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The economic cost of upland and gully erosion on subsistence agriculture for a watershed in the Ethiopian highlands

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Abstract

This study quantifies the costs of erosion in a watershed of the Ethiopian highlands over a two-year period, accounting for topsoil nutrient losses, time costs due to disrupted travel networks, and the value of lost animals and trees. We use a nutrient replacement cost to value topsoil nutrient depletion, daily wage rate to monetise the opportunity cost of labour due to gully erosion, and local market prices to quantify the lost animals and cash crop trees. The total cost of soil erosion in the watershed during the two years was over $18 000, a cost of $22 per ha per year, $17 per person per year or about 19% of per capita income. The nutrient depletion from topsoil comprised only 42% of total costs. Given these large costs, remediation measures focused on participatory community-based efforts should be evaluated to reduce the severity of soil erosion and its associated effects.

Key words: Erosion, replacement cost, gully erosion, Ethiopia, East Africa

1. Introduction

Soil erosion by water is a major problem in the world (Lant *et al*. 2005), with economic, social and environmental implications arising from both on-site and off-site effects (Engel *et al*. 2008). Soil erosion damages capital[1] that supports economic development and improvements in quality of life. Human-induced conversion of natural capital reduces future service flows, unless the capital is restored when degraded (Blignaut *et al*. 2007). Soil erosion threatens the sustainability of agriculture in Ethiopia because of the importance of subsistence agriculture: more than 85% of the population lives in rural areas and relies on land resources for their livelihood (Diao & Pratt 2007; Telles *et al*. 2013). Understanding the economic costs of soil erosion is vital for farmers, soil conservation experts and policy makers in order to put the potential benefits of soil conservation practices into context (Shiferaw *et al*. 2005; Yesuf *et al*. 2005) and to set priorities for land management practices (Igwe & Fukuoka 2010; Kidane & Alemu 2015).

Previous studies that focused on upland erosion estimated that transboundary rivers originating in the Ethiopian highlands carry about 1.3 billion t y^{-1} of soil to neighbouring countries; the Blue Nile alone carries 131 million t y^{-1} (Kidane & Alemu 2015). In watershed-scale studies, the rate of sheet and rill erosion in the Ethiopian highlands ranged from 35 to 130 t ha^{-1} y^{-1} (Bewket & Teferi 2009), and as high as 540 t ha^{-1} y^{-1} for gully erosion (Tebebu *et al*. 2010). These estimates greatly exceed the tolerable recommended limit of 10 to 12 t ha^{-1} y^{-1} (Kimaro *et al*. 2008), and are much greater than the average soil-loss rate in other parts of Africa (30 to 40 t ha^{-1} y^{-1}; Taddese 2001). This underscores the seriousness of soil erosion in the Ethiopian highlands. A number of previous studies conducted in the Ethiopian highlands have used different methods, but indicated that soil erosion costs were likely to be large (Selassie & Belay 2013; Erkossa *et al*. 2015). The broad range of reported values ($5 to $372 per ha per year) arises from differences in both biophysical settings and cost estimation methods.

The objective of this study was to quantify the economic costs of upland and gully erosion in the Birr watershed of the Ethiopian highlands. Specifically, we (i) quantified the spatial and temporal variability of N and available P loss in eroded sediments at stream discharge points in the watershed; (ii) estimated the replacement cost of nutrients (N and available P) lost due to both types of soil erosion in the watershed; (iii) estimated the household-level value of time costs due to the disruption of existing footpaths due to gully erosion and (iv) quantified other environmental costs of gully formation, such as the loss of animals and perennial trees.

