The on-site cost of Soil Erosion: The Case of Mapawa Catchment, Lantapan, Philippines

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INTRODUCTION

Soil erosion is almost universal. It threatens millions of hectares of land in the world today. In the Philippines, soil erosion is a major threat to sustainable production on sloping lands where mainly subsistence farmers carry out food and fibre production. With increasing population and limited arable land, agricultural production activities are now being carried out in the hilly to mountainous lands. But steep slopes, together with high rainfall intensities, reduced vegetative cover, and improper land use exacerbate soil erosion.

The economic impacts of soil erosion control technologies are measured in terms of the incremental net benefits gained from adopting the technology as compared to the erosive farming practice. The cost of the actual loss of soil as a natural resource for food and fibre production and the damage done by erosion are usually neglected. On-site impacts are usually studied by analyzing the effects of soil loss on crop production (Barbier, 1995). Off-site consequences place more pressure on the local environment in terms of sedimentation and siltation that can clog up irrigation channels and lower the water storage capacity of dams, thus increasing expenditure to governments for infrastructure and conservation measures (Norse and Saigal, 1993). El Swaify's (1993) suggestion to place a price tag on the full costs of erosion will help "the sensitization of policy-makers to the need for natural resource conservation."

This paper presents a review of the economics of soil erosion and the methodologies for its estimation and illustrates the replacement cost methodology for estimating the on-site costs of soil erosion. The data collected from the MSEC site in the Philippines were used in the analysis.

ECONOMICS OF SOIL EROSION

Cost-benefit analysis (CBA)

In evolving a policy framework or a programme for soil conservation issues and problems, a major consideration should be the economic and environmental impact evaluation in terms of the extent of benefits derived from and costs (both private and social) incurred in the implementation of such a programme.

The CBA approach used in project appraisal could be extended to the assessment of soil conservation projects. Typically, CBA calculates measured benefits and costs and converts them into an economic rate of return (ERR). Environmental impacts are simply additional costs or benefits (CSERGE, 1994)

For environmental costs and benefits to be incorporated into CBA, the impacts due to soil erosion must be identified and quantified. The next task is to value these impacts. Hufschfmidt and Carpenter (1982) broadly categorized valuation techniques for costs and benefits into three, namely those using (a) actual market process, (b) surrogate market process, and (c) consumer survey methods or hypothetical valuation. Table 1 (Gregersen *et al.*, 1987) gives the typology of these techniques.

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As implied in the actual market prices' technique, the changes in productivity are valued using market prices for inputs and outputs. The benefits and costs are computed for both with and without conservation measures. Surrogate market price approaches value unpriced goods and services of the environment. Hypothetical valuation uses surveys and creates a hypothetical market for otherwise nonmarket goods.

Table 1. A typology of selected valuation techniques (Gregersen *et al.,* 1987).

Valuation technique	Examples of applications: Valuing costs	Examples of applications: Valuing benefits
❖ *Using market prices*		
Changes in value of output	Decreased crop production due to erosion, siltation, contaminated water, or reallocation of land; change in value of fish catch.	Increased crop production due todecreased soil erosion; crop increases from sediment-enriched soils.
Loss of earnings	Value of productive services lost through increased illness and death caused by water-borne diseases, e.g. schistosomiasis.	Earnings loss avoided.
Preventive expenditures	Cost of intake water treatment, resiting of water intakes, desilting structures, check dams.	Expenditures avoided.
Replacement cost	Cost of replacing damaged turbine blades; compensation for production foregone.	Cost avoided.
Cost effectiveness analyses	Least cost way of achieving given water quality level or attaining certain erosion level.	-
❖ *Using surrogate market prices*		
Property or land value approach	Decreased land values due to erosion, sedimentation, or flooding.	Increased property value due to increased productivity from reduction of erosion or flooding.
Travel cost approach	Recreational value lost if resource is harmed.	Value of recreational fishery, lake or beach.
Wage differential approach	-	Estimation of willingness of workers to trade off wages for improved environmental quality.
Acceptance of compensation	Compensation for damage to crops or to health (e.g. Minimata disease).	-
❖ *Hypothetical valuation*		
Direct questioning of willingness to pay (or willingness to accept compensation)	Estimate of willingness to accept compensation for loss of use of a beach, pond or reservoir.	Estimate of willingness to pay for use of a reservoir fishery.
Trade off games	-	Estimate value of improved water quality or decreased soil erosion.

