

1 **LINKING SOIL EROSION TO ONSITE FINANCIAL COST: LESSONS FROM**
2 **WATERSHEDS IN THE BLUE NILE BASIN**

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1 ***ABSTRACT***

2 The study was conducted in three watersheds (Dapo, Meja and Mizewa) in the Ethiopian part of the
3 Blue Nile Basin to estimate the onsite cost of soil erosion using the productivity change approach, in
4 which crop yield reduction due to plant nutrients lost with the sediment and runoff has been
5 analyzed. For this purpose, runoff measurement and sampling was conducted during the main rainy
6 season of 2011 at the outlet of two to three sub-watersheds in each watershed. The sediment
7 concentration of the runoff, and N and P content of the runoff and sediment were determined.
8 Crop response functions were developed for the two plant nutrients based on data obtained from
9 the nearest Agricultural Research Centers. The response functions were used to estimate crop yield
10 reduction as a result of the lost N and P assuming there is no compensation through fertilization.
11 The results show a significant yield reduction and resultant financial loss to the farmers. Considering
12 only grain yield of maize (*Zea mays*), farmers at Dapo annually lose about USD 220 ha⁻¹ and 150 ha⁻¹
13 due to the loss of nitrogen and phosphorus, respectively. In view of the importance of the crop
14 residues including as feed, the loss can be even greater. The study demonstrated that in addition to
15 the long-term deterioration of land quality, the annual financial loss suffered by farmers is
16 substantial. Therefore, on farm soil and water conservation measures that are suitable in biophysical
17 and socio-economic terms in the landscapes and beyond need to be encouraged.

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19 **Keywords:** Ethiopia, Nutrient loss, Runoff, Yield reduction, Cost of Erosion
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1 **1. Introduction**

2 Soil erosion is a global environmental threat that reduces the productivity of all natural ecosystems
3 including agriculture (Kertész, 2009; Pimentel and Burgess, 2013; Leh, et al., 2013). Erosion-induced
4 soil quality deterioration is prevalent throughout the world (Harden, 2001; Zhao et al., 2013)
5 impeding the global food and economic security. The challenges of soil erosion are more severe in
6 the heavily populated, under-developed, and ecologically fragile areas of the world (Young, 1993;
7 FAO and UNEP, 1999), where the adaptation capacity is weak (Cerdà, 2000; Leh et al., 2013).
8 Tesfahunegn (2013) argues citing Lal (1981) and Eswaran et al., (2001) that misuse of soils, resulting
9 from a desperate attempt by farmers to increase production for the growing population exacerbates
10 soil quality degradation, and he further suggests that severity of such degradation is higher in
11 developing countries where the economy mainly depends on agriculture. Soil erosion by water is the
12 greatest factor limiting soil productivity and impeding agricultural enterprises in the humid tropical
13 regions (Sunday et al., 2012). The resource-poor farmers in sub-Saharan Africa (SSA) are exposed to
14 the pressures of soil quality deterioration, the effect of which is aggravated by their limited access to
15 the resources that are necessary to adapt. In the Ethiopian Highlands, reduced agricultural
16 productivity and poverty because of soil quality degradation are widespread (Erkossa et al., 2006).
17 Inappropriate land use, in which land is not used according to its suitability, and poor farming
18 practices are the major factors leading to soil erosion induced soil quality deterioration in the
19 highlands of Ethiopia (Adimassu et al., 2015; Angassa et al., 2014; Belay et al., 2013; Erkossa et al.,
20 2005) and in other parts of the world (Bravo Espinosa et al., 2014), which posed socio-economic
21 and environmental challenges. Studies conducted in northern highlands of the country show that
22 removal of the natural vegetation for expansion of agricultural and rangeland has led to increased
23 soil losses and growing rock outcrops, which leads to nutrient depletion and lowering of agricultural
24 yields (Belaly et al., 2014; Mulugeta et al., 2005; Woldeamlak and Stroosnijder, 2003). Often farmers

1 attempt to produce their traditional crops using techniques that are not necessarily suitable for the
2 new land they access through such expansion.

