Original Research

Journal website : www.jeb.co.in ★ E-mail : editor@jeb.co.in

Journal of Environmental Biology

JEB™ p-ISSN: 0254-8704
e-ISSN: 2394-0379
CODEN: JEBIDP

DOI : http://doi.org/10.22438/jeb/42/2(SI)/SI-244

Geospatial assessment of water induced soil and nutrient erosion in Pabho watershed of Assam, India using USLE model

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Received: 13.06.2020 *Revised*: 15.11.2020 *Accepted*: 15.12.2020

Abstract

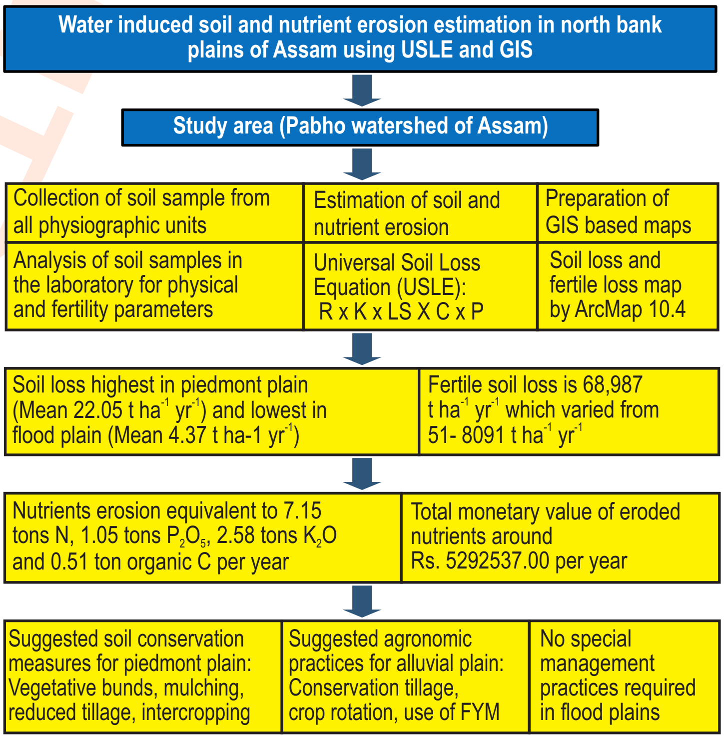
Aim: To assess the water induced soil and nutrient erosion status as well as to suggest conservation measures for Pabho watershed located in the northern Brahmaputra plains of Assam.

Methodology: A study was conducted to generate information about the annual soil loss of Pabho watershed using Universal Soil Loss Equation and ARC GIS. Soil loss was estimated by multiplying five parameters of USLE *i.e.* R (Rainfall erosivity factor), K (Soil erodibility factor), LS (Topographic factor), C (Crop management factor) and P (Conservation support factor).Nutrient erosion as well as its monetary values were also estimated by taking count of fertile soil loss.

Results: The rainfall erosivity factor (R) for watershed area was 895.08 MJ ha^{-1} mm^{-1} and the soil erodibility factor (K) ranged between 0.033 and 0.118.The LS value varied from 0.36 (flood plain) to 1.72 (piedmont plain). The estimated soil loss in the study area varied from 0.38 t ha^{-1} yr^{-1} to 45.97 t ha^{-1} yr^{-1} with a mean value of 10.80 t ha^{-1} yr^{-1}. Annual soil loss was highest in the piedmont plain and lowest in the flood plain. The amount of eroded nutrients from the agricultural land of watershed area was computed to be 7149.39 kg N, 1050.18 kg P_2O_5, 2582.41 kg K_2O and 0.51 ton of organic C per year. The total monetary value of eroded nutrients was estimated to be around Rs. 52,92,537per year.

Interpretation: The study demonstrates the use of USLE as a powerful approach for the assessment of soil erosion and identifying the erosion prone areas. Based on the assessment of erosion soil, loss soil conservation management practices like vegetative bunds, mulching, reduced tillage, intercropping are suggested for piedmont plain soils.

Key words: Nutrient erosion, Soil conservation, Soil loss, USLE model, Watershed



How to cite : Borgohain, S., B. Deka, M. Dutta, R.K. Thakuria and D.K. Patgiri: Geospatial assessment of water induced soil and nutrient erosion in Pabho watershed of Assam, India using USLE model. *J. Environ. Biol.*, **42**, 406-413 (2021).