Data requirements for CBA analysis are demanding because present values are required for the quantitative evaluation of impacts. Often, second-best approaches such as replacement cost or avoidance cost are all that can be attempted.

On- and off-site costs

The economic problem of soil erosion can be categorized into on-site costs due to loss of resources to the individual farmer and off-site or external costs, which are the concern of the society. El-Swaify (1993) listed the components of these costs as:

1. *Costs associated with on-site impacts.* Quantifiable on-site costs are those responsible for productivity changes in farmland. These may be measured, alternatively, as the costs of inputs necessary to maintain farm productivity at a level prior to soil erosion and to harness moving

water and sediments for safe disposal. Components include fertilizer and tillage (to compensate for lost infiltration capacity and the quality in the exploitable root zone), water (to compensate for excessive runoff and inadequate root zone recharge), and installation of land surface configurations, stabilization measures, and soil treatments to enhance infiltration, minimize runoff, and dispose of excess runoff safely so as not to endanger low-lying areas. A major (semiquantifiable) cost in tropical uplands and highlands is the reduced value of eroded areas for water resource development by virtue of declining quality for catchment/watershed purposes.

Nonquantifiable costs are those primarily due to long-term changes in soil quality (degradation) and depth, as the soil for all practical purposes is a nonrenewable resource. Such changes generally cause ultimate abandonment of the land and cultivation of new lands where available.

2. *Costs associated with off-site impacts.* Quantifiable off-site costs are those associated with damage to low-lying lands, downstream life, property, structures, and the environment. These include the costs of flood and burial damage, reduced or eliminated value of water-storage structures through siltation, loss of water that can no longer be stored in silted reservoirs, loss of water quality and productivity of fisheries, contamination and eutrophication due to sediment and runoff borne chemicals, effects on the drainage efficiency and navigability of streams and waterways, and changes in other elements of ecosystem quality that translate into economically important aspects on society.

Estimating the cost of soil erosion

Bishop and Allen (1989) estimated for Mali as a whole, a mean current rate of soil erosion of 20 t ha^{-1} per year on gross arable land. The on-site cost of soil erosion is expressed in terms of reduced crop yields, resulting in mean annual yield losses of between 4 and 25%. For Mali, gross annual losses are estimated to be between 0.5 and 3.1% of the 1988 Gross Domestic Product (GDP).

Norse and Saigal (1993) described the methodology used to assess national economic cost of soil erosion to smallholder farmers in Zimbabwe. The Zimbabwe study used the replacement cost approach wherein the cost of replacing lost N, P, and organic carbon were estimated, considering it as an indicator of the damage incurred by degradation. In the study, empirical data collected from the experimental plots were analyzed to determine quantitative relationships between soil loss and losses of N, P, and organic carbon. Findings were then extrapolated to the dominant farming systems of Zimbabwe using the Soil Loss Estimation Method for Southern Africa (SLEMSA) and regression equations to estimate the total cost to Zimbabwe of the nutrients removed by soil erosion. Using this approach, the financial cost of soil erosion in Zimbabwe was estimated to be US$150 million on arable lands alone, or US$20 to US$50 per ha. This represents 13–60% of gross returns per ha under maize production.

It was reported by Carreker (1971), as cited by Francisco (1986), that an annual yield reduction valued at US$12.15 cm^{-1} of topsoil eroded, a value equivalent to US$1.38 t^{-1} of soil loss. Saydideger *et al.* (1977) reported that three billion tons of soil having an average composition of 0.10% N, 0.15% P and 5% K were eroded annually from agricultural and forestland in the United States. These estimates imply an annual erosion loss of five million tons of plant nutrients. In the United States, the calculated total fertility value of three billion tons of eroded soil reaches approximately US$18 billion y^{-1}. However, no distinct soil loss-yield loss relationship can be established. This might be difficult to determine inasmuch as this kind of interrelationship depends on the nature and thickness of the topsoil, subsoil, and parent material, which do not carry over large areas of land (Troeh *et al.*, 1980).