This study is distinguished from previous ones because it considers a broader range of erosion types and costs addressed, and makes the necessary adjustments to the calculation of the value of nutrients lost. It assesses the costs of soil erosion by water, such as upland sheet and rill erosion and bottomland gully erosion. The valuation also encompasses a wider scope of natural and social capital losses, including losses of replenishable natural capital (N and available P), renewable natural capital (animals and plants), cultivated natural capital (*Eucalyptus* trees and *Rhamnus prinioides* trees) and social capital (travel network disruption). Unlike other economic studies that used secondary datasets for soil-loss information, this study used its own and more accurate measure of the value of nutrients lost in eroded soil by distinguishing between surface erosion and subsurface erosion. Nutrients recorded in the streams originate from both surface and sub-surface soils, but not all these nutrient losses have relevance for crop production (Drechsel *et al*. 2004). Nutrients originating from subsurface soil are also lost and are indicated in nutrient concentrations at the gauging stations, but

[1] There are three types of capital. (i) Natural capital is an economic metaphor for the stock of physical and biological natural resources (types of natural capitals are renewable, non-renewable, replenishable and cultivated capitals); (ii) Social capital (social network, relations, institutions, shared cultural beliefs and traditions that promote mutual trust); (iii) Manufactured capital (buildings, road and other human produced fixed assets).

these nutrient losses have minimal effects on crop yields. Previous studies have often failed to account for impacts such as the loss of animals, damage to perennial trees and time costs, which can have significant effects on food security and poverty in developing countries (Barry *et al.* 2011). Thus, this study provides not only what are likely to be more accurate estimates of soil erosion costs for the watershed under study, but also describes methods that can be applied in other locations.

2. Data and methods

2.1 Study area

The study watershed, Ene-Chilala, is located in the big Birr River watershed in Amhara National Regional State (Ayele *et al.* 2015), an area characterised by rugged topography and steep slopes of between 2 001 and 2 414 m. Land in the watershed is prone to severe soil erosion due to intensive cultivation; the steep topography has poor vegetative cover where agriculture is the dominant activity. Ene-Chilala has a total area of 414 ha, with two nested sub-watersheds of 76 (Weir 1) and 146 ha (Weir 2) respectively. The bottom part of the sub-watershed in between the final outlet and the two nested sub-watersheds has a catchment area of 192 hectares. The main watershed and two nested sub-watersheds each have a gauging station installed at their outlets (Figure 1).

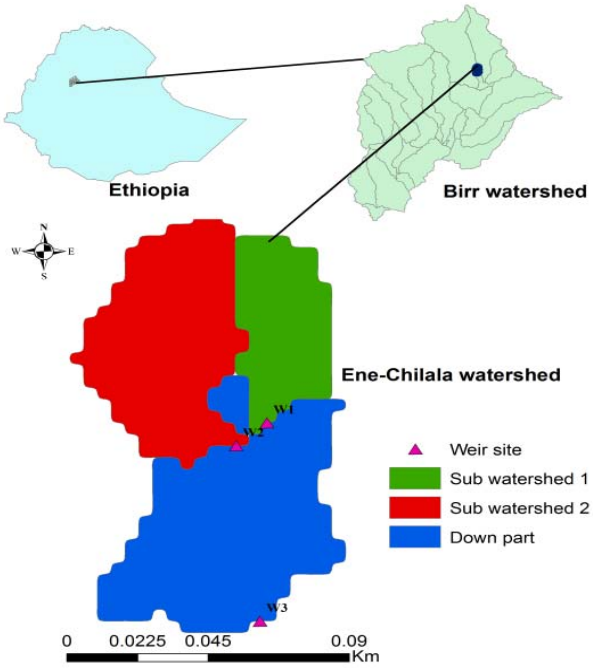

Figure 1: Map showing location of study watershed

2.2 Methods

There is no single method generally recognised for the valuation of soil erosion effects; the natural resource and environmental economics literature indicates a number of methods for assessing the value of soil erosion (Marta-Pedroso *et al.* 2007). The replacement-cost approach and the productivity-change approach remain the most commonly used methods to estimate the financial on-site cost of soil erosion in developing countries (Shiferaw *et al.* 2005; Yesuf *et al.* 2005). The replacement-cost approach calculates the costs that would have to be incurred in order to replace eroded soil, whereas the productivity-change approach estimates the value of land degradation damage equals the value of the lost crop production valued at market prices. These approaches have both merits and limitations; the replacement-cost approach is easier to apply when nutrient loss data

are available. Although the replacement-cost approach has limitations, it is appropriate for the study watershed. The research site is rugged, degraded land, the slopes are steep (Ayele *et al.* 2015), and farmers apply commercial fertilisers to maintain the agricultural production. The subsistence agriculture systems in the watershed are entirely rain-fed, and the amount, timing and duration of precipitation are highly variable. Crop yields thus depend on rainfall and pre- and post-harvest management. We applied four major steps, namely the measurement of erosion and the estimation of the nutrient content of soil loss, the calculation of an economic value for nutrients, the calculation of the time value, and the environmental cost of gully erosion incurred by households.