Introduction

Soil erosion is a complex dynamic process which leads to detachment of soil particle from one place to another place by wind and water. Water-induced erosion is considered as the single most destructive process for declining the availability of land both in terms of area and quality (Lal, 2001). Water-induced erosion involves the process of detachment and transportation of soil by the impact of raindrop and flowing water and subsequently its accumulation to a new area (Wischmeier and Smith, 1978). In India about 90 per cent soil erosion is caused due to water erosion (Saroha, 2017). Soil erosion is integrally linked to nutrient erosion, and excessive soil loss resulting from poor land management has important implications for crop productivity and food security. Researchers involved in soil erosion studies for a long time have developed many models for estimating the soil loss. However, the Universal Soil Loss Equation (USLE) is being considered as the most widely used method to predict long-term rates of soil erosion from field or farm size units. The USLE model (Wischmeier and Smith, 1978) computes soil loss based on the product of rainfall erosivity (R), soil erodibility factor (K), slope steepness (LS), cover management parameter (C) and support practice parameter (P). For proper planning and execution of any development programme on watershed basis, it is essential to have watersheds in the form of maps along with relevant attributes. The GIS technology has considerable potential for using as an aid in quantitative evaluation of soil parameters, including soil loss. Deka *et al.* (2011) integrated the USLE factors and GIS to map the erosion soil loss in the Ghiladhari watershed of Assam. They observed a strong positive correlation of soil loss with relief (r = 0.946**) which indicated that the increase in degree and length of slope resulted more soil and nutrient losses. Parveen and Kumar (2012) used USLE model and GIS for assessing loss risk in Upper South Koel Basin, Jharkhand and estimated that the annual soil loss in the watershed was 12.2 t ha^{-1} yr^{-1}. Bez and Krishna (2014) carried out soil erosion assessment in DumarKocha watershed of Ranchi District in Jharkhand state using USLE and observed that annual soil erosion for the watershed ranged from <5 t ha^{-1} yr^{-1} to >80 t ha^{-1} yr^{-1}. Obi Reddy *et al.* (2016) assessed soil erosion in tropical ecosystem of Goa using USLE and found that about 53% of total geographical area of the state was subjected to severe (20-40 t ha^{-1} yr^{-1}), very severe (40-80 t ha^{-1} yr^{-1}) and extremely severe (>80 t ha^{-1} yr^{-1}) soil erosion. Molla and Sisheber (2017) estimated soil loss and conservation strategies under different slope classes and land uses in Koga watershed in the upper part of Blue Nile basin. Kandpal *et al.* (2018) carried out soil erosion assessment in three forest divisions of Shivaliks hills of Punjab. They found that the Dasuya forest division exhibited maximum soil loss (31.78 %), followed by moderately dense forest of Gurdaspur (29.20 %) and Garshnkar (11.28 %) forest division. Balakrishna and Balakrishna (2019) assessed the soils of Hemavathy river basin for estimating soil loss and identified of critical sub-watersheds. The average annual soil loss of river basin was found to be 8.00 t ha^{-1} yr^{-1} which showed moderate soil loss in the study area. Tsegaye *et al.* (2020) carried out soil erosion assessment in Genda-wuha watershed, Ethiopia using Universal Soil Loss Equation with GIS approach. They found that the average annual soil loss for entire watershed was 7.9 t ha^{-1} yr^{-1}. They also suggested various soil erosion control measures for watershed management and land use planning.

Soil erosion is one of the severe problems for the agricultural development threatening entire north eastern region (NER) of India including Assam. The Brahmaputra valley of Assam is comprised of undulating terrains and, thereby, faces severe problem of soil erosion. The most common type of soil erosion in Assam is loss of topsoil through surface run-off under heavy precipitation which causes decline in productivity of agricultural land. Pabho watershed of Assam located in the north bank plains of Assam has been reported to be erosion prone by the Department of Soil Conservation, Assam. This watershed has a niche of different physiographic units and the soils have different inherent characteristics. However, information on the the erosional nature of the soils of watershed is limited. In view of this, the present investigation was carried out to understand the soil and nutrient erosion behaviour of Pabho watershed by using USLE model and geospatial techniques.

Materials and Methods

Pabho watershed of Lakhimpur district is a part of North Bank Plain Zone of Assam. This watershed is situated between 93°90'E to 94°03'E longitude and 27°10'N to 27°22'N latitude. Geocoded FCC of Resourcesat-1 LISS-III data of 2015 data were visually interpreted and in conjunction with Survey of India toposheets (1:50,000) the physiographic map was prepared. Visual image interpretation based on colour, tonal and textural variations has led to the recognition of three distinct physiographic units which include piedmont plain, alluvial plain and flood plain (Fig. 1). Pabho watershed lovers 9640 ha area among which 1392 ha (14.44 per cent) area was covered by piedmont plain, 4340 ha (45.02 per cent) by alluvial plain and 3908 ha (40.54 per cent) by flood plain. The study area experiences humid sub-tropical climate with an average annual rainfall of 2260 mm. The mean annual temperature was more than 22°C and the differences between mean summer temperature (27.3°C) and mean winter temperature (18°C) was more than 5°C. Hence, the studied area qualifies for hyperthermic soil temperature regime. The soil moisture regime of the area was found to be Udic. GPS based 46 numbers of each surface and core soil samples were collected up to a depth of 0-25 cm from each physiographic unit on random basis. The number of surface soil samples representing different physiographic units comprises: 12, 11 and 23 from piedmont plain, alluvial plain and flood plain, respectively. The collected surface samples were air-dried, grinded and passed through 2 mm sieve. The samples were analyzed for various soil parameters which include: Sand,