There were only few studies that could be cited that dealt with the measurement of productivity loss due to erosion in the Philippines. One was the comparative study of traditional 'kaingin', modified cropping pattern and tree farming on Mount Makiling conducted by Corpuz (1983). The amount of nutrient loss as found in the sediment was used as an indicator of productivity loss. The determined value was then multiplied by the corresponding value of commercial fertilizer at 1980 prices, and the resulting product constituted the cost of buying back the fertility of the soil into its original level. The author found out that the plantation forest-type tree farming had the lowest erosion rate, followed by the traditional kaingin system which had a slightly lower erosion rate than that of the modified cropping pattern. Based on the nutrient loss measurements, but largely due to the observed yield trend over a three-year period, the productivity loss (yield decline) in the kaingin area was 48% in the second year and 67.5% in the third year.

Another study, reported by de Los Angeles (1991), estimated both on- and off-site costs associated with soil erosion resulting from agricultural land use in two major watersheds in Cagayan and Central Luzon. On-site costs of soil erosion were estimated based on lower agricultural productivity due to loss of soil fertility. These costs were estimated at P1,068 per hectare of affected land.

While the other methods directly estimated losses from soil erosion as a function of yield reduction, Cruz *et al.* (1988) uses the replacement cost method in assessing the on-site economic effects of soil erosion in the Magat Watershed. As soil is eroded, the replacement method puts economic value on the losses from soil erosion by looking at what society has to pay to retain land productivity at levels prior to soil erosion.

The replacement cost method assumed that soil erosion leads to a reduction in organic matter and nutrients due to loss of soil. In turn, this process will lead to a decline in crop production unless nutrients are replaced in the soil. Therefore, a good indicator of the economic loss may be based on the cost of replacing these nutrients. Calculation of the amounts of nitrogen, phosphorus, and potassium to be applied to the soil and the valuation of these nutrients at realistic prices are needed.

Economic models for estimating the on-site cost of soil erosion

Francisco (1986) made a review of a number of studies dealing with the empirical and theoretical aspects of soil conservation and soil erosion/sedimentation. However, these studies were conducted in the United States. The models mentioned are the following: a) concept of damage function, b) approximately optimal decision rule, and c) approximation by using the linear programming technique.

The approximately optimal decision rule was applied by Burt and Cummings (1997) to an erosion-prone area suited to wheat and corn production. The model used topsoil depth and percent organic matter as state variables with percent land in wheat as the decision variable. The study found that heavy fertilizer application was economical for intensive cultivation in that area.

The Master Plan for Forestry Development (1990) considered the value of the potential yield losses as the indicator of the on-site costs of soil erosion. The potential wood yield loss per hectare is a function of the annual soil erosion per hectare, which in turn is a function of the annual loss of topsoil, reckoned over the growing period of the plantation.

The equation form is given as:

On-site cost = Soil erosion x soil depth lost to a ton of soil x 1/soil depth x MAI x stumpage price x no. of years

where MAI is the mean annual increment of the tree and stumpage price is the value of the tree before it is cut

General approach and methodology

The study was primarily aimed at using the replacement cost method in assessing the on-site cost of soil erosion. The expected output of this study is twofold: to come up with a practical methodology for economic assessment of soil loss and to estimate the actual cost of erosion in the Mapawa Catchment.

The activities undertaken in the study were:

1. Collection and verification of the data generated by the MSEC project, specifically on sediment load and chemical analysis.
2. Calculation of the amount of organic matter, nitrogen, phosphorus, and potassium in the sediment load.
3. Determination of the amount of soil nutrient lost through soil erosion and its chemical fertilizer equivalent with corresponding market price.
4. Valuation of the soil nutrient losses.

The following information were collected:

- bedload
- suspended sediment load
- total soil loss (sum of bedload and sediment load)
- nutrient content (NPK) of the sediment
- prevailing prices of fertilizer materials in Songco, Lantapan
- transport cost of fertilizer

The data used were those collected from April to July 2000 although bedload and suspended load data were collected as early as February 2000. The weirs were repaired during February and March.