The first step was to measure sediment data from the stream flow. These data were collected during the months of June to September 2013 and 2014. Discharge, sediment and nutrient losses were monitored at three gauging stations (weirs) because of the variability of the landscape conditions. During storm events, stage-discharge and one-litre samples were taken in 15-minute intervals at the three gauging stations. Samples were collected when the water looked turbid (Guzman *et al*. 2013), and the sampling continued at fifteen-minute intervals until the water was no longer turbid. The samples were filtered using Whatman filter papers with a pore opening of 2.5 µm, oven dried, and weighed to determine the mass of sediment captured in each bottle. Suspended sediment concentrations (SSC_i) for storm events were determined by dividing the total sediment load by the total storm runoff (R_i) during that storm period (Tilahun *et al.* 2015). Sediment yield was then calculated as the product of discharge and sediment concentration.

The second step was laboratory analysis of the N and the plant-available P in the eroded soil. The collected sediment data (excluding the loss with runoff) were clustered in fifteen-day intervals for laboratory analysis. The laboratory analysis used the Kjeldahl method for N (Walkely & Black 1934), and the Olsen method for available P (mg Kg^{-1}) (Olsen *et al.* 1954). Nutrient loss is calculated as the product of soil loss and concentration of nutrients in the eroded sediments at the gauging stations (Erkossa *et al.* 2015). Nitrogen and available phosphorous are transported through surface and subsurface flows and become a component of surface runoff at the downslope (King *et al.* 2006).

The study watershed was dominated by gull and river bank erosion, which provided subsurface soil to the streams, and eroded sediments, comprising both surface and subsurface soil layers, collected at the gauging stations. However, commercial fertiliser was assumed to be applied to replace the eroded fertile soil on the surface of the soil. Thus, this study estimated the replacement cost of surface nutrient loss by subtracting the subsurface nutrient loss, which helps to avoid over-estimation of the replacement cost of nutrients. To estimate the nutrient content of the subsoil, samples were collected from cultivated land (from fields assessed as either degraded or non-degraded) and grazing land throughout the watershed. The subsoil samples were taken at 25 to 30 cm depth from 18 locations on degraded farm plots, 18 locations on relatively fertile farm plots, and 18 locations from grazing land (Doerr *et al.* 2006). These soil samples were organised in composite sampling and analysed in the laboratory by the same procedures used for eroded sediment. This allowed the estimation of the replacement value of the commercial fertiliser applied to the surface soil of agricultural farm plots. The average % N and available P content in the subsoil were 0.131 and 9.654 respectively. The surface soil nutrient content, the nutrient that was replaced by commercial fertiliser to maintain crop yield, was calculated by deducting the subsoil nutrient value from the total nutrients collected from the collected sediment at the stream outlet. In some months, the surface nutrient concentrations at the stream discharge were very low compared to the subsurface nutrient concentration and had negative values. In such cases we converted the negative value to zero (implying no surface nutrients lost) to calculate the nutrient replacement cost of the surface soil nutrients.

The third step was the economic analysis, during which a monetary value for the eroded sediment was calculated. The on-site costs associated with nutrient loss were calculated by determining the equivalent cost of fertiliser types and quantities needed to replace the lost nutrients using the replacement-cost approach (Yitbarek *et al.* 2012). This calculates the costs using the value of capital that replenishes the productive capacity of the environment (Adhikari & Nadella 2011). In this case, the capital for replenishment of eroded nutrients is in commercial fertiliser equivalent. Farmers apply commercial fertiliser for the purpose of improving crop yield by restoring surface soil fertility at the crop root zone (Nowkandeh *et al*. 2013). Thus, considering nutrients lost from the topsoil alone was preferable for the estimation of the replacement cost of nutrients in commercial fertiliser equivalent. The value of nutrients depleted from the topsoil was calculated based on the 2013/2014 price of commercial fertiliser from the local distribution agency. Farmers in the watershed typically purchase commercial fertilisers from input supplier organisations, using a two-step payment mechanism: payment of 50% at the time of acquisition and the remainder on credit, with the credit earning an interest rate of about 12.5% per annum (QWOA 2014). Based on the percentages of N and P for urea (46:0:0) and diammonium phosphate (DAP; 18:46:0) in fertiliser, urea contains 46% N and DAP contains 18% N and 20% available P. The values of 1 kg N and P were calculated as follows:

$$V_{Nitrogen} = \textit{Price 1 kg Urea/ N content of Urea applied} \quad (1)$$

$$V_{Phosphorus} = \textit{[Price 1 kg DAP – (Price of 1 kg N)(N content of DAP)] / Available P content of DAP} \quad (2)$$

The average direct purchase prices per 100 kg of urea and DAP were \$56 and \$67 respectively[2] in 2013 and 2014. Fertilisers were distributed to farmers who provided 50% of the purchase cost, and the remainder was provided on credit. We therefore included credit costs in our assessment of the replacement cost of nutrients in the form of purchased fertiliser. The prices of urea and DAP, including the credit costs, were \$70 and \$84 per 100 kg respectively. Based on these unit purchase prices, the cost of 1 kg N was \$1.50 and the cost of 1 kg available P was \$2.80.

The fourth step was to analyse the social and environmental costs of erosion, in addition to the replacement costs for soil nutrients. The social cost of gully erosion includes the opportunity cost of labour for farmers, and the time value due to longer travel distances when gullies destroy existing footpaths. This study focuses on the time value cost due to the Laye-Enset-Bet gully for farmers living above and below the gully. The existing gully cuts across a footpath used by 51 households to access farm plots and to participate in market days. These households thus use alternative paths that increase the travel time by 44 minutes (round trip). Thus, each individual using the alternative road incurred an additional travel cost of 0.73 hours per day on days when farm activity and marketing required travel.

The survey data indicated that the daily labour wage rate in the study area was \$1.56 on average. The average working time in a day was nine hours, so the average wage rate was \$0.17 per hour. Twenty-three households who resided in the village above the gully used the alternative path for marketing activities, whereas 19 households who lived in the same village used the alternative path to access market and farmlands on the other side of the gully. Nine farmers from villages below the gully had farmland upstream of the gully, so they also used the alternative path to access their farm plots. We used the daily wage as a proxy measurement for estimating the opportunity cost due to gully erosion. Human labour and animal power were the most important inputs in farming and marketing activities in the study watershed. Particularly during the peak agricultural production seasons, day labour employment was commonly practised for cash payment or in exchange for oxen and/or donkey

[2] The mean conversion rate of 1 USD (\$)to Ethiopian birr was 19.20 ETB for 2013 and 2014.

labour. The number of family members, oxen and donkey who used the alternative road for farm activity and marketing were enumerated using household surveys. In the study area, farmers who did not have two oxen could obtain ploughing services from other farmers in exchange for two days of work. Similarly, farmers who did not own donkeys could exchange one days' labour for these services. We used this equivalency to quantify the time cost of gully erosion on farmers' farming and marketing activity.

The time cost of gully erosion for farmers, oxen and donkey was calculated as:

Time cost due to gully erosion =
(Hours per week accessing farm plots + hours per week accessing markets)(wage rate) (3)