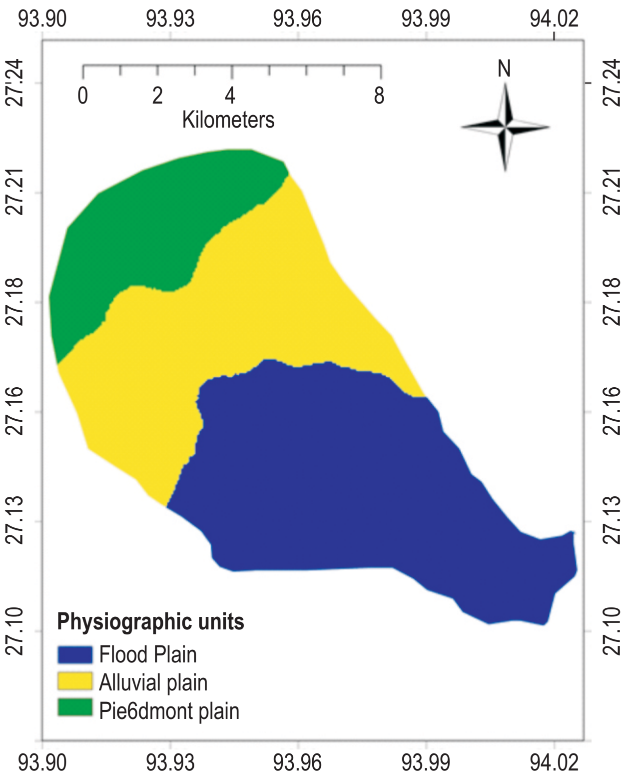


Fig. 1 : Physiographic units of Pabho watershed.

silt and clay by International pipette method (Piper, 1966), organic carbon (Walkley and Black, 1934), available nitrogen (Subbiah and Asija, 1956), available phosphorus (Bray and Kurtz, 1945) and available potassium (Jackson, 1973). Soil permeability class was determined from hydraulic conductivity of core samples as estimated by constant head method (Klute, 1985). The soil structure code was determined by observing the type, grade and size of soil aggregates in the field.

Universal Soil Loss Equation (USLE) model given by Wischmeier and Smith (1978) was used for estimation of soil loss in the watershed area. USLE model has the advantage that while estimating soil loss due weight age is given to all the major input parameters like intensity and amount of rainfall, soil erodibility, land use/land cover and slope. USLE can be expressed as: A= R × K × LS × C × P; where, A is the mean annual soil loss (t ha^{-1} yr^{-1}), R is the Rainfall erosivity factor (MJ mm ha yr), K is the Soil erodibility factor (t ha MJ^{-1} mm^{-1}), LS is the Topography factor, C is the Cover and management factor and P is the Conservation practice factor. Rainfall erosivity factor (R) was calculated following the expression given by Bergsma (1980). The derived relationship is: R = 0.1059 a.b.c + 52; where, a is the average annual precipitation, b is the maximum 24 hrs precipitation with recurrence interval of two years and c is one hour maximum precipitation with recurrence interval of two years.

The monograph developed by Wischmeier (1971) was employed to estimate K values in the study area using the following equation:

$$100\,K = 2.1 \times 10^{-4} \times M^{1.14}\,(12-a) + 3.25\,(b-2) + 2.5\,(c-3)$$

Where, K is the soil erodibility factor, M is the per cent silt + per cent very fine sand, a is the per cent organic matter, b is the soil structure code and c is the soil permeability code. The LS factor for each physiographic unit was determined based on the degree and length of slope using Survey of India Topographical Map on 1:50,000 scale and by following monograms (Wischmeier and Smith, 1978). C factors were computed on the basis of main crop grown/land use collected during the field survey. The conservation practice factors (P) were selected based on field survey information. The guidelines for assessing 'P' values for different land utilization types were taken from published literature (Singh *et al.*, 1981 and Potdar *et al.*, 2003). The soil and nutrient erosion map was prepared under GIS environment using their numerical values. For this, the computed values of all the sample sites were digitized from the location map using ArcMap 10.4. For unsampled location the soil parameter values were estimated using Inverse Distance Weighted (IDW) function as described by Jensen (1986). The interpolated maps were reclassified to get the map units and legends. The boundary of Pabho watershed was then marked over the interpolated maps to get the final map.