Figure 1 illustrates the general procedure for estimating the value of soil fertility that is lost through erosion. From the soil analysis of the soil from each microcatchment, the laboratory data on organic matter, available P, and exchangeable K are converted into N, P, and K content of the sediment. These are then converted into fertilizer equivalent. With the information on the prices of fertilizers, the economic cost of erosion is derived.

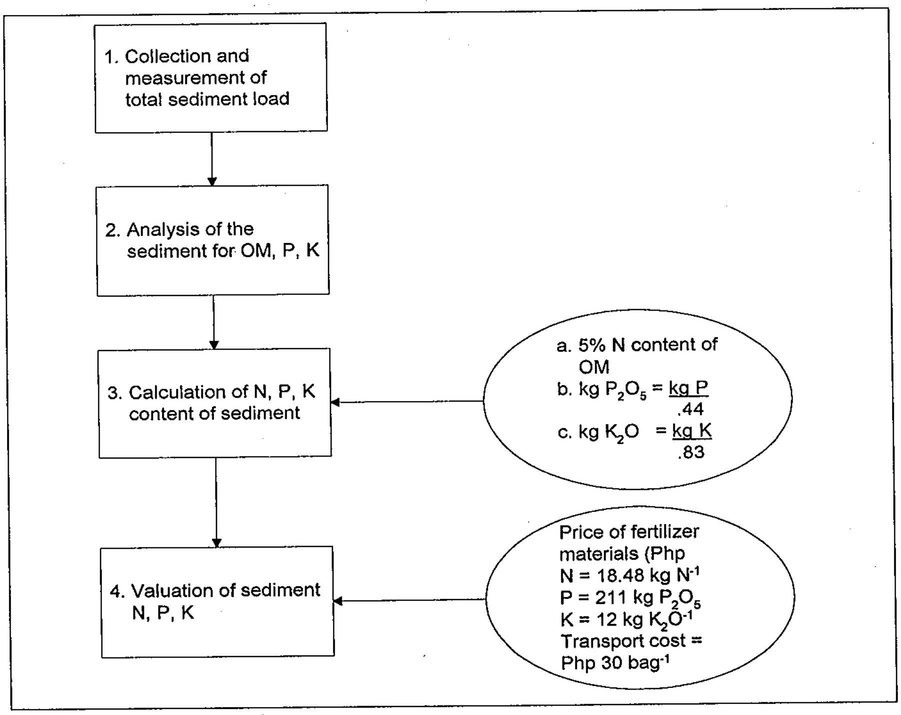

Figure 1. The replacement cost method in estimating the on-site cost of soil erosion.

The following assumptions and limitations were recognized:

1. The values computed and presented are based solely on actual measurement of soil losses from the weir. The actual soil loss may have been high since the weir usually overflows during a storm.
2. Nitrogen, phosphorus, and potassium are the only nutrients considered. Calcium with magnesium and other elements will be included in future analysis.
3. It is also assumed that the nutrients carried away by erosion will actually be used, taken up by crops if these are not lost. However, this assumption is important since the intention is to emphasize the total loss of nutrients, and thus, reduction in the fertility status of the microcatchment.
4. Soil nutrient distribution throughout the soil profile across the microcatchment is assumed to be uniform. Hence, the effect of soil depth on crop yield is negated.

MAIN FINDINGS

Soil erosion and land use

Table 2 shows the erosion rates, land use, and shape of the four microcatchments which were delineated within the Mapawa catchment. On a per hectare basis, the magnitude of erosion is in the order of Microcatchment 4 (MC 4) >>>>> MC 3 > MC 2 >> MC 1, for a period of four months MC4, lost 24,498 kg of soil (53% of the total soil loss), while MC 1 only recorded 80 kg (3% of total soil loss) for the same period. This discrepancy is very noticeable since MC 4 covers only 0.94 ha or 2% of the aggregate area of the four microcatchments, while MC 1 occupies 48%. MC 1 is occupied mostly by grassland and bamboo, hence low soil loss. Also, the cultivated patches in MC 1 are far from the stream.

