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Impacts of soil erosion in an ungauged wetland catchment

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ABSTRACT

Deeporbeel wetland is a permanent fresh water lake in the former channel of the River Brahmaputra located in the Assam state of India. It is a large natural wetland having great biological and environmental importance and is the only Ramsar site in the state. One of the major threats faced by the wetland is is erosion in the catchment and subsequent silt deposition. The paper deals with the estimation of the annual soil loss from the wetland catchment due to interrill and rill erosion in the year 2005 and comparison with that of the base year (1972). An attempt has also been made to identify the main causes responsible for the changes in the annual soil loss rate. The net sediment deposition into the wetland has also been computed as which is only about 32 % of the soil loss due to interrill and rill erosion from the catchment. The temporal changes in the annual soil loss rate can be attributed mainly to the change in land use and variation in average annual rainfall and hence in variation in Rainfall Erosivity Index (R). Sediments trappment through afforestation, construction of check dams parallel to shoreline, reduction in hill cutting and quarry operations in wetland catchment have been suggested as conservation measures for improving the health of wetland.

KEYWORDS

Catchment area;
Erosion;
Land use;
Satellite images;
Sediment load;
Soil loss;
Water spread area;
Wetland.

INTRODUCTION

"Soil Erosion and Land Degradation" is one of the most serious problems for the environmentalist which must be taken into consideration to prevent ecological imbalance in nature, especially, among the natural resources like soil, water and plants. Soil erosion is the detachment and transportation of soil materials from one place to another resulting in the removal of the uppermost fertile soil layer, thus affecting the soil fertility and productivity[13]. Overgrazing, deforestation, faulty cultivation, shifting cultivation and carelessly built roads in the catchment areas have led to the devastating affects. These include gully formation and floods leading to destruction of farmlands and villages, loss of crops, siltation of reservoirs, lakes, wetlands, etc. Eroded sediment can carry nutrients, particularly, phosphates, to waterways and contribute to eutrophication of lakes and streams. Adsorbed pesticides carried with eroded sediments adversely affect surface water quality. The problem has been further enhanced due to the high rate of population growth of both human and livestock resulting in indiscriminate exploitation of natural resources to meet the ever-increasing demand of food, fodder, fuel, fiber and fertilizers.

Different approaches have been suggested by soil scientists for the prediction of soil loss from a particular catchment. The most widely accepted approach is the "Universal Soil Loss Equation" (USLE)[18]. The USLE is highly useful tool for predicting sheet and rill erosion under various conditions of land use and land management. Recent investigations have focused on defining the parameters of the USLE for a greater range of conditions. One of the most important factors in USLE is the land use/land cover which can dominate the trend of watershed degradation to great extents.

The area considered in the study is the Deeporbeel wetland the only Ramsar site in the Assam state of India. In this paper, the annual soil loss from the wetland catchment during the year 2005 has been estimated and compared with that of the base year (1972). An attempt has also been made to identify the main causes responsible for the changes in the annual soil loss rate. The net sediment deposition into the wetland during the year 2005 has also been computed.

Review of literature

The scientific investigation of erosion of soil particles began in the year 1877. Earlier scientists carried out an extensive studies in 1895 on small plots of land to determine quantity of soil erosion. They studied wide range of effects such as vegetation and surface mulches on the interceptions of rainfall, deterioration of soil structures and also effects of soil type as well as slope on runoff and erosion during the period 1877 to 1895. Cook[2] had described a mathematical relationship describing effects of various factors of soil erosion, such as soil erodibility, soil erosivity of rainfall and degree of protection afforded by vegetal cover on process of land deterioration. Zing[19] published the result of his comprehensive study on the effect of degree of slope, slope length and recommended soil loss estimating model. Smith[15] added crop factor (C) and supporting practice factor (P) to the equation formulated by Zing[19]. Ellison[5] formulated an equation for sheet erosion, based on soil intercepted in splash samplers during 30 minutes period. The National Committee of USA in 1946 added the rainfall factor in the land slope practice method and suggested an equation, known as Musgrave equation which was further modified by Musgrave[9] for estimating average soil losses from large heterogeneous watershed. The joint conferences of personnel from SCS, the Soil and Water Conservation Research of Agricultural Research Service and Co-operating State Agencies of USA were held at Purdue University in February and July 1955. They concentrated on the need of reconciling differences among existing soil loss equation and extended this technique to regions, where no measurements of soil erosion by rain storm has been made. Wischmeier and Smith[18] have developed the Universal Soil Loss Equation (USLE) by combining the crop rotation and management factors to the rainfall factor. USLE was modified by replacing its rainfall energy factor with the runoff factor and called the model as Modified Universal Soil Loss Equation (MUSLE). A revised version of the USLE and Rusle was developed for computer applications allowing more detailed consideration of farming practices and topography for erosion prediction by Renard et al.,[12]. Since the mid-1960s, the scientists have been developing process-based erosion computer programmes that can estimate soil loss by considering the processes of infiltration, runoff, detachment, transport and deposition of sediment. Numerous research programmes have been developed / being improved for field use. Some of these process-based models are the Areal Nonpoint Source Watershed Environment Response simulation (ANSWERS) model, Agricultural Nonpoint Source (AGNPS) Pollution model, Water Erosion Prediction Project (WEPP) model and System Hydrologique European Sediment (SHESED) model[6,7].