Results and Discussion

Soil and nutrient erosion related properties : The physico-chemical properties of soils of Pabho watershed pertaining to the estimation of soil and nutrient erosion is presented in Table 1. The textural properties of soils are described by parameters like total sand, very fine sand, silt and clay content. The total sand and very fine sand content of the studied soils ranged from 21.19 to 88.24 per cent and 8.74 - 50.77, respectively. The silt content of the soils of watershed varied from 4.95 to 61.96 per cent, while the clay content was in the range of 3.97-39.73 per cent. Among the different physiographic units, the total sand content was highest at piedmont plain (Mean 68.95 per cent) and lowest at flood plain (Mean value 45.57 per cent). Very fine sand, silt and clay content were highest at flood plain area with mean value of 23.20 per cent, 34.48 per cent and 19.96 per cent, respectively. The texture of studied soils varied from sand to clay loam. The piedmont plain soils exhibited coarser texture ranging between sand to sandy loam. The alluvial plain soils too exhibited relatively coarser texture, which varied from sand to clay loam. The texture of the flood plain soils ranged between loamy sand to silty clay loam. There was a decreasing trend of total sand from the piedmont plain to flood plain but an increasing trend of silt and clay towards downslope. These could be explained in the light of the fact soils which occurred close to native source *viz.* hills were coarser in texture (Deka *et al.*, 1996). The increasing trend of silt and clay from piedmont plain to the flood plains might be attributed to the

Table 1: Physiographic distribution of soil and nutrient erosion related properties of soils of Pabho watershed

Parameters	Piedmont plain			Alluvial plain			Flood plain		
	Range	Mean	CV (%)	Range	Mean	CV (%)	Range	Mean	CV (%)
Total sand (%)	52.32-87.04	68.95	16.74	25.12-88.24	63.83	34.20	21.19-80.26	45.57	40.46
Very fine sand (%)	11.24-24.59	17.80	24.68	8.74-50.77	22.63	47.89	9.56-45.33	23.20	44.00
Silt (%)	4.95-33.66	19.09	39.45	5.68-46.70	21.56	68.90	8.01-61.96	34.48	49.02
Clay (%)	3.97-19.54	11.97	48.08	5.54-28.18	14.61	57.56	9.09-39.73	19.96	42.03
Textural class	Sand to Sandy loam	-	-	Sand to clay loam	-	-	Loamy sand to Clay Loam	-	-
Structure	Single grain to Sub angular blocky	-	-	Single grain to Sub angular blocky	-	-	Single grain to Sub angular blocky	-	-
Organic carbon (%)	0.27 – 1.48	0.63	48.97	0.24 – 1.33	0.65	55.39	1.39–2.67	2.03	19.38
Hydraulic conductivity (cm hr^{-1})	1.09 – 6.16	2.82	72.70	0.58–6.19	3.10	72.90	0.27–6.18	1.48	95.95
Available N (kg ha^{-1})	124.34–276.89	215.31	25.68	163.07–365.23	244.56	23.63	134.2–398.28	247.39	28.16
Available P_2O_5 (kg ha^{-1})	5.13 – 41.04	26.31	43.52	20.52–89.77	45.07	39.32	10.26–43.86	26.67	43.12
Available K_2O (kg ha^{-1})	28.94–114.68	57.07	47.40	28.94–254.01	125.89	61.88	28.94–173.63	83.23	46.32

fact that finer materials were washed down from upslope and, thereby, they got deposited in the downslopes. The existence of significant positive correlation of relief with sand (r = 0.471**) as well as significant negative correlation with silt (r = -0.409**) and clay (r = -0.380**) substantiate the findings. Similar findings were reported by Deka *et al.* (2017). The values of coefficient of variation for very fine sand and total sand were found to be highest in the alluvial plain (47.89 per cent) and flood plain (40.46 per cent), respectively. In contrary, the values of coefficient of variation for both silt (68.90 per cent) and clay (57.56 per cent) were highest in the alluvial plain soils. The silt and clay fraction showed high variability for piedmont plain, alluvial plain and flood plain which substantiate the findings of Oku *et al.* (2010). The structure of soils varied from single grain to sub angular blocky in soils of all the physiographic units. The hydraulic conductivity of soils varied from 0.58–6.19 cm hr^{-1}. The alluvial plain soils exhibited highest hydraulic conductivity (Mean 3.10 cm hr^{-1}), while the soils of flood plain exhibited the lowest hydraulic conductivity (Mean 1.48 cm hr^{-1}). The hydraulic conductivity showed the highest value of coefficient of variation amongst all the studied soil properties which might be due to wide variation in textural properties of soils in different physiographic units of watershed.