3 Soil erosion has on-site and off-site effects. The direct on-site effect is related to agronomic
4 productivity of plants (Lal, 1998), which is often linked to nutrient loss with runoff and sediment.
5 Hailelassie et al. (2005) estimated an annual nutrient depletion rate of 122 kg N, 13 kg P and 82 kg
6 K ha⁻¹ from the Ethiopian highlands. Further, Adimassu et al. (2012) estimated an annual loss of
7 47.8 kg N, 0.60 kg P₂O₅ and 0.40 K₂O ha⁻¹ which he attributed to soil erosion alone. As a
8 consequence of both soil erosion and nutrient depletion, more than 30,000 ha of the country's
9 cropland are estimated to become out of production annually (Grepperud, 1996). Quantifying the
10 economic effects of these soil and nutrient loss, especially before the land is completely out of
11 production remains a daunting challenge. Such information helps to substantiate investment on land
12 management measures for the short and long term benefits to both onsite and off-site land users.
13 Evidently, in the long-term, it is established that improved land and water management brings
14 economic advantages to the land users, but farmers often resist adopting such measures because
15 they lack relevant evidence on how land degradation impacts their earnings and livelihood (Telles et
16 al., 2013).

17 Availability of plant nutrients in the soil limits land and water productivity in areas where absolute
18 quantities of water are not limiting, but even in moisture deficient areas it can be more limiting than
19 water (Breman, 1998). Therefore, management practices that affect the nutrient content of soils
20 directly affect farmers' income. Soil nutrient depletion is an important on-site effect of soil erosion
21 (Bojö and Cassells, 1995; Verstraeten and Poesen, 2000). Such effects can be plausible to farmers
22 and policy makers if expressed in terms of immediate financial cost.

23 According to Telles et al.(2013), the on-site costs of soil erosion can be estimated using the cost of
24 replacement for the nutrients lost, normally macronutrients calculated on the basis of market prices

1 for commercial fertilizers and the quantity necessary to replace the lost nutrients, plus the
2 application cost. This approach presumes that farmers replace the lost nutrients through
3 fertilization, which is not often the case in subsistent farming systems in developing countries. In
4 such cases, it can be argued that rather the cost of not replacing the lost nutrients should be
5 estimated and used as a proxy for the onsite cost of erosion. In line with this, Telles *et al.* (2013)
6 suggest the use of estimated yield reduction as a measure of productivity loss resulting from soil
7 limitations, including loss of the essential nutrients. The objective of this study was to quantify the
8 essential nutrients lost due to soil erosion and to estimate the resultant crop yield and household
9 income losses.

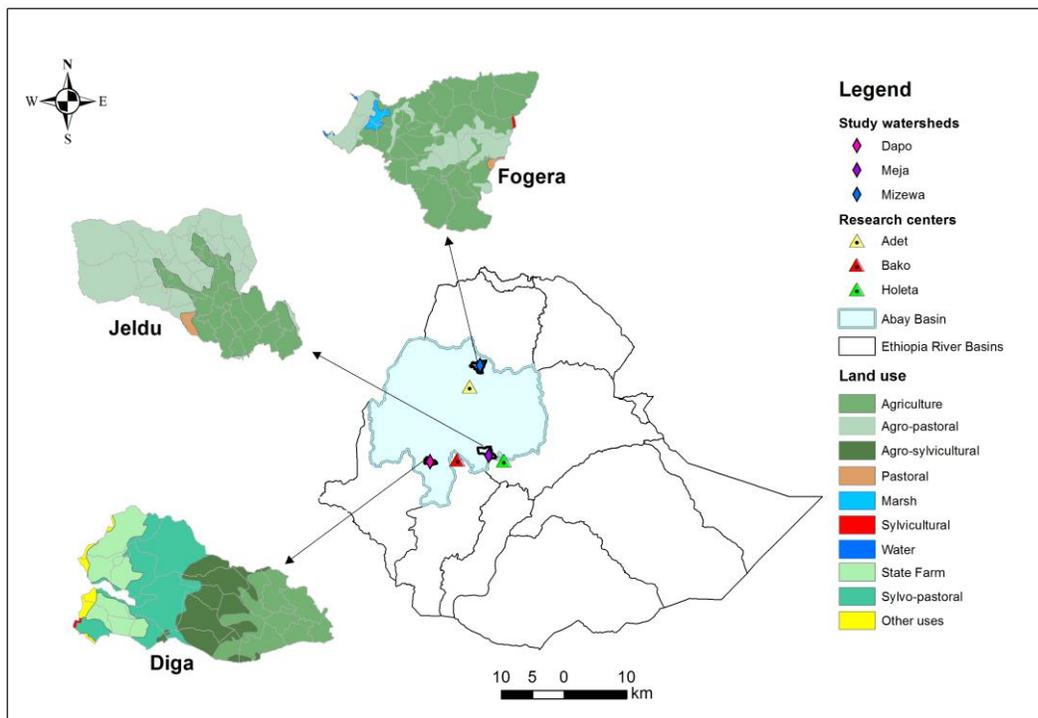
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2 2. Materials and Methods