Studies on USLE were conducted at Soil Conservation Research Demonstration and Training Centre of Indian Council of Agricultural Research (ICAR) to determine some parameters of the USLE from runoff plot study. From 1981 to 2005, various studies were carried out to determine the parameters of USLE for different regions in India. They also evaluated the USLE parameters for different regions of the country and prepared a report on soil prediction research in India. It shows the applicability of this equation for different land use pattern, soil conditions, rainfall condition, erosion

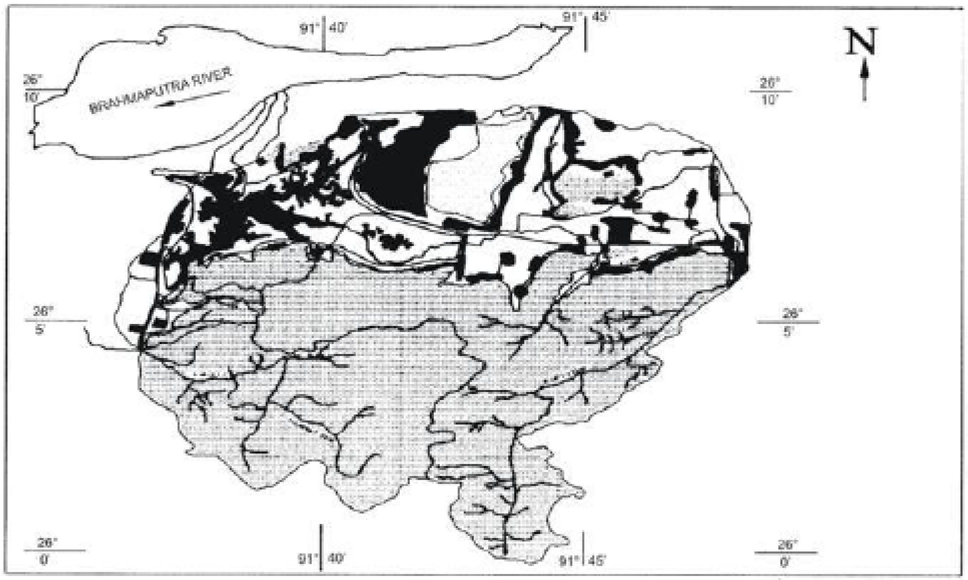

Figure 1: Catchment area of deeporbeel wetland

control practices and topographic condition[19,2,3,16].

The study area

Deeporbeel Wetland is located between 91°36' 39" E and 91 °41' 25"E longitude and 26°05'26"N and 26°09'26"N latitude to the South of Brahmaputra river in Kamrup district and 18 km South West of Guwahati city in Assam state of India. It lies at an altitude of about 50 meter above mean sea level (MSL) and covers an area of about 4,000 ha. It is a large natural wetland having great biological and environmental significance, besides being the only major storm water storage basin for the Guwahati city. The wetland is endowed with rich floral and faunal diversity. In addition to huge congregation of residential water birds, the wetland ecosystem harbours a large number of migratory waterfowl each year. The wetland also interacts with the wild life of the adjacent Rani-Garbhanga reserve forest. The Government in the year 1991 declared 414 ha of the wetland as a Bird Sanctuary. In 1994-95, it was declared as a National Wetland. In the year 2002, it was accorded as a wetland of international importance and was designated as a Ramsar site and was added to that list at number 1207.