The organic carbon content of the soils of watershed ranged between 0.24 - 2.67 per cent. Among the physiographic units, the organic carbon content was highest in the flood plain soil with mean value of 2.03 per cent and lowest in the piedmont plain with mean value of 0.63 per cent. Lower organic matter content in piedmont plain soils could be attributed to higher amount of coarser fraction and slope factor which resulted in washing out of organic matter with the rain water through run off. A significant negative correlation of organic matter with relief (r = -0.216) substantiate this finding. Similar results were also obtained by Deka *et al.* (2011). On the other hand the soils of alluvial and flood plains exhibited somewhat higher organic matter content. This might be due to their relatively flat topography which helped in more retention of water and, thereby, supported better growth of vegetation for building up of organic matter (Sawhney *et al*. 1996). The available N varied from low to medium (124.34 to 398.28 kg ha^{-1}) with a mean value of 238.35 kg ha^{-1}. The increasing trend of available N from the piedmont plain to the alluvial plain might be due to contribution of available N by organic matter fraction. The significant positive correlation (r = 0.401**) between these two parameters supports the finding. The amount of available P_2O_5 in the studied soils recorded low to high (5.13 to 89.77 kg ha^{-1}) with a mean value of 30.97 kg ha^{-1}. However, no definite trend was observed in respect of available phosphorus in different physiographic units of the studied soils. The amount of available K_2O in the studied soils was low to medium (28.94 to 254.01 kg ha^{-1}) with a mean value of 86.60 kg ha^{-1}. Alluvial plain and flood plain showed higher content of available potassium than piedmont plain which might be attributed to high clay content which contributed higher cationic exchange sites in the soils (Deka *et al.*, 2011).

Estimation of soil loss factors : For estimating soil loss of the Pabho watershed, the factors associated with the USLE model were first computed. The details about the estimation of the factors are described below:

Rainfall erosivity factor (R) : Rainfall data for the period from 2000-2018 was obtained from the Department of Agricultural Meteorology, Assam Agricultural University for the study area. The annual precipitation, maximum 24 hrs precipitation and one hour maximum precipitation in the studied area were found to be 226.00 cm, 12.36 cm, and 2.85 cm, respectively. The rainfall

Table 2 : Range and mean of USLE factors and soil loss in different physiographic units of Pabho watershed

	Piedmont plain		Alluvial plain		Flood plain	
	Range	Mean	Range	Mean	Range	Mean
R	-	895.08	-	895.08		895.08
K	0.033 - 0.091	0.050	0.033-0.093	0.06	0.034-0.118	0.090
LS	1.72 - 1.72	1.72	0.36-1.04	0.98	0.36-0.36	0.36
C	0.40 - 0.50	0.42	0.01-0.50	0.36	0.29-0.5	0.30
P	0.54 - 1.00	0.62	0.54-1.00	0.69	0.30-1.00	0.52
Soil loss(t ha^{-1} yr^{-1})	11.04 - 45.97	22.05	0.38-18.64	11.98	0.94-10.92	4.37

Table 3 : Land under agriculture, fertile soil loss and nutrient erosion in different physiographic units of Pabho watershed

	Piedmont plain		Alluvial plain		Flood plain	
	Range	Total	Range	Total	Range	Total
Land under agriculture in different sampling sites (ha)	28 - 320	1700	81 - 322	1840	44 - 222	2266
Annual fertile soil loss from agricultural land of different sampling sites (t yr^{-1})	565 - 8091	34045	51 - 5968	24671	60 - 1315	10271
Nutrient erosion(Kg)						
Avail. N	9.87-233.82	3365	4.38-635.05	2610	9.87-233.82	1175
Avail. P_2O_5	0.76-24.09	468	1.76-111.02	460	0.76-24.09	122
Avail. K_2O	2.59-55.07	779	0.66-482.03	1437	2.59-55.07	366
Org. C	0.66-21.59	213	0.51-79.28	207	0.66-21.59	93

erosivity factor (R) for the watershed area was determined to be 895.08 (Table 2) and it was found to be a driving factor of soil erosion processes in the study area.

