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Assessment of cost of soil erosion and energy saving value of soil conservation measures in India

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ABSTRACT

As far as adaptation of soil conservation measures is concerned, recent experiences have shown that the traditional or sheer technical ways to express the consequences of erosion are not so convincing to policy planners and decision makers. One possible way of attracting attention of land managers is to express the damage of soil erosion and benefits of soil conservation practices by expressing them in monetary and energetic terms for better understanding of the potential users. In the present study, economic cost of erosion in India was calculated based on the cost of replacing the lost nutrients employing replacement cost principles and in turn the cost of producing fertilizers was estimated in terms of energy spent for replacing the lost nutrients. It is estimated that to compensate for the nutrient losses inflicted by 1 mm loss of soil due to water erosion from one hectare land area, an additional 1642 MJ of energy is expended, which is equivalent to about 91 kg of petrol. Considering 140 million ha (Mha) of net sown area in India, an additional energy requirement worked out to be about 14 million tonnes (Mt) of petrol per year. Based on an average loss of grains or seeds of 8.9 Mt of cereals, 2.8 Mt of oilseeds and 1.7 Mt of pulses, respectively, the calculated amount of energy in the aboveground biomass of these crops is estimated as 557070 tera joules (TJ) of energy, which is equivalent to 29.32 Mt of fuel wood or 12110 mega l of Kerosene. The study further revealed that any soil conservation measure or a combination there of in conjunction with appropriate management practices which can reduce soil erosion by 1 ton has the potential to save 655500 k joules (KJ) of energy, equivalent to 15 kg fuel oil.

1. INTRODUCTION

Basic requirement of food for human population is satisfied through optimal use of the soil resource. But productivity of this precious resource is getting adversely affected due to over exploitation. Although more than 99% of world's food comes from soil, experts estimate that each year more than 10 Mha (25 M acres) of crop lands are degraded or lost as rain and wind sweep away topsoil. Soil erosion is integrally linked to land degradation, and excessive soil loss resulting from poor land management has important implications for crop productivity and food security, and thus sustainable use of the soil resource is essential for the existence of humans as well as other life forms. This natural cum human-induced problem must, therefore, be seen as having a highly significant socio-economic dimension.

Soil erosion and associated non-point source pollution are major problems in many parts of the world, including India, leading to serious land degradation problems. Across the globe, 24 billion tonnes of topsoil is eroded annually from farmland, and it is expected that 30% of world's arable land will be depleted within 20 years (FAO, 2011). A recent national database on land degradation in India shows that 120.7 Mha or 36.7% of the total arable and non-arable land surface of the country suffers from various forms of degradation (NAAS, 2010) with water erosion being the chief contributor - 83 Mha (68.4%). Annual soil loss rate in India is about 15.35 t $ha^{-1}yr^{-1}$ (Sharda and Ojasvi, 2016), resulting in loss of 5.37 to 8.4 Mt of nutrients, reduction in crop productivity, occurrence of floods / droughts, reduction in reservoirs' capacity (1 to 2% annually), and loss of biodiversity. Loss of crop productivity, one of many negative impacts of soil erosion by water, has serious consequences for a country's food, livelihood and environmental security. A recent study (den Biggelaar *et al*., 2003) has shown that the value of annual production losses for some selected crops worldwide could amount to over US$ 400 million. Yield reductions in Africa due to past soil erosion may range from 2 to 40%, and if the present trend of erosion continues unabated, yield reductions may average 16% by 2020 (Lal, 1995). In South Asia, annual loss in productivity due to water and wind erosion is estimated at 36 Mt of cereal equivalent, valued at US$ 7200 million (UNEP, 1994).

In India, about 15.7% losses of rainfed crops equivalent to 13.4 Mt in physical terms and ₹ 205.32 billion in monetary terms (Sharda and Dogra, 2013) have been reported due to water erosion. Out of the total production and monetary losses at national level, the cereals are the major contributors (66% and 44%, respectively), followed by oilseeds (21% and 32%, respectively) and pulses (13% and 24%, respectively). The above figures and many other sources show that the damage inflicted on soils due to land degradation over many years are significant and have resulted in valuable land becoming unproductive and often eventually being abandoned (Pimentel *et al.,* 1995; Pimentel and Kounang, 1998). The increasing demand for food due to population growth requires increasing agricultural production, which often leads to exploitation of marginal areas and competition with other land uses. Generally, the economic impact of land degradation is severe in densely populated regions of South Asia and Sub-Saharan Africa. Thus, soil resource must not be neglected in any developmental endeavor at local, regional or global level.