The wetland is surrounded by the Bharalu river basin on the East, Basistha basin in the South East, Kalmoni river on the West, Jalukbari wetland on the North and Rani and Garbhanga reserve forests on the South. Figure 1 shows the catchment area of the wetland. The National Highway (NH-37) passes a little distance away from the Eastern boundary of the wetland. The wetland has a mesothermal climate characterized by high humidity and moderate temperature. The minimum and maximum temperatures range between 7°C to 26°C in January and 23°C to 37°C in July/August respectively. The average annual rainfall in the area is 1733 mm and about 90% of the rain occurs between April and September, the maximum rainy months being July and August. Relative humidity varies between 50% to 90%. Major part of the catchment area of the wetland is the reserve forest of Rani Garbhanga forest and the runoff water from the area flows into the wetland mainly through Basistha and Kalmoni rivers. Human activity exists on the Eastern and Northern parts of the wetland. Sewage from the Eastern part of Guwahati city flows into the wetland without treatment through Basistha river. According to the master plan of Guwahati city, the land use pattern in the wetland catchment can be classified as follows:

- Agricultural
- Industrial and commercial
- Public and semipublic
- Residential
- Transport and communication

Methodology

The USLE Model suggested by Wischmeier and Smith[18] has been used for the computation of soil loss from interrill and rill erosion as shown by Eq. 1.

A=RKLSCP **(1)**

Where, A=average annual soil loss, t/ (ha-year) ; R=rainfall erosivity factor, t-m-mm/ (ha-hr-year); K=soil erodibility factor, t/ (ha-year) per erosivity factor (R); L=slope length factor; S=slope steepness factor; C=crop management factor; P=conservation practice factor

The magnitude of soil erosion depends on two forces the detachment of soil particles by the impact of rainfall energy called the erosivity of rain and the ability of the soil to resist the detachment of its particles by this force is called the erodibility of soil. This relationship is expressed as shown in Eq. 2.:

Soil erosion=f [(erosivity of rain)×(erodibility of soil)] (2)

The USLE is also based on similar principles. The erosivity of rain is represented by the factor R and the erodibility of soil surface system by the multiples of the factors KLSCP. Considering the watershed as a system represented by the multiples of factors KLSCP, the input force is represented by the rainfall erosivity factor R and the output (the response to the input), which is the soil erosion, is represented by 'A'. The system model of USLE is shown in figure 2.

1. Rainfall erosivity factor (R)

The erosivity factor of rainfall (R) is a function of the falling raindrops and the rainfall intensity. Wischmeier and Smith[18] found that the product of kinetic energy of the raindrop and the maximum intensity of rainfall over duration of 30 minutes in a storm, is the best estimator of soil loss. This product is known as the Erosion Index (EI) value.

In the absence of rainfall intensity data around the watershed, the R-factor can however be approximated using monthly mean and annual precipitation data. For Indian conditions, a simple relationship between R-factor and the total annual rainfall has been derived[1] And developed after analyzing the data collected from 45 stations distributed in different rainfall zones throughout India. The relationship can be expressed by the following equation

$$R = 79 + 0.363 \times X_a \quad (3)$$

Where, R = annual rainfall erosivity factor, X_a = average annual rainfall in mm.

The coefficient of correlation for the above equation was found to be 0.83.

In the present study, the Eq. 3 has been used to calculate the value of specific year R-factor for 1972 and 2005 for computation of soil loss.

2. Soil erodibility factor (K)

The soil erodibility factor (K) is the susceptibility of the soil particles to erosion per unit of rainfall erosivity factor. In the study, the 'K' value has been estimated from TABLE 1[1,10].

For obtaining the textural classification, soil samples were collected and analyzed. The specific gravity of the soil samples was determined by Pycnometer method. Hydrometer analysis of the soil samples was done to determine the percentage of sand, clay and silt content[8]. The textural class of the soil has been determined from the Textural Classification Chart of U.S. Public Roads Administration[11]. To determine the percentage of organic matter present in the soil, the Modified Walky and Black Method was used[17]. Based on the textural classification and % organic matter content, the 'K' values of the soil samples were determined.