The other cost of gully erosion arose due to losses of animals and perennial trees (Marta-Pedroso *et al.* 2007; Moges & Holden 2009). A number of animals were killed after being trapped in the gully during the rainy season. Trees also were destroyed by gully expansion during the rainy season. The number and type of animals and trees affected were valued using local market prices. Animals killed were valued at their potential sales price (the replacement cost of lost animals). Losses occurred in both privately owned and traded tree species (*Eucalyptus* and *Rhamnus prinioides*) and communally owned tree species (*Syzygium guineense – Dokima* in Amharic, and *Acacia abyssinica).* Losses of privately owned trees were straightforward to value because the trees are grown for consumption and profit (Zhang & Li, 2005). The number and age of damaged *Eucalyptus* trees were enumerated. The trees were classified into three age groups (the market price and purpose of *Eucalyptus* trees depend on their age) – aged between two and eight years; between nine and 12 years; and above 12 years. The local market prices per tree were $0.80, $1.70 and $6 respectively. The economic valuation was the number of trees in each age group multiplied by the respective local market price. *Rhamnus prinioides* trees provide leaves for flavouring the local beer ('tella'). They are harvested two or three times a year and yield for about 25 years once mature. We estimated the cost of erosion for *Rhamnus prinioides* trees assuming the 15-year yield. We enumerated the number of trees and annual income lost from the trees, then added this to the cost of yield loss from gully erosion damage in each year for the upcoming 15 years. We calculated the present value of these losses by discounting using a 5% interest rate, which is the rate at which funds can be borrowed from the Central Bank of Ethiopia. The valuation of the loss of communally owned multipurpose trees is difficult, because 1) transaction data are not available and 2) the cost of replacing these trees is unknown, since they are propagated in the wild. Thus, our calculation of losses will somewhat understate the true valuation because we did not include communally owned trees.

Finally, the total cost of soil erosion was calculated by summing the value of resources lost in 2013 and 2014, excluding the opportunity cost of time. The opportunity cost of time due to gully erosion was evaluated using data from 2013 on-farm and market activity, and the annual opportunity cost for 2014 was assumed to be the same. The average annual cost was estimated by calculating the mean value of the total cost for the two years.

3. Results

3.1 Sediment yield and nutrient depletion

3.1.1 Suspended sediment yield

Plant nutrient loss reflects the temporal and spatial variability in sediment yield (Erkossa *et al.* 2015). The rates of sediment yield vary between 2013 and 2014 at the different locations in the Ene-Chilala watershed; the erosion rate at the outlet of the watershed (Weir 3) was 75 t ha^{-1} y^{-1} in 2013 and 10 t

ha^{-1} y^{-1} in 2014. The likely reasons for the lower erosion in 2014 were community participatory rehabilitation of the gullies, soil and water conservation projects organised by the government, and the lower precipitation in 2014 (761 mm) than in 2013 (1 047 mm; Ayele *et al*. 2015). Higher sediment yield was observed downslope (Weir 3) than in the two nested upslope watersheds (Weir 1 and Weir 2). These rates are similar in magnitude to an erosion rate of 1 to 40 t ha^{-1} y^{-1} for upland catchments, and reached up to 400 t ha^{-1} y^{-1} for the gully-dominant bottom lands (Tebebu *et al.* 2010; Tilahun *et al.* 2015). This suggests that gully erosion located in the saturated bottom lands contributed a substantial proportion of the sediment yield in the watershed. In this watershed, subsoil sediments from gully erosion were the dominant source of sediment yield, which further justifies our calculating the replacement costs by distinguishing between topsoil and subsoil nutrient losses.

3.1.2 Nutrient depletion

In the study area, commercial fertiliser typically is applied twice in the rainy season: one application occurs at the beginning of the rainy season (May and June) for crops such as maize, wheat and barley; the other application is for the teff crop in August. Therefore, the highest concentration of nutrients in the stream discharge was recorded in June and August, while the lowest was recorded in July. Nutrient concentrations were generally higher from sediments originating from the upland catchment Weir 1 compared to Weir 2 and Weir 3. The likely reason for the low concentration in the stream discharge at Weir 2 and Weir 3 was the dilution of surface soil nutrients with high runoff, coupled with severe gully and riverbank erosion in the lower elevation locations of the watershed, which contributed high subsurface soil nutrients. Therefore, catchment condition and time of commercial fertiliser application were the two most important determinants for the nutrient variability in stream discharge. The total mass of nutrients depleted depends on the sediment yield (Ockenden *et al.* 2014); however, the nutrient concentrations in the eroded sediments from the surface soil were inversely proportional to the sediment yield. Nutrient concentration was high at the beginning of the rainy season; the likely reason would be the application of commercial fertiliser before the maximum rooting of crops (Kuzyakov & Xu 2013). These suggest that nutrient concentration measurements reflect the nutrient losses related to the application of commercial fertiliser. The per hectare N depletion rate was 8 kg ha^{-1} y^{-1}, and that of available P was 0.05 kg ha^{-1} y^{-1} (Table 1), a result consistent with the findings of Tesfahunegn and Vlek (2013) in northern Ethiopia. These concentrations in sediments provide a useful context for the severity of nutrient depletion in the watershed.