3 2.1 The study sites

4 The study was conducted in three watersheds Dapo, Meja and Mizewa with two sub-watersheds for
5 the first and three sub-watersheds each for the last two, all in Blue Nile Basin (Figure 1). All the
6 watersheds, except the lower part of Dapo, are situated in the highlands (above 1500 m asl) based on
7 the Ethiopian agro-ecological classification systems, but farmers in the districts traditionally classify
8 the areas into high, middle and low lands. The altitude range of each traditional class was later
9 determined using GPS handsets (Table 1). The sites receive relatively high rainfall ranging from 900
10 mm at Meja to over 2000 mm at Dapo, the major part of which is received during the main rainy
11 season in summer (May to September) (Figure 2).



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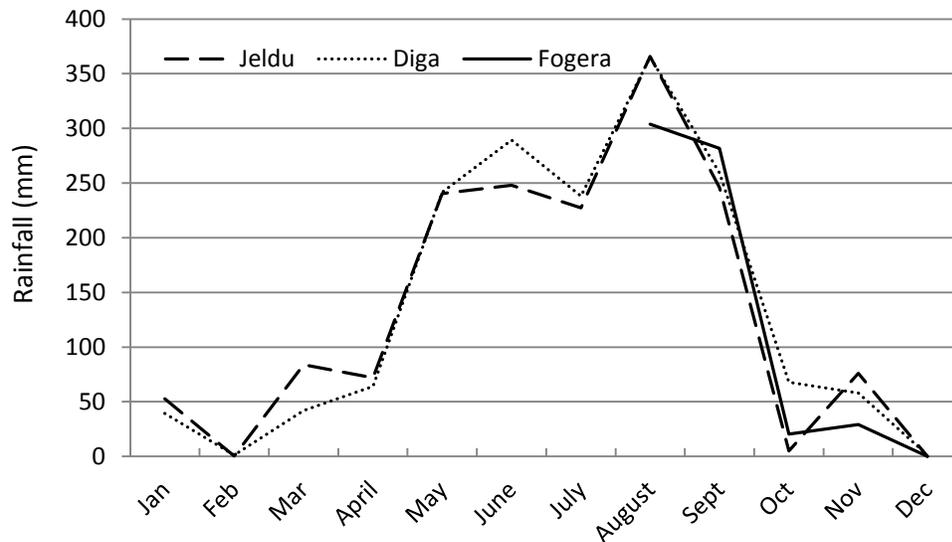
13 Figure 1: Location and land use map of the study sites with the nearest agricultural research centers

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2 Table 1: Description of the three study watersheds based on office of agriculture annual report (2006 to
 3 2010), ILRI Baseline Survey (2010) and own survey