The soil erodibility factor (K) reflects the integrated efect of soil properties and, thereby, exhibits the general proneness of a particular type of soil to erosion. The K factor for each location was calculated using field and laboratory estimated data of texture, organic matter content, structure and permeability of surface soil samples following monograms given by Wischmeier and Smith (1978). The range and mean K value for different physiographic units are given in (Table 2). The soil erodibility factor (K) of the studied soils varied from 0.033 to 0.118. The K value was found to be lowest (Mean 0.050 t ha MJ^{-1} mm^{-1}) in piedmont plain, while the flood plain soils exhibited highest K value (Mean 0.090 t ha MJ^{-1} mm^{-1}). This might be due to coarser nature of piedmont plain soils which contributed higher permeability of water and, thereby, lesser runoff. Similar findings were also reported by Deka *et al.* (2011).

The LS factor of the physiographic units (Table 2) varied based on the degree and length of slope. The lowest LS factor values of 0.36 was observed in the very gently to gently sloping soils of the flood plain areas. In contrary, the moderately sloppy lands of piedmont plain which was at higher elevation showed the highest LS value (1.72). The crop cover and management factor (C) helps in determining the relative effectiveness of soil and crop management systems in reducing or preventing soil loss. The crop cover and management factor (C) values used for different types of land units were: paddy cultivation: 0.29 (for lower relief) and 0.40 (for higher relief), tea cultivation (0.01), waste land (0.50) and fallow land (0.69). These values were determined using information on land use/land cover and following the tables given by Obi Reddy *et al*. (2016). The C factor indicated the effect of conservation plans on soil loss and the possible distribution of soil loss potential with subsequent adoption of crop rotations or other management practices (Van der Knijff *et al.,* 2000).

The conservation practice factor (P) factor reflects the effects of practices that would reduce the quantity and rate of runoff water and, thereby, could reduce the intensity of erosion. The P values were chosen based on field survey information. It was observed that the studied area had no any soil or water conservation measures, and hence the P values were assigned based on land utilization types. Under agricultural land the single crop land had poor bunding as compared to double crop and hence the 'P' value of 0.54 was assigned to single crop land and 0.30 to double crop land. For tea plantation 'P' value was assigned to be 0.70 as growing of plantation crop is a type of conservation practice. Fallow land and wasteland were assigned 'P' value as 1.00. Amongst the different physiographic units the highest (Mean 0.69) and lowest (Mean 0.52) 'P' values were observed in alluvial plain and flood plain, respectively.

Estimation of soil loss : After estimating the different USLE factors (R, K, LS, C and P) the total soil loss (A) was computed by

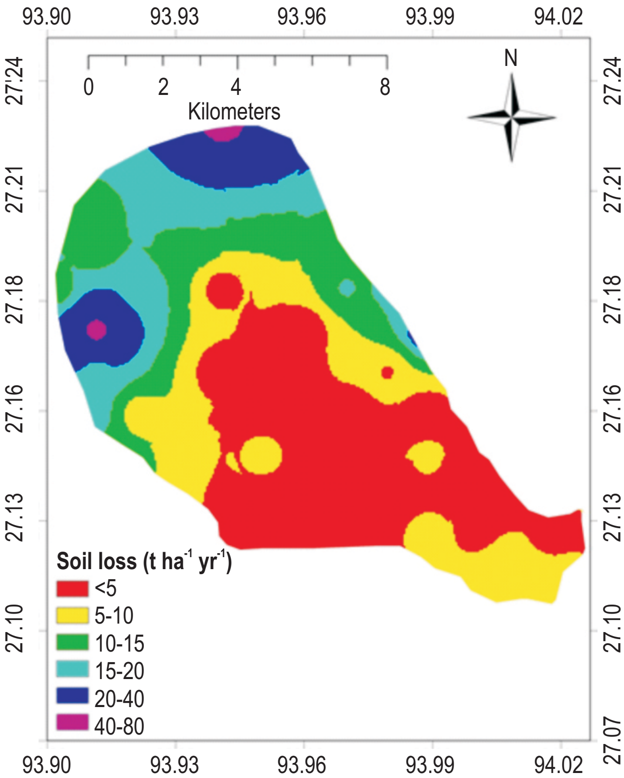


Fig. 2 : Soil loss map of Pabho watershed.