Maintaining integrity of the linked land and water systems to meet an increasingly sophisticated set of competing demands has become a well-accepted global priority (NAAS, 2018). Integrated river basin development has been embraced as an ideal tool for reconciling these demands since the mid-20th century. But the practice has been overrun by the sheer pace of economic development, and the subsequent expansion of urban, industrial and agricultural land use in river basins. A decade into the 21st century, a return to integration should be much better informed. Advanced knowledge on the hydrological cycle, improved agricultural practices and new tools for mitigating impacts of chemical pollutants and managing wastewater now offer a set of knowledge-rich solutions to reduce environmental impact. However, experiences have shown that the traditional ways or pure technical ways to express the consequences of erosion are not convincing to policy planners and decision makers. One possible way of attracting attention of land managers and financiers is to express the damage of a complex problem like soil erosion and simple benefits of soil conservation practices is by expressing them in terms of easily understandable language. Language in terms of money and energy is most widely understood, and loss of biomass yield due to erosion provides the link between erosion and money. Present information in this regard is available more in technical form, but is far from creating a conducive environment for policy planners to make informed decisions based on readily available knowledge. In the present study, an attempt has been made to express technical information about impacts of soil erosion on crop productivity in terms of easily understandable language of finance and energy for the benefit of planners and policy makers.

2. MATERIALS AND METHODS

We collected the relevant information on average soil loss and crop productivity loss due to erosion in India from reliable data sources (Sharda *et al.,* 2010; Mandal and Sharda, 2011; Mandal, 2014; Sharda *et al.,* 2010; Sharda and Dogra, 2013). Direct consequences of erosion by water are reduction in fertility status and productivity of soil as a medium for biomass production by removal of top most fertile soil containing organic matter and plant nutrients. The removal impairs not only the fertility status, but also the physical condition of the soil leading to decline in crop yields depending upon type of crop and depth of soil. In addition to adversely impacting agronomic production, soil degradation can also dampen economic growth, especially in countries where agriculture is the driving force for economic development.

Cost of erosion in India was calculated following two approaches. Firstly, the value of nutrients lost from the top soil loss was calculated based on cost of replacing the lost nutrients using replacement cost principle. Valuation of major nutrients contained in top 1 mm soil was estimated from estimates of carbon and N, P and K losses from rolling and undulating slopes (Mandal, 2014). It was observed that about one tonne of farm yard manure (FYM) is needed to compensate the loss of organic carbon caused due to erosion of 1 mm of top soil. Additionally, about 52 kg of urea, 15 kg of superphosphate and 21 kg of muriate of potash per year will be required to replace the loss of N, P and K nutrients, respectively by erosion of top 1 mm soil.

Secondly, the cost of producing fertilizers was estimated in terms of energy, spent for replacing the lost nutrients due to erosion through fertilizers. To quantify the total energy loss due to erosion, standard data on energy used for various fertilizers inputs were utilized. Further, the amount of carbon produced per unit of energy used for production of fertilizers depends on the contribution made for it by non-renewable and renewable resources. The amount varies from 24 kg C GJ^{-1} for coal, 19 kg C GJ^{-1} for oil and 14 kg C GJ^{-1} for natural gas (DTI, 2001). As adjustment for renewable and non renewable resources varies from country to country, we used 15 kg C GJ^{-1} as the conversion factor.

It is estimated that India suffers an annual loss of 13.4 Mt in the production of major rainfed cereal, oilseed and pulse crops due to yield reduction by water erosion (Sharda *et al.,* 2010). As per grain loss of these crops, the total biomass loss was estimated based on grain: straw ratio of different crops suggested by Bhattacharyya (2007). Then, bio-energy was computed based on energy of seeds and straw/stalk on dry weight basis as suggested by Ravelle (1976). Equivalent energy loss in terms of fuel wood and kerosene was computed following Tripathi and Sah (2001).

3. RESULTS AND DISCUSSION

Many times the damage due to soil loss is imperceptible by farmers and land managers. For example, 1 mm of annual soil loss is not noticeable through naked eyes. However, this 1 mm soil is equivalent to about 15 tonnes of soil loss per hectare per year (assuming the bulk density of soil as 1.5 g cm^{-3}). Although in term of visual perception, 1 mm loss of soil is very negligible; however, the cost involved in recovering from the damage due to this soil loss in terms of loss of carbon and nutrients is substantial (Table 1). The total cost of replacement is estimated at about ₹ 2,000/- per year.