Watershed name	Landscape position	Altitude range (m a.s.l)	Mean annual rainfall (mm)	Major crops	Major challenges
Dapo	upper	Higher than 2000	1,376 to 2,037	tef, finger millet, niger seed, sorghum	Demographic pressure, deforestation, overgrazing, soil erosion, soil fertility depletion, termites, water and land scarcity, inefficient irrigation scheme, lack of water storage systems high rate of deforestation soil acidity
	middle	1451-2000		maize, sorghum, sesame, finger millet	
	lower	Less than 1450		maize, sorghum, sesame, finger millet	
Mizewa	upper	2000-2200	974 to 1,516	barley, tef, faba bean	shallow water table (2-4 m) flooding, water logging, upper and middle: shallow and stony soils bottom part: water shortage
	middle	1800-2000		maize, finger millet, tef	
	lower	1785-1800		rice	
Meja	upper	2700 - 3200	900 to 1,350	potato, wheat, barley	Inefficient irrigation practice: <ul style="list-style-type: none"> ▪ 60% delivery loss ▪ water application is by wild flooding deforestation, cultivation of steep slopes, soil erosion, plant nutrient depletion, shallow soil depth
	middle	2300 - 2700		wheat, tef, sorghum	
	lower	1800 - 2300		maize, tef, sorghum	

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2 Figure 2 Rainfall of the study sites in 2011 with Fogera's data only for August to December

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4 2.2 Farming systems

5 Crop-livestock mixed cropping agriculture is the dominant livelihood, while the major crops grown
 6 vary between and within the watersheds based on altitude (Table 1). While irrigation is limited to the
 7 valley bottoms and on the sides of streams, rainfed cropping of maize (*Zea mays*), barley (*Hordium*
 8 *vulgare*), wheat (*Triticum aestivum*), tef (*Eragrostis tef* Zucca), and sorghum (*Sorghum bicolor*) is widespread
 9 in all the sites but potato (*Solanum tuberosum*) is also an important crop in the highland part of Meja.
 10 Population pressure, land degradation, inefficient use of water (rainfed and irrigated) and
 11 inappropriate land use and land and water management practices, are among the common challenges
 12 to the sustainability of the watersheds (Erkossa et al., 2009).

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1 **2.3 Runoff measurement**

2 Runoff was measured three times a day (at 8 am, 12 pm and 6 pm) and averaged to get a daily flow
3 during the rainy season (which was at least 90 days) in 2011 at two to three selected gauging sites in
4 each watershed. Discharge was measured using the Velocity-Area Method (Chitale, 1974). A current
5 meter (*Model 0012B Surface Display Unit and Model 002 Flow Meter*) was used to measure the flow
6 velocity (V). The flow depth at predefined cross-sections was measured using graduated wading rod
7 simultaneously at several points spaced at varying intervals depending on the width of the stream.
8 The cross sectional area (A_i) of the flow was calculated using the flow depth (h_i) at each point. The
9 average flow velocity at each point (V_i) and the average discharge at each sub-cross sectional area (q_i)
10 were calculated using Eq. 1 and the total flow (Q) passing the outlet was calculated using Eq.2.

$$q_i = v_i * a_i \qquad \text{Eq. 1}$$

$$Q = \sum_{i=1}^n q_i \qquad \text{Eq. 2}$$

11 where:

12 h_i = flow depth at each cross section (m)

13 a_i = cross sectional area at each point (m^2)

14 q_i = discharge at each cross sectional area ($m^3 \text{sec}^{-1}$)

15 V_i = flow velocity at each cross sectional area ($m \text{sec}^{-1}$)

16 Q = Total discharge ($m^3 \text{sec}^{-1}$)

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1 A steady-flow discharge rating curves (Figure 3) were developed by fitting the measured gauge to
2 discharge into power curve; water levels were measured throughout the study period using a staff
3 gauge and the discharge was calculated from the equations of the curves (Eq. 3).

$$Q = c(H + a)^b \quad \text{Eq. 3}$$

4 Where: $Q =$ discharge ($\text{m}^3\text{sec}^{-1}$)

5 $H =$ measured water level (m)

6 $a =$ water level (m) corresponding to $Q = 0$

7 $c =$ coefficients for the relationship corresponding to the station characteristics