3. Topographic factor (LS factor)

TABLE 1: Soil erodibility factor (K)

Textural class	Organic matter content (%)		
	< 0.5	2.0	4.0
Sand	0.05	0.03	0.02
Fine sand	0.16	0.14	0.10
Very fine sand	0.42	0.36	0.28
Loamy sand	0.12	0.10	0.08
Loamy fine sand	0.24	0.20	0.16
Loamy very fine sand	0.44	0.38	0.30
Sandy loam	0.27	0.24	0.19
Fine sandy loam	0.35	0.30	0.24
Very fine sandy loam	0.47	0.41	0.33
Loam	0.38	0.34	0.25
Silt loam	0.48	0.42	0.29
Silt	0.60	0.52	0.42
Sandy clay loam	0.27	0.25	0.21
Clay loam	0.28	0.25	0.21
Silty clay loam	0.37	0.32	0.26
Sandy clay	0.14	0.13	0.12
Silty clay	0.25	0.23	0.19
Clay		0.13- 0.2	

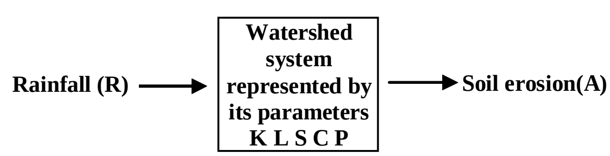

Figure 2 : System model of the universal soil loss equation (USLE)

The larger the slope length, higher the concentration of overland flow, and higher the velocity of flow which triggers a higher rate of soil erosion. On steep slopes, the flow velocity is high, which causes scouring and cutting of soil. In the study, the average slope length (L_p) and the average percentage slope (s) for each of the three sub-catchments were calculated. The combined LS value was determined from the following equation:

$$LS = \frac{L_p^{0.5}\left(1.36 + 0.97s + 0.1385s^2\right)}{100} \quad (4)$$

4. Land cover and management practices factor (CP factor)

Vegetative cover dissipates the impact force of raindrops on the soil surface and protects the soil from splash erosion by modifying the volume drop size, coefficient of distribution, impact velocity and kinetic energy of rainfall. The conservation practice factor (P) is the ratio of soil loss from a plot with a specific conservation practice to the corresponding soil loss from a plot with up and down cultivation under identical conditions.

In this study, the land cover (C) factor has been taken into consideration based on the results of the field experiments conducted for open forest, agricultural land, barren/grazing land and settlement for Indian conditions[1,14]. The 'C' factors of various land uses is shown in TABLE 2.

The management practice (P) factor is applied only in the agricultural land. The value of 'P' factor varies from 0.5 to 0.9 based on the slope steepness of the land surface. For up and down cultivation, the value of 'P' is considered as 1 and for contour farming, its value is considered as 0.80 for slope less than 1 %[4]. The value of 'P' factor has been taken as 1 for agricultural land and also for non-agricultural land in the study.

For calculating the sediment load into the wetland, suspended sediment concentration were measured for monsoon and post-monsoon seasons of the year 2005 and pre-monsoon season of the year 2006. As pre-monsoon suspended sediment data of 2005 was not available, it was assumed to be equivalent to the pre-monsoon data of 2006. Suspended sediment loads were computed by combining the water discharge (as obtained from the calculated water balance shown in figure 3) and suspended sediment concentration for the respective seasons. The Bed load has been estimated based on the empirical relationship between suspended load and bed load.

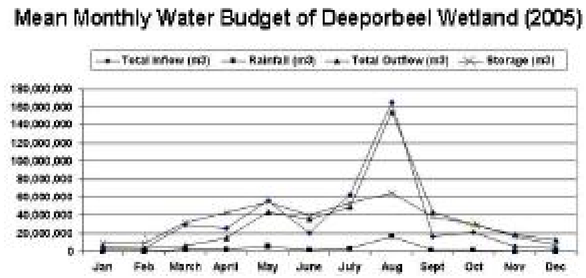

Figure 3 : Mean monthly water budget of deeporbeel wetland for the year 2005

TABLE 2: Values of 'C' factor for various land use

Land use	C Factor
Open forest	0.02
Agricultural land	0.27
Barren land / Grazing land	0.21
Settlement	0.15

TABLE 3: Results of soil loss during the year (1972) (Base Year) and (2005)

Sl.no	Details	Year 1972 Area (km^2)	Year 1972 Soil Loss (t/year)	Year 2005 Area (km^2)	Year 2005 Soil Loss (t/year)
1	Forest	134.70	475,404	116.89	360,722
2	Barren Land	6.10	22,344	18.36	58,788
3	Settlement Area	15.00	39,255	54.72	125,145
4	Grazing Land	12.90	47,253	0.21	672
5	Crop Land	51.50	242,937	27.60	113,629
	Total	220.20	827,193	217.78	658,956