3.2 Economic cost of soil erosion

3.2.1 Replacement cost of topsoil nutrients

The average nutrient replacement cost was \$10 ha^{-1} y^{-1} (Table 1), which is consistent with other studies in the Ethiopian highlands, which found it to be \$9 ha^{-1} y^{-1} (Tesfahunegn & Vlek 2013), and \$5 ha^{-1} y^{-1} (Selassie & Belay 2013). These studies also considered the nutrients derived from the topsoil. In both cases, the nutrients were analysed by taking samples from the topsoil to analyse. In the case of Selassie and Belay (2013), the soil loss was calculated by using the universal soil loss equation (USLE), which measures the amount of soil loss from surface soil erosion (rill and sheet erosion) without including the gully (subsoil) erosion, whereas Tesfahunegn and Vlek (2013) calculated the sediment yield from the reservoir deposition for 16 years. Both of these studies calculated the cost of erosion using the replacement-cost approach. However, the figures were markedly lower than those in the studies by Erkossa *et al.* (2015) in different watersheds of the Ethiopian highlands. They found \$372 ha^{-1} y^{-1} in Diga, \$200 ha^{-1} y^{-1} in Fogera, and \$63 ha^{-1} y^{-1} in the Jeldu district. The on-site cost of soil erosion due to N and P was \$179 and \$193 ha^{-1} y^{-1} for Diga, \$52 and \$148 ha^{-1} y^{-1} for Fogera, and \$24 and \$39 ha^{-1} y^{-1} for Jeldu. These studies calculated the cost of soil erosion by recording the sediment yield from stream flow at the gauging stations (weirs). The amount of nutrients was calculated from sediment that collected at the gauging stations, so they likely

included nutrients that originated from the subsoil. The cost of soil erosion was calculated using the productivity approach. Therefore, the sampling methods, the soil loss calculations and the method for valuing losses were the likely reasons for the wide range of results from these studies.

The replacement cost of nutrients from the whole watershed at Weir 3 was higher than the two nested watersheds upland (Table 1). In addition, the replacement cost was higher in 2013 than in 2014. This clearly indicates that the replacement cost of nutrients is consistent with the amount of sediment yield (Ockenden *et al.* 2014), and suggests that a reduction in the replacement cost of nutrients can be accomplished with cost-appropriate soil conservation methods.

3.2.2 Replacement costs of topsoil and subsoil nutrients

Nutrient concentrations in the eroded sediment measured from suspended sediment in the stream flow at the outlet of the watersheds (Weir 3) were much larger than for surface soil alone. The result is comparable with the sediment nutrient content in Northern Ethiopia, at 0.11 to 0.19% for N and 5.38 to 10.88 mg Kg^{-1} for P (Haregeweyn *et al.* 2008). Erosion caused the depletion of nutrients from both the surface and subsurface soil, and the sediment collected at the outlet of the watershed originated from the surface and subsurface soil. As noted earlier, nutrients exported from a watershed originating from the subsurface soil is not the cause for a loss in crop yield because it is out of the plant root zone, but could impose a cost on the environment. The average nutrient replacement cost of nutrients exported from a watershed based on sediment collected at Weir 3 and originating from both surface and subsurface soil was \$69 ha^{-1} y^{-1}, 86% higher than losses from the surface soil only (Table 1). Thus, the cost of soil erosion based on sediment collected at the gauging station without deducting the subsurface nutrients can be misleading for the purposes of valuing farm-level losses, and the importance of distinguishing between topsoil and subsoil losses is especially relevant in a watershed where there is subsoil source gully erosion.