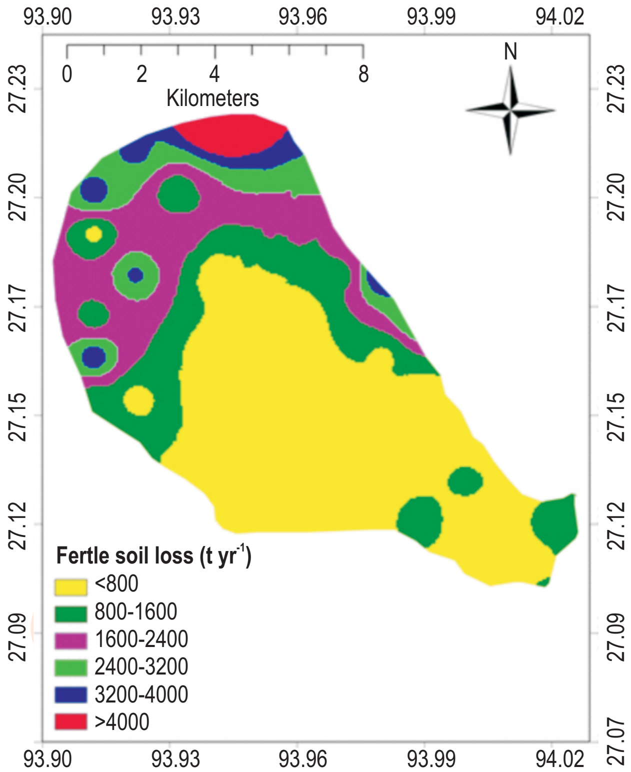


Fig. 3 : Fertile soil loss from different physiographic units of Pabho watershed.

multiplying all the factors. The soil loss in the studied area varied from 0.38 t ha^{-1} yr^{-1} to 45.97 t ha^{-1} yr^{-1} (Table 2) with a mean value of 10.80 t ha^{-1} yr^{-1}. The annual soil loss was found to be highest in the piedmont plain (Mean value 22.05 t ha^{-1} yr^{-1}) and lowest in the flood plain (Mean value 4.37 t ha^{-1} yr^{-1}). Based on estimated soil loss, the watershed area was grouped into different erosion classes *viz.*, slight (<5 t ha^{-1} yr^{-1}), moderately slight (5-10 t ha^{-1} yr^{-1}), moderate (10-15 t ha^{-1} yr^{-1}), moderately severe (15-20 t ha^{-1} yr^{-1}), severe (20-40 t ha^{-1} yr^{-1}) and very severe (>40 t ha^{-1} yr^{-1}). The spatial distribution of different soil erosion classes is represented in Fig. 2. Nearly 24.78 percent (2,389 ha) area of the watershed was under slight erosion having soil loss of less than 5 t ha^{-1} yr^{-1}. Moderately slight (2069 ha) and moderate erosion (2300 ha) area of the watershed were found to be 21.46 per cent and 23.86 per cent, respectively. Amongst the watershed area, moderately severe (2256 ha), and severe (593 ha) erosion classes covered 23.40 per cent and 6.15 per cent, respectively. Nearly 0.35 per cent (33 ha) area exhibited very high erosion status.

From the investigation it was found that the soil erosion was in the range of moderate to very severe in the piedmont plains located at the upslope. In contrary, the soils at downslope like alluvial plain exhibited very slight to moderately severe erosion. The flood plain soils with gentle slope exhibited very slight to moderate erosion. The soil loss showed a decreasing trend from piedmont plain towards the flood plain area. Slope played an important role with reference to the susceptibility of an area to soil erosion (Sharma *et al.*, 1985).

Estimation of fertile soil loss : The annual fertile soil loss of a sampling site was computed by multiplying the amount of soil loss with the existing amount of agricultural land in that site. The information about the amount of agricultural land in various sampling sites of Pabho watershed was collected from the Department of Agriculture, Assam. The variation of agricultural land and fertile soil loss in different physiographic units of Pabho watershed is presented in Table 3. It was found that the total agricultural land of Pabho watershed was 5806 ha, which encompasses 1700 ha land from piedmont plain, 1840 ha from alluvial plain and 2266 ha from flood plain. The annual fertile soil loss from agricultural land of different sampling sites was found to be highest in piedmont plain (34045 t yr^{-1}), followed by alluvial plain (24671 t yr^{-1}) and flood plain (10271 t yr^{-1}). This is attributed to higher soil loss in piedmont plain which gradually decreased towards flood plain. The spatial distribution of annual fertile soil loss from agricultural land of different sampling sites of the watershed area has been presented in Fig. 3. It was observed that about 3463 ha (35.92 per cent) area of the watershed had fertile soil loss value less than 800 t yr^{-1}, while 2218 ha (23.01) per cent) area had fertile soil loss between 800-1600 t yr^{-1}. Nearly 1870 ha (19.40) per cent) area exhibited fertile soil loss value between 1600-2400 t yr^{-1}. The fertile soil loss between 2400-3200 t yr^{-1}, and