5. Data used

The catchment area has been delineated based on 1972 toposheet. The total catchment area has been subdivided into three catchments, viz. catchment area for the main inlet channel (Basistha and Morabharalu river), catchment area for the second inlet channel (Kalmoni river) and catchment area which contributes to direct runoff. Using planimeter, the catchment area and land use area of each catchment have been calculated. The total area was found to be 220.20 km^2. For the year 2005, the land use statistics of the wetland catctment have been obtained from Assam Remote Sensing Application Centre (ARSAC), which is based on LISS-III satellite images. Soil classification and suspended

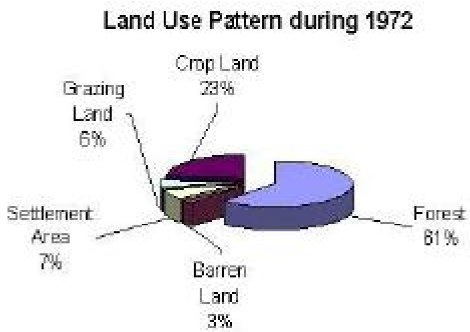

Figure 4: land use pattern during (1972)

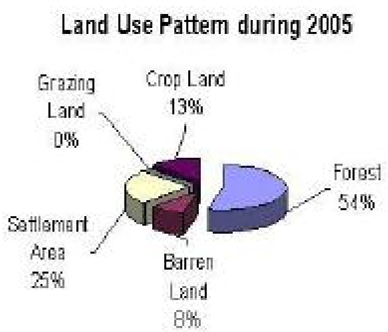

Figure 5 : Land use pattern during (2005)

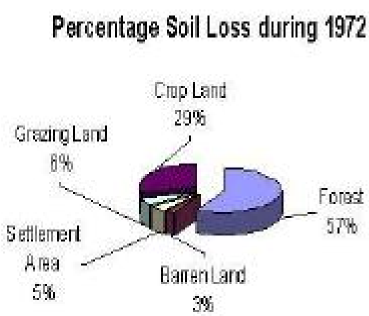

Figure 6: Percentage soil loss during (1972)

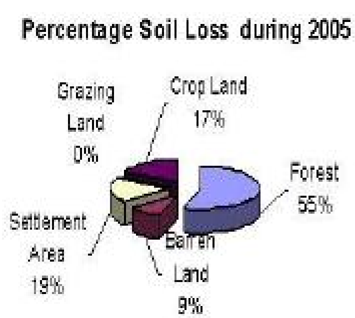

Figure 7: Percentage soil loss during (2005)

sediment concentration are based on primary data. Meteorological data was collected from the Regional Meteorological Centre, Guwahati (Assam).

RESULTS AND DISCUSSIONS

TABLE 3 shows the results of estimated soil loss from the wetland catchment due to interrill and rill erosion during the base year (1972) and 2005.

The average annual soil loss due to interrill and rill erosion during the base year has been estimated to be 37.56 t / (ha-year). During the year 2005, it was estimated to be 30.25 t/(ha-year). This soil loss rate is more than the current rate of soil loss from agricultural land in India i.e. 20 to 30 t / (ha-year)[4].

From toposheet and satellite image data, the change in land use since 1972 has been computed. Figures 4, 5, 6 and 7 shows the percentage of the land use pattern in the wetland catchment and the percentage of the soil loss for the years 1972 and 2005.

The sediment load into the wetland was computed for pre-monsoon, monsoon and post-monsoon seasons of the year 2005. Inflow of sediment during monsoon (May to August) was very high, particularly, through the main inlet channel (combined flow of Basistha and Mora-Bharalu rivers). The total sediment load entering into wetland during the year has been estimated to be 308,685 t and that flowing out of the wetland to be 99,214 t. Thus, the net sediment load deposited during the year 2005 was 209,471 t, which is only about 32 % of the estimated soil loss from the catchment due to interrill and rill erosion for the year 2005. If the total silt load carried in is assumed to be uniformly distributed over the wetland, the average depth of silting over 1834 ha average water spread area of the wetland comes to be 7.14 mm /year.

CONCLUSIONS

The following are the conclusions of the study:

- The decrease in soil loss rate during the year 2005, in comparison to the base year, can be attributed mainly to lesser annual precipitation and also to the changes in land use, particularly, conversion of agricultural and grazing land into settlement areas.
- The total sediment load entering into wetland during the year is only about 32 % of the soil loss from the catchment due to interrill and rill erosion.
- Siltation of the wetland bottom is becoming a serious problem leading to the degeneration of the

wetland. The sediment should be trapped in the catchment areas through afforestation and by constructing check dams parallel to the shoreline. This will help in accumulation of silt in the littoral zones. Hill cutting and quarry operation in the wetland catchment should be stopped immediately.

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