Table: 1
Quantity of nutrients lost through 1 mm of soil loss over a hectare and their replacement cost

Nutrient (kg)	Replacement cost (₹)	
C - 225	FYM	1,000
N - 24	Urea	546
P - 1	SSP	308
K - 10.5	MOP	158
Total		2,012

We calculated the replacement cost of 1 mm soil loss due to water erosion induced nutrients losses from one hectare land area (Table 2). To compensate for the nutrient losses inflicted by erosion, an additional 1642 MJ of energy is expended, which is equivalent to about 91 kg of petrol (assuming 40% conversion efficiency of petrol to useful energy). As reported by Sharda and Ojasvi (2016), the average annual soil loss in India is 15.35 t ha^{-1}, therefore, it needs an additional energy of about 100 kg of petrol to compensate the nutrient losses. Considering 140 Mha of net sown area in India, an additional energy requirement worked out to be about 14 Mt of petrol per year.

Prioritization of Highly Degraded Areas Based on Energy Calculation

Numerical assessment of soil erosion risk is an effective decision making tool for land users to identify best management practices. An analysis of erosion risk based on a criteria evolved for integrating potential erosion rates with soil loss tolerance limits (*T*-values) revealed that only about 50% of the total geographical area (TGA) of India falls under five priority erosion risk classes, each requiring different degree of erosion management (Sharda *et al.,* 2011), as presented in Table 3. Difference between potential erosion rates and *T*-values were considered to compute the erosion risk at a given location. These differences were categorized into five classes. The upper most priority class (Class 1) was decided based on difference between maximum potential erosion rate category (>40 t $ha^{-1}yr^{-1}$) and minimum *T*-value (2.5 t $ha^{-1}yr^{-1}$) and rounding it off to the nearest integer of 5 on the lower side *i.e.* >35 t $ha^{-1}yr^{-1}$ as only 11% area of the country falls under very severe potential erosion rate category of >40 t $ha^{-1}yr^{-1}$. Likewise,

Table: 2
Energy needed and carbon emitted by 1 mm of soil erosion (15 t ha^{-1}) considering compensation

Lost nutrient replacement by fertilizer	Energy required for fertilizer production (MJ kg^{1})	Carbon emitted @ 0.015 kg C MJ^{-1}	Nutrient loss per mm of soil erosion (kg)	Energy needed to compensate lost nutrients (MJ)*
Nitrogen	65.3	0.98	24.0	1567.2
Phosphorus	7.2	0.11	1.0	7.2
Potassium	6.4	0.10	10.5	67.2
Total	78.9	1.19	35.5	1641.6

**Nutrients include only N, P and K*

Table: 3
Criterion for classifying erosion risks into different priority classes

Priority class	(E-T) (t $ha^{-1}yr^{-1}$)	Remarks	Energy needed to compensate lost nutrients (MJ)*
1	> 35	Very high priority. Needs special soil and water conservation measures	>3825.0
2	25-35	High priority for soil conservation	2725.0-3824.9
3	15-25	Medium priority for soil conservation	1641.6-2725.0
4	5-15	Less priority for soil conservation	1083.4-1641.6
5	0-5	Very less priority for soil conservation	541.7
6	<0	Requires no treatment	-

**Nutrients include only N, P and K*

the range of lower most priority class (Class 5) has been fixed between 0 and 5 corresponding to lower most potential erosion rate category of < 5 t $ha^{-1}yr^{-1}$ as the difference (E-T) less than zero would not require any measure from conservation point of view. For (E-T) values between 5 and 35, three priority classes at uniform interval of 10 *i.e.* 25-35, 15-25 and 5-15 t $ha^{-1}yr^{-1}$ corresponding to priority classes 2, 3 and 4, respectively were constituted. If potential erosion rate is equal to or less than *T*-value then it was classified as no risk class (Class 6). On the whole, erosion risk in different states has been prioritized into six classes signifying extremely sensitive (Class 1), very highly sensitive (Class 2), highly sensitive (Class 3), moderately sensitive (Class 4), and low priority (Class 5) risk classes, while Class 6 represents risk free area. About 44% of TGA falls under no treatment category or risk free Class 6. By following this procedure or methodology for each state, a thematic map (1:4.4 million scales) for the erosion risks in India was developed in GIS environment (Fig.1). As per spatial distribution, percent of TGA of the country under priority classes 1, 2, 3, 4 and 5 has been computed at about 2, 12, 8, 17 and 10%, respectively. We further computed here that how much energy is required to compensate the nutrients' loss through these priority classes. It helps to translate the more technical information of soil loss and tolerance limits to more easily understandable term of energy loss (Table 3).