Table 4 : Total nutrient erosion and their monetary value

Nutrient	Nutrient erosion	Equivalent loss as fertilizer/manure*	Rate of fertilizer/ manure**	Monetary value of nutrient loss
	(ton)	(ton)	(Rs per ton)	(Rs per yr)
Available N	7.15	15.54	5700.00	88578.00
Available P_2O_5	1.05	6.56	7600.00	49856.00
Available K_2O	2.58	4.30	12582.00	54103.00
Organic C	0.51	1020	5000.00	5100000.00
Total	11.29			5292537.00

*Urea for available N, Single super phoshphate for available P_2O_5, Muriate of potash P for available K_2O, Farm yard manure for organic C; ** Indian Potash Limited

1600-2400 t yr^{-1} were found to be 1545 ha (16.03 per cent) and 377 ha (3.91 per cent), respectively. About 167 ha (1.73 per cent) area of the watershed exhibited very high annual fertile soil loss (>4000 t yr^{-1}).

Estimation of nutrient erosion : Due to fertile soil loss, nutrients were being eroded from agricultural land of different sampling sites in the Pabho watershed. The nutrient erosion of the watershed was computed based on the nutrient content of different soil sampling sites and the annual fertile soil loss from the corresponding sites. The nutrient erosion (Table 3) in terms of available N varied from 9.87-233.82 Kg, 4.38-635.05 and 9.87-233.82 in piedmont plain, alluvial plain and flood plain, respectively. Nutrient erosion in terms of available P_2O_5 was found to be highest (Mean 468 kg) in piedmont plain and lowest (Mean 366 kg) in flood plain. Similarly, the eroded amount of organic carbon was found to be highest (Mean 213 kg) in piedmont plain and lowest (Mean 93 kg) in flood plain. However, nutrient erosion in terms of available K_2O was highest in alluvial plain (Mean 1437 kg) and lowest in flood plain (Mean 366 kg). Higher amount of nutrient erosion in piedmont plain could be attributed to higher fertile soil loss from that area.

Estimation of monetary value due to nutrient erosion : The total annual loss of available N, available P_2O_5 and available K_2O in the Pabho watershed was estimated to be 7.15 tons, 1.05 tons and 2.58 tons, respectively (Table 4). The eroded nutrients in terms of available N, P_2O_5 and K_2O were found to be equivalent to 15.54 tons of urea (46% N), 6.56 tons of single super phosphate (16% P_2O_5) and 4.30 tons of muriate of potash (60% K_2O) fertilizer. The total monetary value of the eroded nutrients was estimated by taking the prevailing market price of urea, single super phosphate and muriate of potash @ Rs. 5700.00, Rs. 7600.00 and Rs. 12582.00 per ton, respectively. It was found that owing to nutrient erosion a sum of Rs 192537.00 was being lost from the Pabho watershed annually (Table 3) which includes Rs. 88578.00 as available N, Rs. 49856.00 as available P_2O_5 and Rs. 54103.00 as available K_2O. By considering the C:N ratio of stable organic matter as 1:10, the annual loss of soil organic carbon from the watershed area (0.51 ton) was found to be equivalent to 5.1 tons of nitrogen. The average nitrogen content of farm yard manure being 0.50 per cent, it was found that to supplement 5.1 tons of nitrogen about 1020 tons of farm yard manure will be required. Taking an average market price of farm yard manure as Rs. 5000 t^{-1}, the monetary value of the eroded organic carbon was estimated to be as Rs. 5100000.00. Thus, the total monetary value of the eroded nutrients from the Pabho watershed accounted to be as Rs 5292537.00 per year.

Suggested conservation measures : The piedmont plain soils were coarse textured with low organic matter content showing moderate to very severe erosion. As such vegetative bunds, mulching, reduced tillage, use of farmyard manure, inter cropping with nitrogen fixing trees and crops would improve the erosion status and productivity of these soils. Similar management practices were also suggested by Deka *et al.* (2011) for the upper piedmont plains of Sonitpur district (Assam) which exhibited an annual soil loss of 15.61 t $ha^{-1}yr^{-1}$. The alluvial soils showed very slight to moderately severe erosion and, hence, good agronomic practices like conservation tillage, crop rotation, use of mulching will be effective for improving the soil erosion status. The flood plain soils having very slight to slight erosion require no special soil conservation measures.

Add-on Information

Authors' contribution: S. Borgohain: Collected and analyzed soil samples; **B. Deka:** Guided first author and prepared the manuscript; **M. Dutta:** Analyzed soil chemical parameters; **R.K. Thakuria:** Analyzed soil physical parameters; **D.K. Patgiri:** Statistical analysis of data.

Research content: The research contents is original and has not been published elsewhere

Ethical approval: Not Applicable

Conflict of interest: The authors declare that there is no conflict of interest.

Data from other sources: Not Applicable

Consent to publish: All authors agree to publish the paper in *Journal of Environmental Biology*.

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