Study on Surface Soil Erosion of Bhogdoi River Basin Using GIS and Remote Sensing

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Abstract. The river Bhogdoi is a small but perennial river coming down from the foothills of Assam-Nagaland border into the plains of Assam and finally pours into the Brahmaputra. The river is surrounded by the hills of the Naga-Patkai range on the south and the floodplains of Brahmaputra on the North. Soil erosion is one of the most serious problems in recent times which affects both cultivable and forest lands. It creates serious problems in agriculture and water resources management. This paper emphasizes on determining the surface soil erosion around Bhogdoi river basin. Since the study area experiences heavy rainfall, so it is obvious that rainfall plays an important role in study of surface soil erosion. Again, the change in land use/land cover plays an important role in surface soil erosion more specifically, the change in vegetation. This study evaluated the impact of combined effect of rainfall and LULC change and impact of change in vegetation on soil erosion. For this, Morgan, Morgan and Finney, MMF model was used. Various input parameter to the model were derived using RS and GIS using ArcGIS software and finally soil erosion was estimated. In the combined effect, average soil erosion in 1975 has been found to be 5.18 kg/m^2 which has been increased to 5.32 kg/m^2 in 2008 followed by 5.53 kg/m^2 in 2018. In the study of impact of vegetation change, it has been found that average soil erosion in 1975, 2008 and 2018 were 3.39 kg/m^2, 3.43 kg/m^2 and 3.64 kg/m^2 respectively.

Keywords: MMF model, Remote sensing and GIS, Soil erosion.

1 Introduction

Soil erosion is one of the most serious problems in recent times which affects both cultivable and forest lands. It creates serious problems in agriculture and water resources management by removing the top fertile soil and its subsequent deposition in reservoirs and lakes. Various human activities disturb the land surface of the earth, and thereby induce the significant alteration of natural erosion rates. Soil erosion by running water has been recognized as the most severe hazard threatening the protection of soil as it reduces soil productivity by removing the most fertile topsoil. Integrated use of remote sensing and GIS can be used in soil erosion assessment studies. The input parameters required for soil erosion modeling can be generated by remote sensing. Geographical Information System helps in creation of a database for the catchment which is very much useful for carrying out spatial analysis thereby

helping the decision makers in framing appropriate measures for critically affected areas.
In order to demonstrate the estimation of surface soil erosion using RS and GIS techniques, Morgan-Morgan and Finney model has been applied in Bhogdoi river basin which lies between the geographical territories of both Assam and Nagaland, India.

2 Study Area

2.1 Description of the Study Area

The study area lies within the geographical territories of both Assam and Nagaland. Geographically, the basin lies between 26º17′17″ and 26º49′22″ north lines of latitudes and 94º1′30″ and 94º29′2″ east lines of longitudes and covers an area of 1179.65 km^2 including both plains and hills within it. The part of the basin in Nagaland is formed by low hills not exceeding 1400 m above msl (mean sea level) while the part in Assam is topographically plain. In Nagaland, the river has a hilly course in the Tertiary Naga-Patkai ranges (Mukokchung district). In Assam, it flows through the southern Brahmaputra plains of Jorhat District. The Bhogdoi basin enjoys a sub-tropical monsoon climate. The average annual rainfall in the area is around 215 cm.

