivery of some silt load therein. Another cause for the flood and its steadiness is the netting across the crop river/canal in for the purpose of catching fish by fisherman. Some causes are responsible for flash flood. These are soil erosion, peak discharges, textural condition of the alluvial, heavy rainfall in short time, heavy rainfall on the upper basin area. To reduce the flood action plan was taken few years ago for drazing the silt, but it is not implemented till today. There is another action plan, to stop netting across the river/channel for catching fish by the fisherman excessively, but it also under consideration. If frequency of netting becomes less, it will not be the cause of water logging for long time. To protect the erosion in the Kaliaghai river basin, which is the cause of excessive sedimentation in lower part, some action should be taken, like agriculture activity to be performed rationally, check dam construction in the upper basin area in every tributary, where it falls into next order stream, increasing vegetation coverage to reduce run-off as well as the soil loss of the river basin area.

Acknowledgement

One of the authors (BP) expresses sincere gratitude to Department of Remote Sensing and GIS, Vidyasagar University for providing digital image interpretation laboratory facility to carry out the research work.

References

1. Chaplot V, Darboux F, Bourennane H, Leguedois S, Silvera N and Phachomphon K (2006) Accuracy of interpolation techniques for the derivation of digital elevation models in relation to landform types and data density. *Geomorph.* 77, 126-141.
2. Coltelli M, Fornaro G, Franceschetti G, Lanari R, Migiaccio M, Moreira JR, Papathanassaou KP, Puglisi G, Riccio D and Schwabisch M (1996) SIR-C/X-SAR multifrequency multipass interferometry: A new tool for geological interpretation. *J. Geophys. Res.* 101, 127-148.
3. Dowding S, Kuuskivi T and LI X (2004) Void fill of SRTM elevation data - principles, processes and performance, In: images to decisions: remote sensing foundations for GIS applications, *ASPRS, Fall Conf.* Sep. 12-16, Kansas City, MO, USA.
4. Fisher PF and Tate NJ (2006) Causes and consequences of error in digital elevation models. *Prog. Phys. Geog.* 30, 467-489.
5. Gamache M (2004a) Free and low cost datasets for international mountain cartography. Documentation for the Alpine Mapping Guild, 42.
6. Kandrika S and Venkataratnam L (2005) A Spatially distributed event based model to predict sediment yield. *J. Spatial Hydrol. Spring*. 5 (1), 1-19.
7. Renard KG, Forster G, Weesies G, McCool D and Yoder D (1997) Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). *Agri. Handbook*, 703, Washington DC.
8. Robert PS (2000) Engineer, soil management/OMAFRA; Don Hilborn- Engineer, Byproduct Management /OMAFRA.
9. UNEP (1997) World atlas of desertification. 2nd edition, Arnold London.