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Cost estimation of soil erosion and nutrient loss from a watershed of the Chotanagpur Plateau, India

Aastha Gulati[1] and S. C. Rai[2,*]

[1]TERI University, Vasant Kunj, New Delhi 110 070, India
[2]Department of Geography, Delhi School of Economics, University of Delhi, Delhi 110 007, India

Soil erosion is a major threat to the sustainability of agriculture in mountain regions of the world. The present study was conducted to assess overland flow, soil and subsequent nutrient loss from different land-use/land-cover in a watershed of Chotanagpur Plateau. It was observed that overland flow was greatest in orchard (30.73%) and lowest in vegetable field (15.84%). Soil loss from the field plots ranged between 9 and 37 tonnes/ha during the monsoon months. Nutrient leaching was highest in paddy fields. A strong positive correlation was observed between organic carbon and soil loss ($P < 0.01$). On an average, 590 kg of macro-nutrients (N, P and K) were lost per hectare during the monsoon season. Approximately INR 8893 ha^{-1} (US$ 137 ha^{-1}) would be required to replace this loss through inorganic fertilizers. Agricultural practices in mountain areas should be strengthened with more agroforestry components to promote conservation of soil, water and nutrients.

Keywords: Agroforestry, land-use/land-cover, macro-nutrients, watershed.

SOIL erosion is a major threat to the sustainability of agriculture all around the world and more specifically in developing countries. It adversely affects the productivity of agricultural, forest and rangeland ecosystems[1–4]. Soil erosion rates are highest in Asia, Africa and South America, with an average rate of 30–40 tonnes ha^{-1} annually[5,6]. In the last 40 years, about 30% of the world's arable land has become unproductive and much of it has been abandoned for agricultural use[7]. Farming systems are managed traditionally and are dependent on surrounding natural resources. The soil without tree cover on hilly slope associated with more intensive agricultural practices is vulnerable to erosion and reduced fertility. Various studies[3,8,9] suggest that removal of organic matter and essential nutrients takes place during the process of soil erosion. However, nutrient erosion is not given the needed attention, as it is a slow process and does not lead to major catastrophes. Often, to offset the nutrient loss caused by erosion, large quantities of fertilizers are applied. This shadows the debilitating effect that soil erosion has on the productive capacity of agricultural lands. Topsoil depletion not only results in depleted nutrients, but also

*For correspondence. (e-mail: raisc1958@rediffmail.com)

affects the soil biota and soil structure[7]. In recent years, rapid population growth, urbanization and industrialization have increased the food demand and decreased the agricultural land holdings size[10], further adding to degradation of land.

Estimating soil erosion in monetary terms is significant and highlights the importance of conservation. The major on-site cost of erosion in agricultural fields is expended to replace the lost nutrients and water. It has been estimated that soil erosion in USA costs about US$ 37.6 billion each year in terms of productivity loss[11]. According to another estimate[9], it is around US$ 20 billion annually. About 5.4 mt of fertilizer worth US$ 245 million is washed away by erosion across India[3]. As a result of ammonia volatilization and leaching, about half the amount of fertilizers applied each year in areas of heavy rainfall during the southwest monsoon in India is lost[3]. This clearly implies that use of excessive fertilizers is not the solution for eroding nutrients. Therefore, understanding the relationship between land-use/land-cover and hydrology is critical to the prediction of nutrient budgets for the functioning of the watersheds. The lack of appropriate data on erosion rates often acts as a barrier in objective evaluation of the applicability of conservation practices. Keeping this in mind, the present study aims to estimate and quantify the rate of soil and nutrient erosion from selected agricultural fields in the watershed, as opposed to land management in general. By making such an estimate the study aims to form the basis for soil management programmes and policies.

The selected watershed lies in the Chotanagpur Plateau. The area extends from 23°26′30″N to 23°30′10″N and 85°18′20″E to 85°20′15″E, with an altitudinal variation of 600–715 m amsl, with a total area of 14 sq. km encompassing seven villages (Figure 1 *a*). The average slope varies from 1% to 5%. The watershed receives an average annual rainfall of 1300–1500 mm, which occurs mostly between June and September. Monsoon rains are characterized by high intensity and short duration, which are capable of producing large volumes of run-off (Figure 1 *b*). The mean summer and winter temperatures are 23.8°C and 8.6°C respectively. Sandy clay loam soil texture dominates the watershed[12].