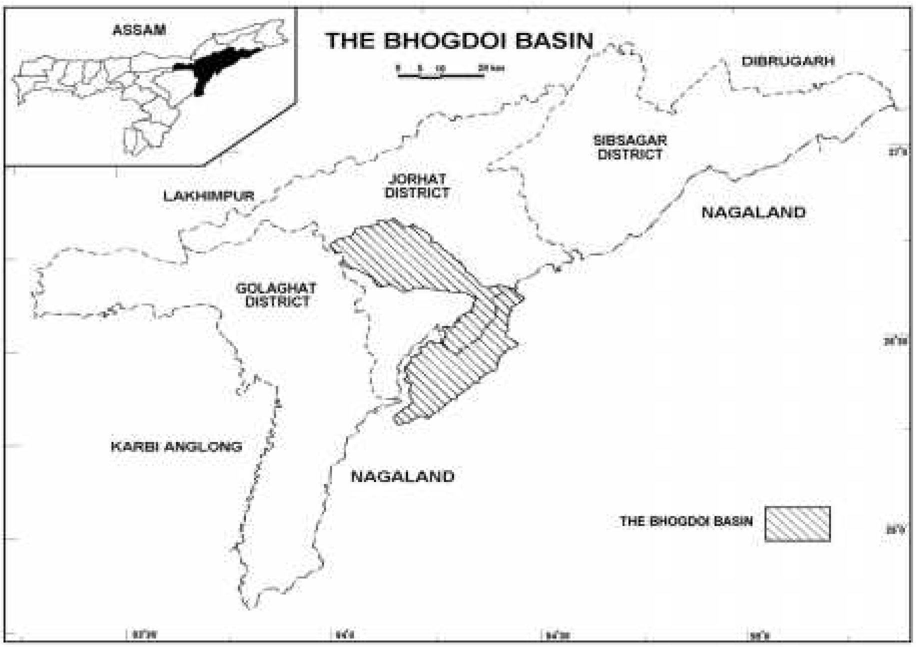


Fig. 1. Location map of the study area

3 Methodology

3.1 Preparation of Spatial Database

The Survey of India toposheets No. 83 F/10, F/14, J/1, J/2, J/3, J/4, J/5, J/6, J/7, J/9, J/10 (Scale 1:50,000) of 1975 were georeferenced, mosaic and used for preparation of base map using ArcGIS software. From the base map the Bhogdoi river basin was delineated along with river Bhogdoi and its tributaries (Fig.2.) by digitizing in GIS environment. Different attribute data like area, perimeter of the basin and length of the river were generated in GIS and save in personal geodatabase.

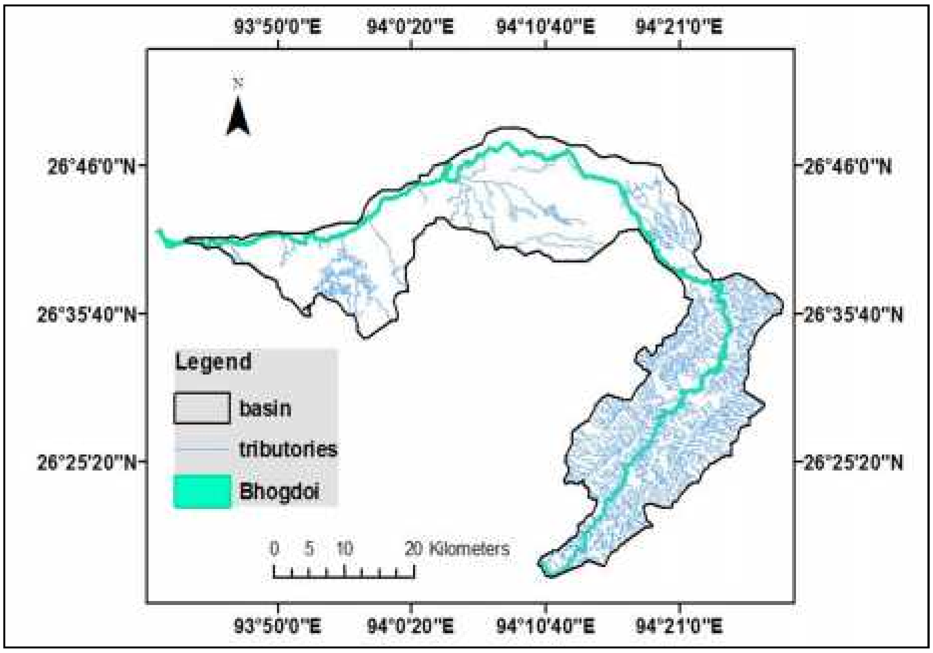


Fig. 2. Bhogdoi River basin along with river Bhogdoi and its tributaries.

3.2 Land Use/ Land Cover Change Study

The base map of 1975 was used to prepare Land use/Land cover (LULC) map of 1975. IRS-P6 LISS-III satellite imagery acquired from National Remote Sensing centre (NRSC) Hyderabad were georeferenced and registered with the base map using ground control points (GCPs) were used to map the land use/land cover status of Bhogdoi River basin of the year 2008. Satellite imagery of Bhogdoi basin was downloaded from Google Earth Pro software and was used to map the land use/ land cover status of the year 2018. The land use/land cover map of 1975, 2008 and 2018 were prepared following on screen visual interpretation method by digitizing in

ArcGIS 10.1.The attribute tables were created for the respective years to store the information such as area in square kilometer and type of the various land use/land cover categories. The different types of LULC digitized were settlement, cultivation, Tea garden, water body, open scrub and forest respectively.