Table 1: Rate of nutrient and value losses from the Ene-Chilala watershed in 2013 and 2014

	Nutrient and value losses				
Soil category, year, station	**N loss (kg/ha/y)**	**Value of N loss ($/ha/y)**	**P loss (kg/ha/y)**	**Value of P loss ($/ha/y)**	**Total value of loss ($/ha/y)**
Nutrients derived from surface soil					
2013					
Weir 1	8	11	0.18	0.51	12
Weir 2	5	7	0.19	0.53	8
Weir 3	11	16	0.05	0.14	16
2014					
Weir 1	4	6	0.05	0.13	6
Weir 2	8	12	0.06	0.16	12
Weir 3	2	3	0.02	0.06	3
Overall average at WS outlet (Weir 3)	7	10	0.04	0.10	10
Nutrients derived from surface and subsurface soil					
2013					
Weir 1	24	36	1.93	5.42	41
Weir 2	37	56	1.77	4.95	61
Weir 3	78	116	0.15	0.42	116
2014					
Weir 1	8	12	0.05	0.15	12
Weir 2	16	24	0.11	0.31	24
Weir 3	14	22	0.07	0.21	22
Overall average at WS outlet (Weir 3)	46	69	0.11	0.315	69

Unit cost of nutrients: The price of 1 kg N was $1.50, while the price of 1 kg available P was $2.80.

3.2.3 Time value cost of gully erosion

The total increase in opportunity cost of time during crop management activities due to the presence of the gully was $206 per year (Table 2). This is about $6 per household per year. Time costs for marketing were nearly eight times larger due to the higher frequency of market visits during the year. Forty-two households lived in the village on the other side of the gully and were required to use an alternative road to access the market, and they incurred costs of nearly $1 600 per year, or about $40 per household per year. The overall opportunity cost of labour due to the need to use an alternative road to access farm plots and the market on the other side of the Laye-Enset-Bet gully was $1 801 per year (Table 2), or about $35 per affected household per year. These costs are in fact likely to be somewhat larger. There are a number of other gullies in the watershed that probably have similar effects on the use of time in the community, but due to resource constraints we did not evaluate these. We also did not evaluate time costs associated with the gully related to non-productive purposes (such as other routine movements or social visits).

Table 2: Additional time costs for agricultural and marketing activities of households due to the Laye-Enset-Bet gully

Activity for which additional time is required	Total additional time per year due to gully, hrs/y	Wage rate ($/hr)	Total time cost ($/y)
Agricultural activity	1 640	0.17	206
Marketing	12 852	0.17	1 595
Total	14 492	0.17	1 801

3.2.4 Value of animal losses

Another economic cost of gully erosion in the study area was the death of animals trapped in the gully during 2013. A total of eight animals were lost during these two years and the economic cost was greater than $1 000 (Table 3). The death of these animals occurred in the rainy seasons. Although we valued the animals at their sales price, the loss of animals also implies other, indirect costs for farmers

because this may disrupt breeding and ploughing activities. A previous study of gully erosion in Nigeria indicated that the average annual effects included 16 houses damaged, 128 people displaced, and the deaths of one person and three animals (Danladi & Ray 2014). This suggests that gully erosion can have severe impacts other than impacts on crop yields, but the economic value of these losses was not calculated.

Table 3: Value of animals lost due to gully erosion during 2013 and 2014, Lay-Enset-Bet gully

Type of animal	Number of animal deaths	Price, $/animal	Total cost, $
Heifer	1	208	208
Bull	3	160	479
Calf	2	68	135
Donkey	1	125	125
Ox	1	260	260
Total	8		1 208

3.2.5 Value of tree losses

Another effect of gully erosion was the permanent loss of trees. The sales of *Eucalyptus* trees are one source of income for farmers in the community, so lost trees can have important household-level effects. The total cost of erosion on *Eucalyptus* trees was $243. Farmers valued harvests of *Rhamnus prinioides* from a single tree at $4.20 per year. The 15-year discounted monetised erosion cost of the *Rhamnus prinioides* tree was $2 036, which was calculated on the basis of the 5.01% interest rate offered by the Central Bank of Ethiopia and by assuming the only current erosion loss, at $160 per year (Table 4).

Table 4: Number and value of trees affected by gully erosion in 2013 and 2014, Laye-Enset-Bet gully

Perennial tree species, age group	Trees lost, number	Average price, $/tree	Total cost, $/year
Eucalyptus trees	142	varies	243
2 to 8 years of age	80	0.8	64
9 to 12 years of age	45	1.7	77
More than 12 years of age	17	6.0	102
Rhamnus prinioides trees	38	4.2	160
Total	180	2.23	402

Note: The communally-owned tree species, *Acacia abyssinica* and *Syzygium guineense*, were not valued.