Soil erosion in a given priority class has to be brought within the permissible limits or *T*-value to prevent loss of productivity and achieve sustainability of production systems (Sharda and Mandal, 2018). Therefore, critical geographical areas of the priority classes were identified based on the targeted erosion rate or *T*-value at a given location in each state. Priority area with a target value of 2.5 t $ha^{-1}yr^{-1}$ is considered as most critical, requiring immediate attention by adopting appropriate conservation strategies. As per present analysis, out of the total priority area of 162 Mha under 5 erosion risk classes in all the states, about 11% (17.80 Mha) area is found to be most critical with a target value of only 2.5 t $ha^{-1}yr^{-1}$. Similarly, under the five priority classes, 11.97 Mha (7.4%), 35.23 Mha (21.8%), 47.41 Mha (29.3%) and 49.22 Mha (30.4%) areas are critical in decreasing order of magnitude with target value of 5.0, 7.5, 10.0 and 12.5 t $ha^{-1}yr^{-1}$, respectively.

Crop yields on eroded soils are lower than those on protected soils. This is because of the fact that erosion affects soil environment by reducing top soil depth, water holding capacity, nutrients and organic carbon contents. Erosion adversely affects biomass productivity by reducing top soil depth, water availability, depleting nutrients and organic matter. Increase in runoff under severe erosion allows less water into the soil matrix and thus reduces water availability. Based on an average loss of grains or seeds of 8.9 Mt of cereals, 2.8 Mt oilseeds and 1.7 Mt pulses, respectively (Sharda *et al.,* 2010), the calculated amount of energy in the aboveground biomass of these crops is about 557070 TJ of energy, which is equivalent to 29.32 Mt of fuel wood or 12110 mega l of Kerosene (Table 4).

Protecting top soil

Human survival and well-being cannot be enhanced

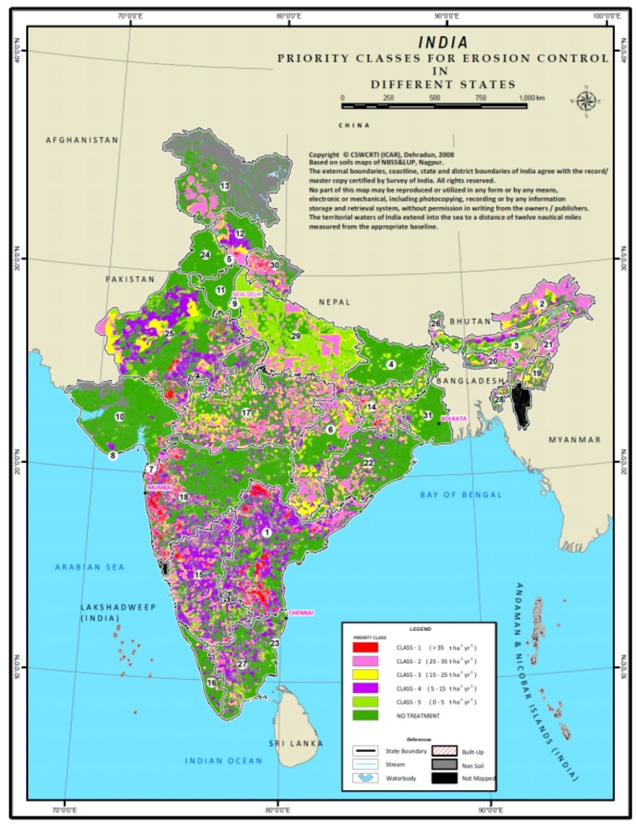

Fig. 1. Priority classes for erosion risk areas in different states of India

Table: 4
Total biomass and bio-energy losses due to soil erosion in India

S.No.	Crop types	Total loss of above ground biomass (Mt)		Total energy loss (TJ)	Equivalent to amount of fuel wood (Mt) / kerosene oil (Mega l)
		Grain	Straw/stalk		
1	Cereals	8.9	13.35	348360	18.33/ 7574
2	Oilseeds	2.8	5.6	153580	8.08/ 3338
3	Pulses	1.7	1.7	55130	2.91/ 1198
		Total = 34.05		557070	29.32 Mt of fuel wood or 12110 mega l of Kerosene

without planned interventions. If we are wise and develop ways to manage soils appropriately, the resource base will be adequate to carry and sustain us indefinitely. The current level and continuing rates of land degradation have reduced and will continue to reduce our capacity to sustain our quality of life. While there are many valid data sets available from several parts of the world, they are often limited geographically or are first-line estimates that lack standardization and follow up assessments, which precludes trend analysis. One of the first steps to properly manage land resources is a global characterization of soil resources with respect to assessment of risk, resilience and restoration.