3.3 Morgan-Morgan and Finney (MMF) Model

MMF model is a physically based empirical model and works by separating the process of soil erosion in the sediment phase and water phase. The water phase determines the runoff volume and the available energy of rainfall used to detach the soil particles. In the sediment phase of the model, the detachment of the soil particles is taken as a function of the soil erodibility, energy of rainfall and the interception of rainfall that is affected by vegetation. The MMF model makes comparison of the rate of predicted splash detachment with the transport capacity of the runoff or the overland flow, and the lower value of the two methods is taken as the rate of soil erosion, determining which one of these two (detachment or transport) is the factor of limitation (Morgan et al. 1984).

Water Phase

In the water phase, rainfall energy was computed by,

$$E = R \times (11.9 + 8.7 \times \log I) \quad (1)$$

Where, E is kinetic energy of rainfall (J/m^2), R is the annual rainfall (mm) and I is the intensity of erosive rain (mm/hr). This is taken as 11 for temperate climate, 25 for tropical climate and 30 for strongly seasonal climate.

The overland flow was estimated by,

$$Q = R \times \exp(- R_C / R_o) \quad (2)$$

Where, Q is the depth of overland flow (mm), R is the annual rain (mm), R_c is the soil moisture storage capacity under land cover (mm) and R_o is the mean rain per day (mm).
The soil moisture storage capacity was computed by,

$$R_c = 1000 \times MS \times BD \times RD \times (E_t/E_o)^{0.5} \quad (3)$$

$$R_o = R/R_n \quad (4)$$

Where MS is the moisture content of soil at field capacity, BD gives the bulk density of soil (mg/m^3), RD gives rooting depth of topsoil (m), E_t is the actual evaporation (mm/day), E_o gives the potential evaporation (mm/day) and R_n is the number of rainy days. RD is the soil depth from the surface to the A horizon base (up to an impermeable layer).

Sediment Phase

The detachment of soil by the rain drops was computed by:

$$F = K \times (E \times e^{-aA})^{b} \times 10^{-3} \quad (5)$$

Where, F is the rate of soil detachment by raindrop impact (kg/m^2), K is the soil detachability index (g/J) defined as the weight of soil detached from the soil mass per unit of rainfall energy, E is the rainfall energy and A is the percentage rainfall contributing to permanent interception and stream flow. The values of exponents are as: a= 0.05, b=1.0

The distributed transport capacity map G was computed by:

$$G = C \times Q^{d} \times \sin(S) \times 10^{-3} \quad (6)$$

Where, G is the transport capacity of overland flow (kg/m^2), C is the crop cover management factor and S is the steepness of ground slope (degree). The value of exponent d= 2.0

3.4 Estimation of Soil Loss using MMF Model

To determine the spatial distribution of average annual soil loss, the parameters of MMF models, viz., A, C, Et/E_o, and RD for land use/cover map were calculated using typical values of plant parameters (Morgan et al., 1984), and are presented in Table 1 and Soil parameters (K, MS and BD) are presented in Table 2. The land cover parameters and soil parameters were stored in attribute table associated with soil and land cover maps respectively. From the LULC maps, the maps of percentage rainfall contributing to permanent interception and stream flow (A) map, ratio of actual to potential evapotranspiration (E_t/E_o) map and crop cover management factor (C) map were prepared. The soil map was prepared and the soil type of entire region is mainly Sandy loam/Silty loam. From the soil map, the soil moisture content (MS) at field capacity map, bulk density (BD) of top layer map and soil detachability index (K) map were prepared in GIS environment. The overland flow (Q) map was generated using equation (2). R_c map was generated with integration of parameter maps (MS, BD, RD, E_t/E_o) using equation (3). The parameters R and R_n were calculated from the daily rainfall data. R_o was computed using annual rainfall (R) and number of rainy days (R_n). Finally, the rate of soil detachment by raindrop impact map (F) and transport capacity of overland flow map (G) were prepared using equation (5) and (6) respectively and the minimum values from each of them were used for preparation of final soil loss map.