It is to be noted, as indicated in Table 2, that 50% of MC 4 is intensively cultivated and planted to crops. The area is fallowed after harvest although 0.1 ha is continuously tilled after a harvest of sweet potato to prevent the buildup of *Pseudomonas solanacearum*, the soil-borne pathogen causing bacterial wilt. The farmer applies fertilizer only to sweet potato planted in this 0.1 hectare. Further, the cultivated portions are adjacent to the stream.

Erosion loss in MC 3, which is mostly occupied by houses and other structures, is also relatively higher than in MC2 and MC1. This may be attributed to the erosion from the foot trails and road network.

Table 2. Drainage area, soil loss, land use and shape of the microcatchments, Mapawa Catchment.

Microcatchment		Soil loss		
NO.	Area (ha)	Apr-Jul 2000 (kg ha-1)	Land use	Shape
MC 1	24.82	79.61	20% cultivated to vegetable and root crops 80% Falcata, Eucalyptus, grassland	Triangular Cultivated areas far from stream
MC 2	16.74	364.90	40% cultivated 60% grassland	Elongated
MC 3	14.90	536.73	10% settlement, built-up 90% grassland	Elongated
MC 4	0.940	24,498.51	50% cultivated (14% of Cultivated area is left bare) 50% grassland, trees	Rectangular Cultivated area adjacent to stream

Nutrient losses

The environmental relevance of soil erosion on site is its effects on productivity. It is assumed that erosion will result in a decline in the organic matter and nutrient content of the soil. As a consequence, crop production is expected to decline unless the lost nutrients are replaced. One of the assumptions made in the analysis is the linearity of nutrient distribution throughout the soil profile. The reason for this is that the total nutrient loss from each microcatchment is taken as a whole without relating it to soil depth. Generally, as revealed in Table 3, nutrient distribution in the microcatchments follows a decreasing trend with depth. It follows that nutrients are concentrated in the topsoil and it is expected that with constant rate of soil loss, the amount of nutrient loss with time will decrease as the upper layers are removed. Future measurements will determine if the nutrient loss will follow this trend.

Table 3 Organic matter, phosphorus, and potassium content in 2 soil profiles at Mapawa Catchment.

Depth (cm) (cm)	OM %	Available P mg kg-1	Exchangeable K cmol kg-1 soil
Pedon 1			
0-13	5.93	4.72	0.33
13-49	4.11	3.32	0.35
49-94	1.31	3.46	0.14
94-184	1.10	3.60	0.67
Pedon 2			
0-13	5.44	4.22	0.47
13-30	3.90	2.52	0.11
30-72	2.53	2.54	0.06
72-127	1.10	2.68	0.05

These situations emphasize that the application of the replacement cost approach should at least be done at the microcatchment level. Within the microcatchment, the various land uses will have to be categorized so that the individual contribution of the various land uses to the total nutrient loss can be approximated.

In general, the soil in the four microcatchments has moderate to highly adequate levels of organic matter (3.20–5.93%) and potassium (66–408 mg kg^{-1}) but is generally deficient in phosphorus (0.80–13 mg kg^{-1}) (Table 4).

Table 4. Some chemical properties of the soils in the four microcatchments, Mapawa, Lantapan, Philippines.

Microcatchment		pH	OM %	P Mg kg^{-1}	K mg kg^{-1}
MC1					
	Cultivated area	4.4–4.9	4.90–5.10	3.90–10.2	120–144
	Newly opened area	4.9	5.65	29	408
MC2					
	Cultivated area	4.4–5.1	4.11	2.7–12.9	114–375
	Grassland	4.8		0.8-2.7	267
MC3					
	Forest area	4.4	5.93	2.6	87
MC4					
	Cultivated area	4.8	3.18	3.3	66

As expected, the highest losses in organic matter, phosphorus, and potassium come from MC 4 and relatively very low losses from MC 1. Nutrient losses generally increase with erosion. The losses for P and K are higher in MC 2 than MC 3. This is due to the relatively higher P and K content of the eroded soils from MC 2. It can also be noted that soils in MC 2 contain high amounts of P and K as compared to MC 3 (Table 5).