Soil erosion is not new and rather is as old as the earth itself. But with the advent of agriculture, the acceleration of soil erosion on mismanaged land has increased manifold. Very often, the rate of soil erosion reaches a point where it exceeds the soil formation rate. Rates of soil erosion well in excess of rates of soil loss tolerance limit are a recipe for disaster and there is a clear need for improved understanding of soil loss tolerance for the formulation of appropriate soil conservation strategies. In ideal situation, the erosion level should be contained within the permissible limit specified for a given location, which ranges between 2.5 to 12.5 t $ha^{-1}yr^{-1}$ (Mandal and Tripathi 2009; Mandal *et al.,* 2010). Once this threshold is crossed, the inherent fertility of the land begins to fall. The second Green Revolution, needed to feed the global projected population of 9.2 billion by 2050, must be based on sustainable management of soil and water resources. The projected increase in population will occur, where the soil resources are most scarce and severely degraded. Therefore, technological interventions for sustainable management of soil and water resources are a must to protect this valuable resource especially in ecologically fragile regions. Some technological options are presented in Table 5.

Reliable and proven soil conservation technologies include ridge-planting, no-till cultivation, crop rotation, strip cropping and contour planting, and cover crops. Although specificity of practices varies, all conservation measures reduce erosion rates. Each conservation measure may be used separately or in combination with other practices. Medium term experimental evidences in lower Himalayan Region 12 revealed that annual soil erosion rate of 1 t caused a loss of about 15 kg grain of maize (Mandal *et al.,* 2015). This indicates a loss of about 37.5 kg of total above ground biomass including 22.5 kg stover. The energy content in this biomass works out to be 655500 KJ. Thus any soil conservation measure or a combination of practices (minimum till + mulch; contour cultivation + green manure) which reduce soil erosion by 1 tonne has the potentiality to save 655500 KJ of energy equivalent to 15 kg fuel oil (Foley, 1978).

4. CONCLUSIONS

Soil erosion, particularly in India, creates serious social, economic and ecological problems and consequently results in land degradation. During 20 years period since 1992 Earth Summit in Rio de Janeiro, India's farmers have lost nearly 120 billion tonnes of top soil through erosion at a time when they were called on to feed 390 million additional people. These disquieting numbers suggest that Earth's arable land may not be able to sustain a population of more than 10-12 billion. The sustainability of a system depends on its capacity to overcome the resilience of each of its components. Thus, there is a great need for protection of soil resource following the suggested prioritization of erosion classes.

Table: 5
Technological options for sustainable soil and water management

Problems and issues	Proven technologies	Strategies and approaches
1. Soil erosion and degradation	Residue recycling, mulching, cover cropping in conjunction with contour farming, terracing and simple engineering structures	• Minimize soil loss within permissible limit. • Adopt "Grain to Human & Residue to Soil" rule.
2. Drought stress	Water harvesting and recycling, mulch farming, improving irrigation efficiency through drip, sprinkler and furrow irrigation	• Farming techniques for water conservation. • Providing technical support in constructing farm ponds and efficient irrigation systems.
3. Nutrient depletion and low soil fertility	Nutrient cycling, manuring, biological nitrogen fixation, bio-solids, judicious use of fertilizers, zeolites as slow release fertilizers, nano-enhanced materials and biochar-based amendments	• Providing clean cooking fuel to the rural house-holds so that animal manure and crop residues can be used as soil amendments. • Making fertilizers available to farming community by developing local sources of fertilizer.
4. None or slow adoption of proven technologies	Involving farmers in the decision process, participatory approaches	• Improving land tenure, and addressing gender and social equity. • Micro finance for purchasing inputs.
5. Lack of resources for adopting recommended management practices	Enhancing farm income, growing high value crops, trading soil C credit	• Paying farmers for ecosystem/ environmental services.

Following a systematic approach, monetary and energy losses of nutrients and bioenergy due to water erosion were estimated for India. The analysis highlights the urgency to minimize the production losses in rainfed areas of the country. The assessment is a major step forward in understanding the losses suffered by the country due to land degradation by water erosion across major crops, states, zones and the country as a whole. This would sensitize the policymakers, planners, conservationists and environmentalists to develop appropriate strategies to prevent huge losses in production of major rainfed crops due to water erosion in different states and zones.

Finally, recognizing the enormous cost of soil wastages by erosion and excessive loss of rainwater as runoff from unprotected lands, we highlighted the need of soil conservation measures. Our experiences showed that the traditional ways or pure technical ways to express the consequences of erosion is not convincing to policy planners and decision makers. One possible way of attracting the attention of the land managers and financiers is to express the damage of erosion and benefits of conservation practice in terms of easily understandable language as attempted in this study.

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