Overland flow, soil and nutrient loss were estimated from 18 experimental plots under different land uses during 2010–2012 from three events each year in the rainy season. Nine erosive rainfall events were considered for each monsoon season, totalling 27 events during three years of study. These were estimated using natural shallow surface run-off channels and artificially delineated plots[13,14]. Each erosion plot (Figure 1 *c* and *d*) was 3 m × 2 m for estimation of overland flow and soil loss, and three plots were laid in each type of land-use/land-cover practice. The chosen fields included those on the lower, more productive lands and the higher, more marginal and less productive/less fertile areas. All fields were subject to broadly same cropping cycles and land management regimes. The overland flow and soil loss along the slope were estimated from the collecting tank after each observed rainfall event. After the rainfall event was over, the amount of overland flow generated from each plot was measured. The eroded soil was collected from the collecting tank, air-dried and sampled in the form of bed load sediments and suspended clay materials. Available nitrogen, available phosphorus, available potassium and organic carbon were estimated using standard methods[15]. Before the start of the experiment, soil characterization of the region was done to know the soil type[12].

The average annual precipitation for the three years was 1403 mm. Overland flow (percentage of rainfall during the rainy season) was estimated to be largest in orchard (30.73%) and lowest in vegetable field (15.84%). Average soil loss ranged between 9 and 37 t ha^{-1}. Maximum soil loss was observed in the orchards and minimum in fallow fields (Table 1). High overland flow and soil loss from orchards could be attributed to negligible ground cover and high incident precipitation. Similar observation of a higher average sediment loss in plots with no/less ground cover has been reported earlier[16]. Organic carbon associated with eroded soil showed a strong positive correlation ($P < 0.01$; $r^2 = 0.897$). Storm event-wise analysis between rainfall, overland flow and soil loss shows significant relationship between them (Table 2). The highest soil loss (16 t/ha) was recorded on 22 July and 15 September 2010.

Concentration of macro-nutrients, i.e. N, P and K and organic carbon in parent soil and eroded soil during the rainy season for different identified land-use types showed significant results at the $P < 0.05$ level (Table 3). Nitrogen concentration was higher in eroded soils. Similar was the case for organic carbon, with vegetable field as an exception. Total phosphorus content was lower in eroded soil, except in paddy fields. The eroded soil samples obtained from field experiments (486 samples) were analysed for nutrients mined in them. On an average, 590 kg of nutrients (N, P and K) was lost per hectare during the monsoon season. Maximum nitrogen, phosphorus and potassium was mined from paddy fields: 236.6, 18.2 and 364.27 kg/ha respectively. Minimum nitrogen was mined from orchard fields (208.97 kg/ha), whereas minimum phosphorus and potassium was obtained from millet fields (13.34 and 338.87 kg/ha). Maximum organic carbon content eroded with soil was from orchard fields (73.42 kg/ha) and minimum from fallow fields (23.84 kg/ha). Analysis of the data clearly shows that maximum nutrient erosion was from paddy fields. This implies unsustainable use of fertilizers in the most common land-use type of the region.

The average retail prices of the commonly used fertilizers were obtained through market surveys. Data on type and consumption of inorganic fertilizer were collected for the 2012 growing season. Three major chemical