Table 1. Values of Plant parameters (For MMF model)

Land Cover	A	E_t/E_o	C	RD
Settlement	20	0.10	0.1	0.00
Forest	30	0.9	0.08	0.1
Cultivation	25	0.58	0.3	0.05
Tea Garden	25	0.8	0.5	0.1
Open scrub	35	0.8	0.05	0.05
Water body	0	1	0	0

Table 2. Soil parameter values (For MMF model)

Textural category of soil	MS	BD	K
Sand	0.08	1.5	0.3
Sandy loam	0.28	1.2	0.3
loam	0.20	1.3	0.4
Silt loam	0.25	1.3	0.4
Clay loam	0.40	1.3	0.4
Silty clay loam	0.25	1.3	0.4
Clay	0.45	1.1	0.4

Finally the combined effect of both rainfall and vegetation as well as the effect of vegetation alone was analyzed. In analyzing the effect of vegetation alone, the average rainfalls over last 49 years were taken and the same value was applied for the three years (1975, 2008, and 2018).

The derivation of final soil loss map for the year 2018 is shown below:

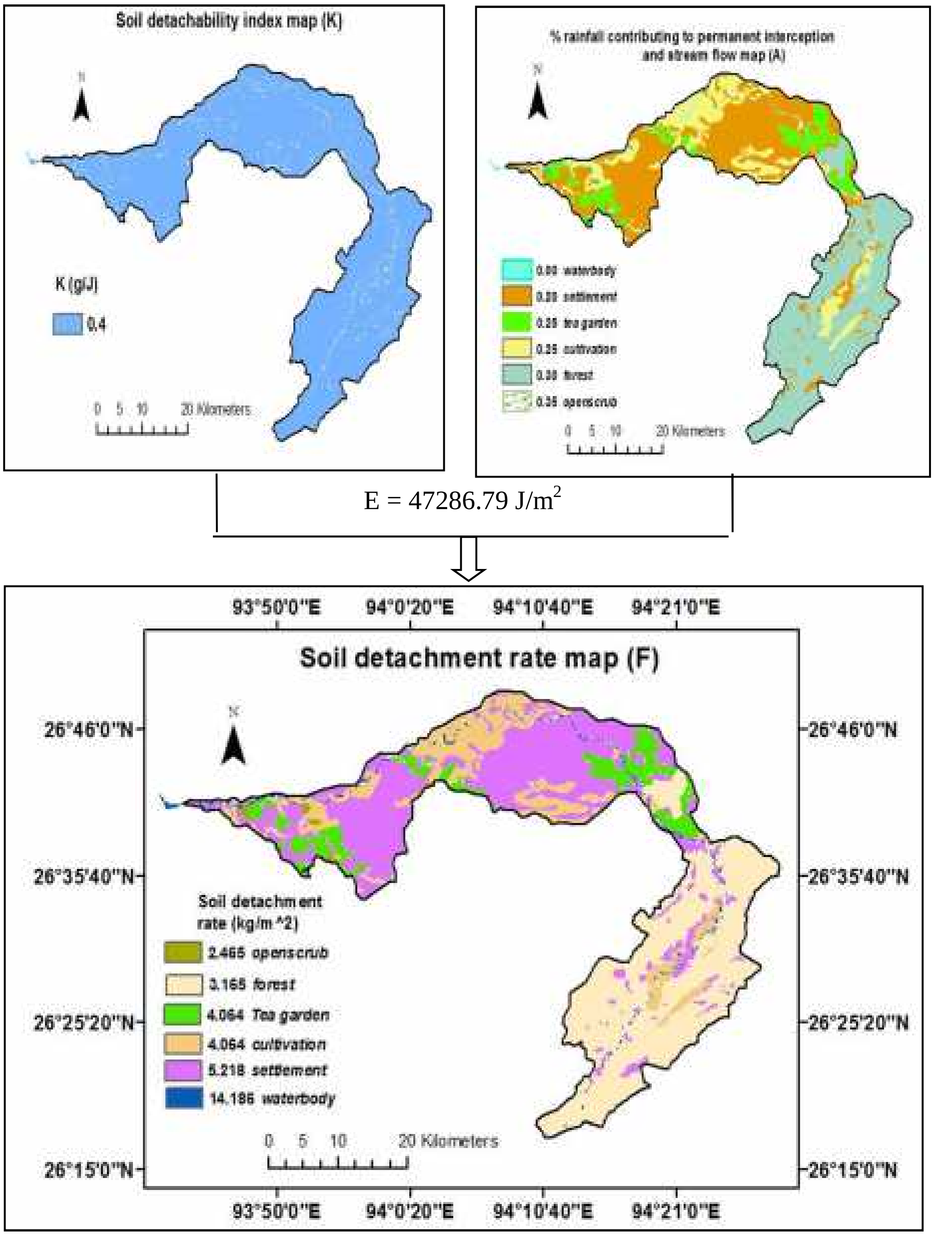


Fig. 3. Derivation of soil detachment map (F)

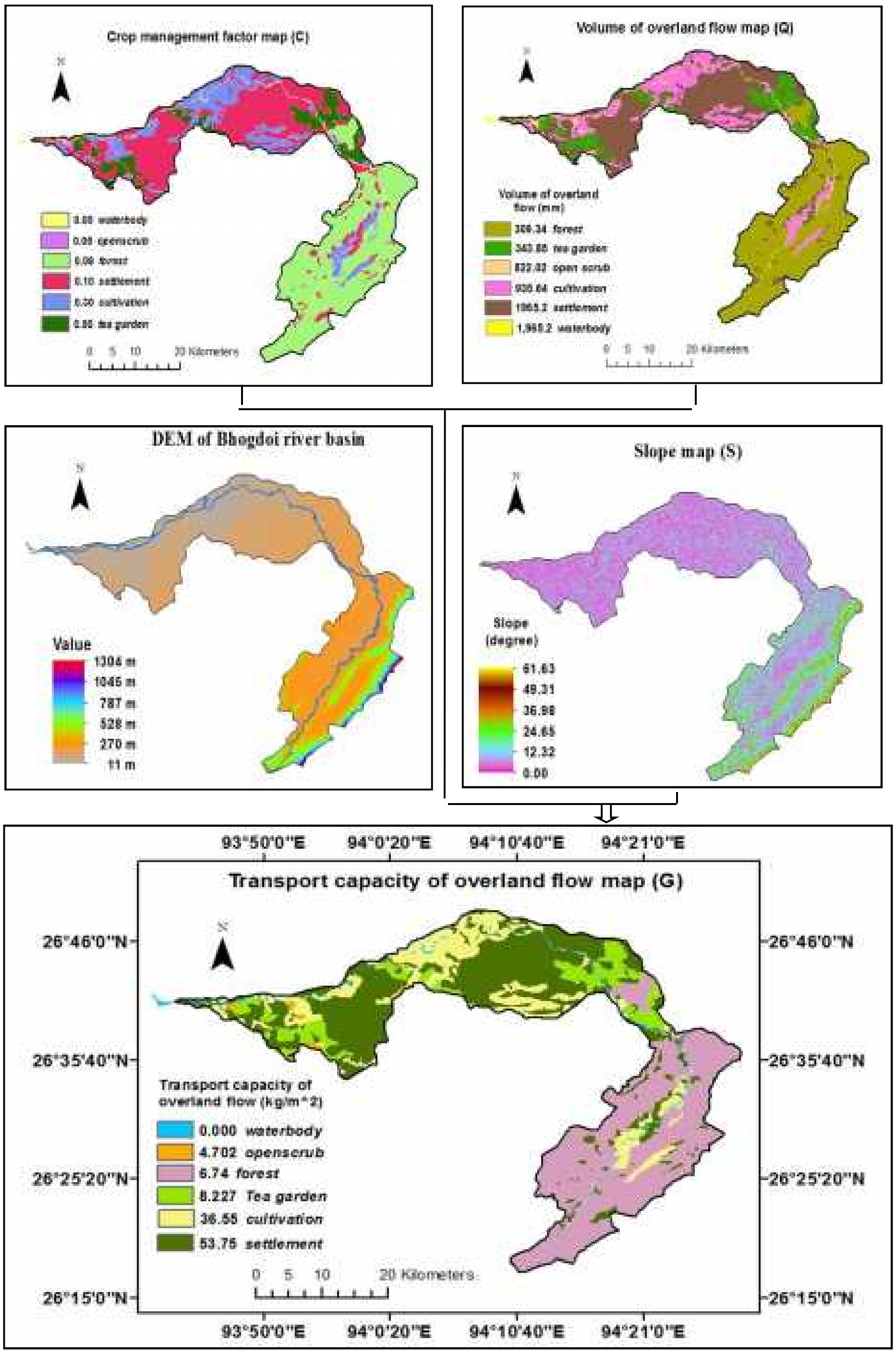
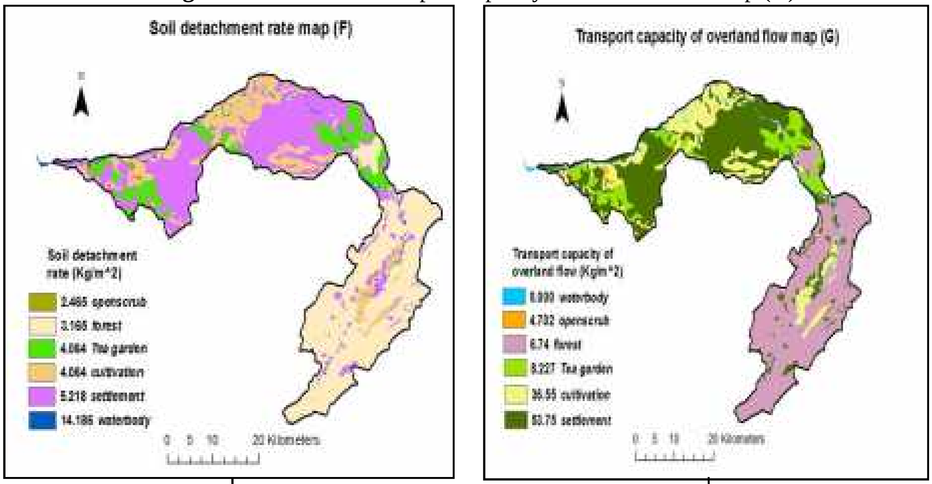