Table 5. Soil and nutrient loss from four microcatchments from April to July 2000.

Microcatchment		Soil loss (kg)		Organic matter (kg)		P (kg)		K (kg)	
No.	Area (ha)	Total	per ha	Total	Per ha	Total	per ha	Total	per ha
MC1	24.93	1,364.0	54.71	215.40	8.64	0.0041	0.00016	0.6092	0.02444
MC2	17.88	12,319.6	689.02	639.30	35.76	0.0373	0.00209	3.0874	0.17270
MC3	7.96	6,886.1	865.09	600.70	75.46	0.0176	0.00221	1.3061	0.16408
MC4	0.94	23,028.6	24,498.51	1,376.40	1,464.26	0.0416	0.04426	2.9444	3.13234

Cost of soil erosion

In the replacement cost method, the cost of replacing the nutrients lost with the eroded soil is taken as the measure of economic loss. Table 6 shows the cost of nutrient losses in the four microcatchments for April–July 2000. As in the case of soil loss, the equivalent amount of nutrient loss in MC 4 is also the highest (48%) among the four microcatchments. On a per hectare basis, the microcatchment's loss is almost 12 times that of the three other microcatchments combined.

Table 6. Cost of nutrient losses from the four microcatchments, April to July 2000.

Microcatchment		N (Php)		P (Php)		K (Php)		Total cost	
No.	Area (ha)	Total	ha^{-1}	Total	ha^{-1}	Total	ha^{-1}	Total	ha^{-1}
MC1	24.93	213.35	8.56	0.20	0.01	9.54	0.38	223.09	8.95
MC2	17.88	633.33	35.42	1.82	0.10	48.36	2.70	683.51	38.22
MC3	7.96	595.09	74.76	0.86	0.11	20.46	2.57	616.41	77.44
MC4	0.94	1,363.32	1,450.34	2.03	2.16	46.12	49.06	1,411.47	1,501.56

Munasinghe and Lutz (1993) emphasized that the estimate of the replacement cost is *not* a measure of benefit of avoiding the damage, since the damage costs may be higher or lower than the replacement cost. In the case of Mapawa Catchment, although the cost of soil erosion in MC 1 is only PHP 8.95, in effect, it lost more than MC 3 since the latter is not used for crop production or if any, production area is negligible. Hence, although not actually computed, it may be assumed that the benefit of avoiding the damage in MC 3 is less.

There are two basic considerations in the estimation process. First, in areas with no production, nutrient loss would have no on-site cost. Second, due to the differences in erosion rates for each microcatchment due to major land uses, type, and nature of the microcatchment, location of the cultivated patches relative to the streams, and other factors, "averaging" of soil erosion for the entire catchment may not be advisable. In fact, each microcatchment has to be categorized according to land use, farming practices, and other factors to come up with a more accurate economic valuation.

CONCLUSION AND RECOMMENDATIONS

The replacement cost approach has been adopted because of the availability of data on actual soil loss, chemical analysis of the sediments, and fertilizer prices.

As used in this study, the replacement cost approach, which is simple, with direct and easy computation could give a reliable indication of the economic costs of soil loss. On the other hand, sufficient data and information on the linkage between erosion, plant production, and economic return are needed if the change in the productivity approach will be used.

However, the study still lacks a deeper economic perspective as it only dealt with the specific value of nutrient loss and did not consider the cost of investment and profit to be derived in case the landowner adopts soil erosion measures. This could project a clearer picture of the economic impact of soil conservation technologies.

Although the microcatchments in Mapawa, Lantapan were selected for this study, the principles and method in the valuation of soil erosion can be applied to other microcatchments at other MSEC sites.

Prediction models such as USLE, GUEST, and GIS-assisted models could be used with the replacement approach for estimating the soil loss in areas where erosion rates have not been measured or for estimating future erosion losses and concomitant costs.

The analysis could be extended into CBA in the future when data that establish a relationship between soil erosion and productivity are available. CBA identifies and measures the impacts of soil conservation projects or policies in terms of costs and benefits. Besides, it provides criteria to judge the desirability of soil conservation projects.

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