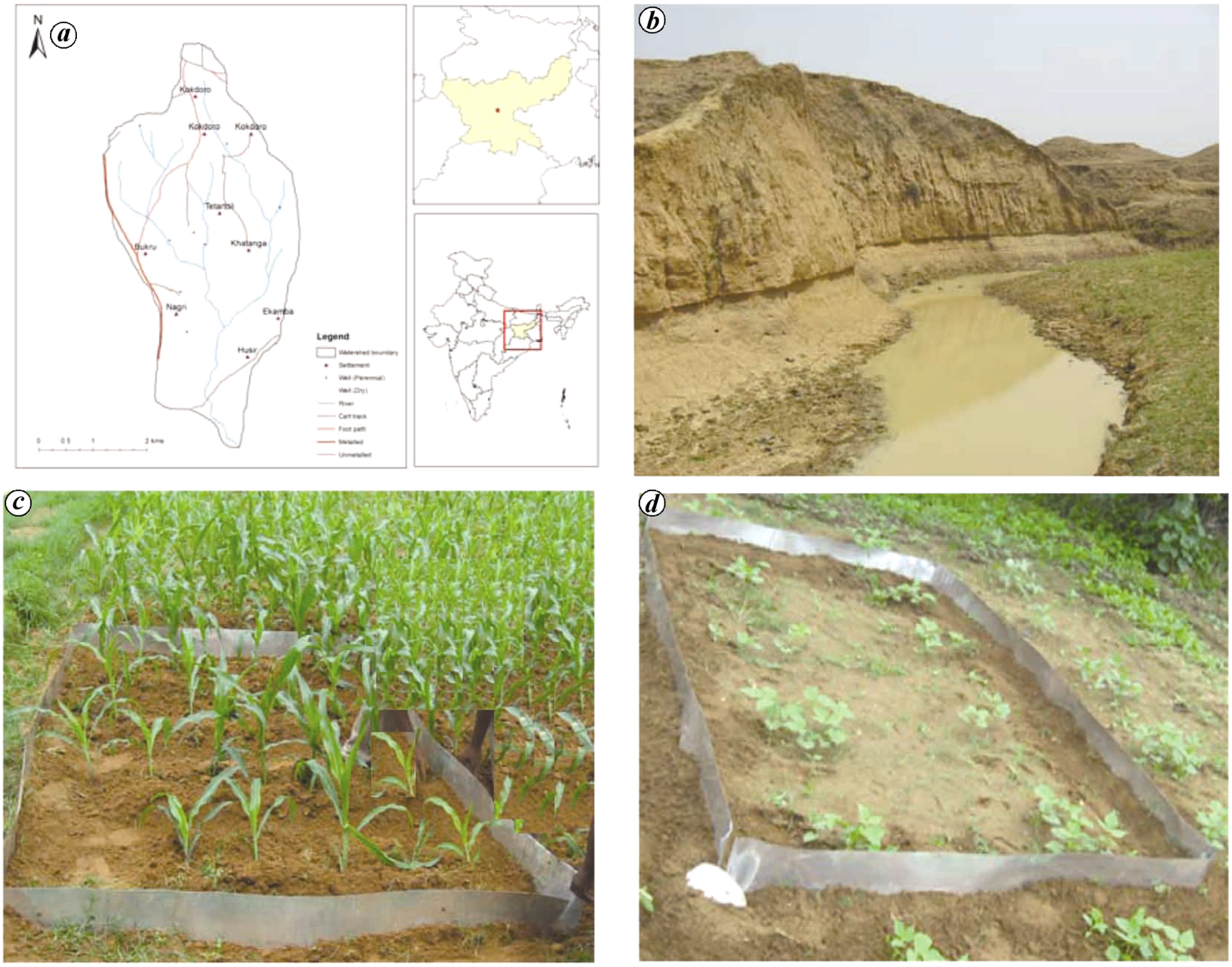

Figure 1. ***a***, Location of the study site. ***b***, Soil erosion at the site. ***c***, ***d***, Erosion plot in different land-use practices: (***c***) maize and (***d***) vegetable.

Table 1. Rainfall, overland flow and soil loss during rainy season in selected sites under different land-use/land-cover of the Jumar Nala watershed

Land-use/cover	Rainfall* (mm)	Overland flow (% of rainfall)	Soil loss (t/ha)
Fallow land	1535.20	25.59	8.56
Maize	1536.00	27.34	32.18
Millet	1534.20	17.74	25.98
Orchard	1534.80	30.73	37.14
Paddy	1534.40	25.48	20.81
Vegetable	1534.00	15.84	14.11
ANOVA *P* values	–	0.01	0.01

*Total rainfall of the 27 observed events.
Values of overland flow and soil loss are mean of 81 samplings.

fertilizers (urea, DAP and MOP) used were taken into consideration. The price for the elemental forms of the nutrients was calculated. The price ratios between elemental N, P and K were derived from the prices of their raw materials. From the calculated mean prices of elemental N, P and K, input costs per nutrient for inorganic fertilizer were assessed. However, the real cost for inorganic fertilizer will be somewhat higher than that of the elemental nutrients. This is because the packaging, transport and labour costs have not been accounted for. The fertilizer consumption pattern (obtained from the survey) and the season-wise fertilizer consumption pattern (obtained from Fertilizers Association of India) for the district indicate that the proportions in which macronutrients are applied to the system are imbalanced, even more so if crop requirements are taken into consideration. The survey results show that farmers tend to invest more in N, although data from Fertilizers Association of India show an increasing demand for K and a decline in N demand.

The unscientific agricultural practices and subsequent soil and water loss are responsible for significant economic and environmental costs of soil erosion[3]. In the present study the major observed on-site cost of erosion is attributed to nutrient loss. When erosion by water occurs

Table 2. Storm event-wise rainfall, overland flow and soil loss in selected sites under different land-use/land-cover of the Jumar Nala watershed

Storm date	Observed rainfall (mm)	Overland flow (mm)*	Soil loss (t/ha)*
22-Jun-10	48.4	12.6	4
7-Jul-10	49.4	12.8	14
22-Jul-10	52.7	13.7	16
26-Jul-10	86.2	19.8	4
10-Aug-10	85.8	26.6	7
16-Aug-10	45.8	13.7	3
27-Aug-10	57.6	17.9	2
5-Sep-10	53.2	15.4	2
15-Sep-10	42.8	12.4	16
23-Jun-11	39.4	9.5	14
5-Jul-11	41.6	12.5	12
25-Jul-11	46.4	13.0	6
27-Jul-11	62.4	15.6	13
12-Aug-11	54.2	11.9	7
20-Aug-11	67.4	16.9	2
29-Aug-11	40.2	12.1	4
9-Sep-11	64.8	17.5	8
18-Sep-11	64	17.9	4
21-Jun-12	88.6	26.6	1
9-Jul-12	68.3	15.0	4
26-Jul-12	36.7	9.2	7
30-Jul-12	68.2	18.4	15
15-Aug-12	69.8	20.2	14
20-Aug-12	68.5	15.8	10
30-Aug-12	52.2	12.5	8
13-Sep-12	54	15.7	13
23-Sep-12	26.4	6.3	10
ANOVA *P*-values			
Observed rainfall	–	0.01	0.005
Soil loss	0.005	0.005	–