Crop management factor map (C)
N
waterbody
openscrub
forest
settlement
cultivation
tea garden
0 5 10 20 Kilometers
Volume of overland flow map (Q)
N
Volume of overland flow (mm)
forest
tea garden
open scrub
cultivation
settlement
waterbody
0 5 10 20 Kilometers
DEM of Bhogdoi river basin
N
Value
1304 m
1045 m
787 m
528 m
270 m
11 m
Slope map (S)
N
Slope (degree)
61.63
49.31
36.98
24.65
12.32
0.00
Transport capacity of overland flow map (G)
93°50'0"E
94°0'20"E
94°10'40"E
94°21'0"E
26°46'0"N
26°35'40"N
26°25'20"N
26°15'0"N
N
Transport capacity of overland flow (kg/m^2)
0.000 waterbody
4.702 openscrub
6.74 forest
8.227 Tea garden
36.55 cultivation
53.75 settlement
0 5 10 20 Kilometers

Fig. 4. Derivation of Transport capacity of overland flow map (G)



SOIL LOSS = MIN (F, G)
(Minimum Value)

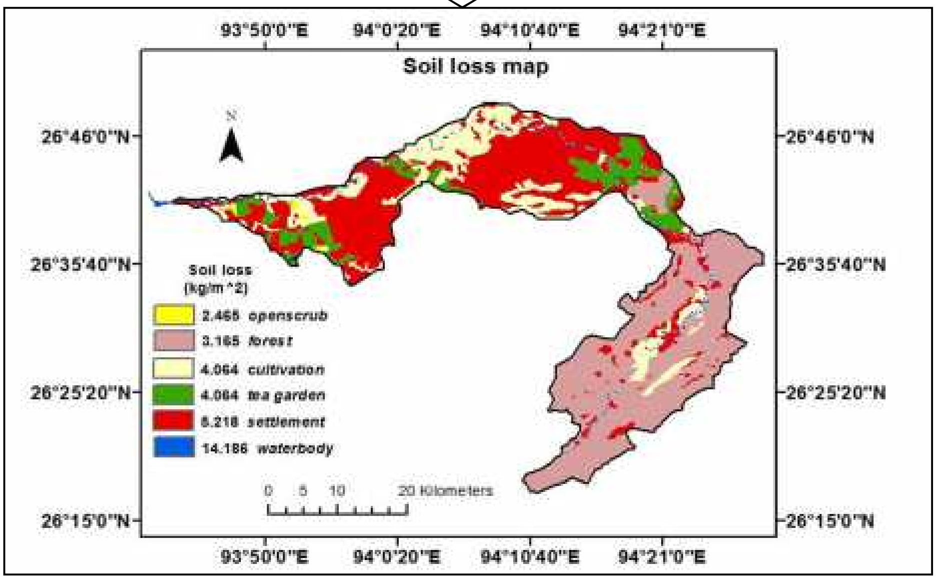


Fig. 5. Final Soil Loss Map

In the same way the soil loss map for the year 1975 and 2008 were prepared to get the annual soil erosion in kg/m^2 (Fig 6 and Fig 7). The average soil erosion was then estimated for the three respective years. By this method a combined effect of both rainfall and land use/land cover change was analyzed.

4 Results and Discussions

The change in land use/ land cover has great impact on soil erosion. In this study, a combined effect of rainfall and land use/ land cover has been analyzed for 1975, 2008 and 2018 respectively. Morgan, Morgan and Finney model has been used to estimate soil erosion. The rate of surface soil erosion depends mainly on the amount of rainfall for a particular period .More precipitation leads to the more amount of surface run off which ultimately increased the soil erosion. The amount of soil erosion is also accentuated due to deforestation. From the study, it has also been observed that the amount of area covered by vegetation has decreased since 1975 which results the more surface soil detachment resulting more erosion. The analysis of combined effects of rainfall and LULC change during the study period reveals that the rate of soil erosion was maximum in 2018 followed by 2008 and 1975 respectively. In 1975 the rate of soil erosion was about 5.18 kg/m^2 which were increased to 5.32 kg/m^2 in 2008 and 5.53 kg/m^2 in 2018 (Table 3). The increase in rate of soil erosion can be attributed due to decrease in vegetated cover and also increase in rainfall.

Table 3. Combined effects of rainfall and LULC change

Year	Annual Rainfall (mm)	Area of the river basin in (km^2)	Total area covered by vegetation (km^2)	Soil Erosion (kg/m^2)
1975	1845.2	1179.65	796.04	5.18
2008	1889	1179.65	698.60	5.32
2018	1965.2	1179.65	672.22	5.53