Although we did not monetise the impact of erosion on communally owned multipurpose trees, we enumerated the number trees damaged, and the degradation of these trees may have an important impact in the watershed. Degradation contributes to the drying out of streams covered by these trees, lack of shade for animals during the dry seasons, and less firewood in the area. Thus, the negative consequences of these species' losses include local environmental change.

3.3 Total economic costs

This two years of data indicate that soil erosion has significant economic costs for the subsistence farmers in the watershed (Table 5). The total cost of soil erosion was estimated to be $18 313 in the two-year study period (2013 and 2014) in the Ene-Chilala watershed. About 43% of this loss was due to soil nutrients, and 39% was the opportunity cost of time incurred due to the gully's disruption of the footpaths. Thus, typical measurements of soil nutrient losses alone may understate the costs incurred by households, especially as a result of gully erosion.

Table 5: Total economic and environmental costs of soil erosion in 2013 and 2014

Cost category	Total cost (US $)
Soil nutrient loss	7 848
Opportunity cost of time	7 204
Animal losses	1 208
Eucalyptus trees	243
Rhamnus prinioides	1 810
Total	18 313

Note: The annual cost ($ y^{-1}) was calculated by dividing the total cost by two.

The community on this watershed level lost on average $9 157 per year due to soil erosion. Given the population of 525, the cost of soil erosion was $17 per individual per year, and the loss per household was $93 per year. This community depends on subsistence mixed agriculture, crops and livestock for their livelihoods, and the losses comprise a large proportion of the average annual income generated from agriculture. According to Selassie *et al.* (2011), the annual cash income of households from subsistence agriculture in the study area ranged from $133 to $776 in 2007, and it is likely that incomes have not increased significantly since then. This implies that the average annual cost of soil erosion was equivalent to anything from 12% to 70% of annual household income. The nutrient depletion from topsoil alone cost 9% of the per capita agricultural income, which is roughly consistent with other studies, which indicated values of 14% in Ethiopia (Ahmed & Ismail 2008) and 7% to 10% in sub-Saharan Africa (Shiferaw *et al.* 2005). The socio-economic and environmental cost of soil erosion was $22 ha^{-1} y^{-1}, which also is consistent with the figure of $20 ha^{-1} y^{-1} found by Shiferaw *et al.* (2005) for sub-Saharan Africa. Although our estimated costs are large relative to household incomes and suggest significant effects on livelihoods in the study watershed, they may underestimate the livelihood impacts, for two reasons. First, the use of replacement cost to estimate the cost of nutrient losses may not fully reflect the livelihood costs if nutrients are not (or cannot be) replaced. Second, the estimated costs do not consider the off-site costs of soil erosion, such as filling up reservoirs, which, when empty, reduce hydroelectric generation and water supply for irrigation (due to the lack of a reservoir in the study watershed), nor the effects on the quality of water and aquatic ecosystems. We also did not estimate the value of some goods and services of the environment due to a lack of appropriate proxies. There are many costs of soil erosion that cannot easily be quantified with the existing valuation techniques, like social capital (culture, political stability) and other forms of natural capital. This paper presents the estimated cost of on-site natural and social capital losses only, so the presented value will underestimate the true, longer term costs of soil erosion. We thus recommend further research exploring both on-site and off-site costs.

4. Conclusions

The results indicate that erosion has a significant economic impact on the livelihood of the community, and that soil nutrient losses make up only about half of the value of total costs. Overall, soil erosion costs each individual in the watershed up to 19% of annual income per year. The magnitude of these losses suggests that remediation measures should be evaluated to reduce the severity of soil erosion and its associated effects, but these should be undertaken only after an assessment of the costs of remediation and its impact on soil erosion costs. Although the magnitude of soil erosion losses appears large relative to average household incomes in the watershed, lower cost methods of reducing the impacts of erosion will likely be appropriate, given the community's limited financial resources. Government and NGOs might most effectively focus on participatory, community-based soil conservation practices such as those described in Ayele *et al.* (2015), giving priority to hotspot erosion areas.

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