*Values of soil loss and overland flow are the mean of 18 field plots across six selected land uses.

Table 3. Nutrient concentration of parent and eroded soil (mg/g) under different land uses of Jumar Nala watershed

Land-use/cover	Soil type	Total N (mg/g)	Total P (mg/g)	Organic carbon (mg/g)
Fallow land	PS	1.78	0.79	18.89
	ES	8.67	0.68	22.71
Maize	PS	4.32	0.63	21.34
	ES	10.77	0.56	59.86
Millet	PS	2.29	0.73	42.58
	ES	4.11	0.56	54.12
Orchard	PS	2.98	1.22	27.11
	ES	3.81	1.09	69.74
Paddy field	PS	4.12	1.52	32.09
	ES	15.48	2.38	38.42
Vegetable field	PS	2.33	1.18	48.24
	ES	3.92	0.96	25.95
ANOVA *P* values*				
Land use		0.05	NS	0.05
Soil type		0.05	0.05	0.05
Land use × soil type		0.05	NS	0.05
LSD (0.05)		1.27	–	10.98

PS, Parent soil; ES, Eroded soil.
*Beneath each column *P* values associated with an analysis of variance are given, with LSD values ($P = 0.05$) applicable for means of land use and soil type. NS, Not significant.

at an average rate of 23 t/ha, about 365 mm of overland flow and 590 kg of nutrients are lost per hectare (Table 4). In order to give more importance to the nutrients that get eroded with the soil, the study aimed to put a monetary term to it. This was done by calculating the amount a farmer or any agency/organization would have to spend

Table 4. Cost estimate of replacing the eroded nutrients through inorganic fertilizers

Fertilizer type	Urea	DAP	KCl (MOP)
Fertilizer price (INR/t)*	9640	79,113	30,645
Element	N	P	K
Element content (%)	83	31.6	62
Element cost (INR/t)	8,001.20	24,999.71	18,999.90
Element cost (INR/kg)	8.00	25.00	19.00
Element price ratio	1	3.12	2.37
Average amount of element lost (kg/ha)	219.26	15.75	354.99
Cost of eroded nutrient (INR)	1754.34	393.72	6744.69

*Based on market price for the year 2012.

to replenish the nutrients lost (as a result of soil erosion) by use of inorganic fertilizers. It was estimated that approximately INR 8893 ha^{-1} (US$ 137 ha^{-1}) would be required to replace the lost macro-nutrients through inorganic fertilizers alone (Table 4). The on-site cost of erosion will however be much higher than this value, since the cost of replacing topsoil, conserving water and compensating for the lost crop productivity has not been accounted in this study. These losses cause significant ecological damage. They may deplete soil biodiversity, change soil structure and affect plant composition.

The effect of the consequent soil degradation and resultant nutrient mining is a decline in soil fertility, which makes the current crop production unsustainable and is likely to worsen the situation. The results show that land-use type has a marked effect on soil erosion, associated nutrient and organic matter loss. As expected, less ground vegetation cover (as in the case of orchards) favoured soil erosion and nutrient loss. Similar results have been reported earlier[10,14]. This suggests that adopting practices that encourage increased ground cover (such as agroforestry, mulching) would help in soil and nutrient conservation. It would also enhance the soil fertility and crop productivity, thus being economically and ecologically beneficial. A well-fitting, positive, linear function between soil loss and organic carbon loss supports the suggestion made. However, high nutrient loss from paddy fields is indicative of excessive fertilizer input. This is also supported by the observations made during the field experiments. Paddy is the major crop in the area. Hence, unsustainable paddy cropping is likely to affect the farm household incomes. Further, an unstable nutrient pool is likely to lead to decrease in crop yield. A number of studies mentioned above, document this relationship between soil fertility and crop productivity. The negative balance over many years is manifesting itself as declining crop yields. If soil nutrients are not replenished according to the requirement, the supply from the available soil stock will decrease with time (in case of K and P) and the overflow of fertilizers (especially N) will result into many off-site damages. Apart from conservation practices such as agroforestry, farmer awareness programmes with respect to fertilizer usage should also be strengthened.

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