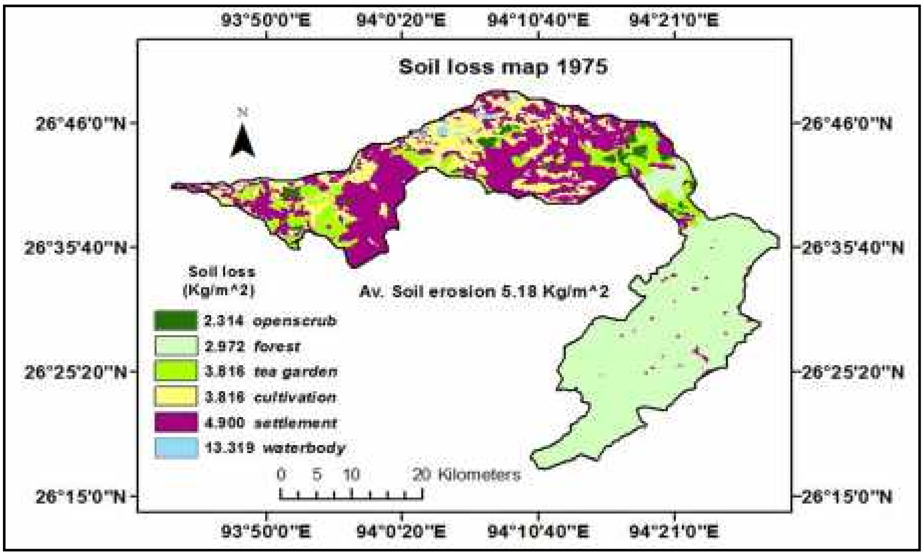


Fig. 6. Soil loss map of 1975

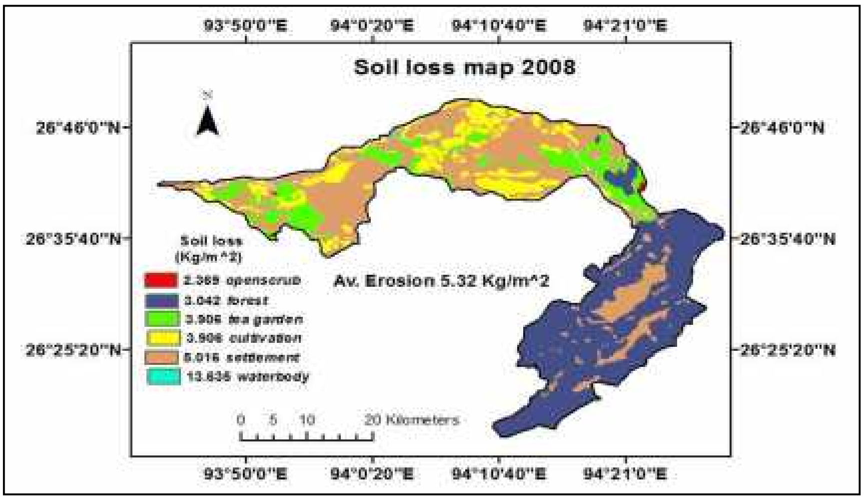


Fig. 7. Soil loss map of 2008

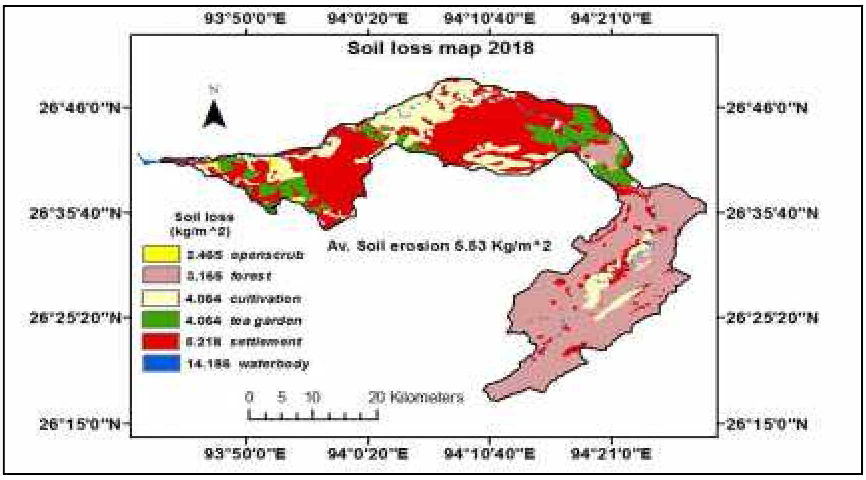


Fig. 8. Soil loss map of 2018

5 Conclusion

From the study of combined effect of annual rainfall over the study area and the LULC change reveals that the annual soil erosion was maximum in 2018 (5.53 kg/m^2) followed by soil erosion in 2008 (5.32 kg/m^2) and in 1975 (5.18 kg/m^2). Annual rainfall was maximum in 2018 (1965.2 mm) followed by annual rainfall in 2008 (1889 mm) and annual rainfall in 1975 (1845.2 mm). The result obtained from Morgan- Morgan and Finney Model shows that surface soil erosion is minimum in forested areas and open scrub areas. Cultivated areas resulted in more soil loss than forested areas due to practicing of shifting agriculture, locally called 'jhum' cultivation that reduces the soil fertility and no crops can be grown leaving the land as fallow land. Human built-up areas caused greater soil loss leaving the soil surfaced with little or no vegetation provides a prime opportunity for soil to be eroded by wind or water moving across the soil surface. Water body has resulted in maximum soil loss; it is because water is abundant and has a lot of power. It can detach soil particles and transports the detached particles downhill. These particles move from the field, and end up in streams and waterways resulting in increase in siltation of the river bed.

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