8 $b =$ coefficient for the power relation of the station characteristics

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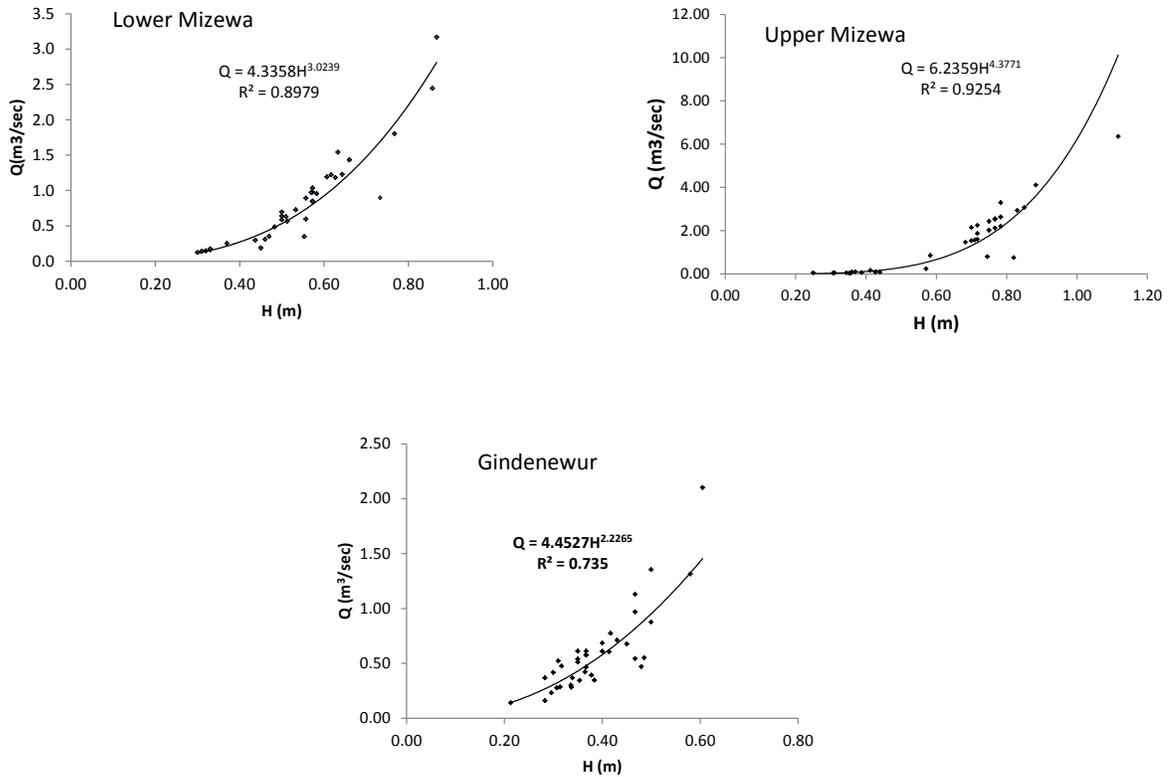


Figure 3: Discharge rating curve for some of the sub-watersheds

2.4 Runoff sampling and suspended sediment loss estimation

Depth integrated runoff samples were collected manually at the outlet of the sub catchments using one liter plastic bottles three times a day. The daily samples were mixed and two liters were subsampled and bulked for ten consecutive days in a 20 L jerry can and kept in refrigerators at 4 °C in laboratories. The suspended sediment in the bulked samples was allowed to settle and the clear water at the top was decanted into laboratory beakers. The turbid part remaining at the bottom was filtered using Whatman filter papers number 4 and oven dried and weighed. The suspended sediment concentration of the runoff for each ten successive days was obtained by dividing the mass

1 of the oven dry sediment by the volume of the runoff during the ten days interval. The decanted
2 water and that left after filtration were mixed and subsampled for chemical analysis.

3 2.5 Estimates of N and P loss

4 The two essential plant nutrients, N and P content of the suspended sediment and the runoff water
5 was determined following standard procedures for these elements (Table 2). The sum of the
6 nutrients lost associated with the suspended sediments and dissolved in runoff was considered as the
7 total loss of these nutrients during the study period (Eq. 4-6). Although rainfall started in May,
8 discharge measurement and runoff sampling started in July, after some significant runoff had
9 escaped, thus the total nutrients loss captured during the recording period is only a fraction of what
10 has been lost during the entire rainy season.

$$\text{Total nutrient loss (g)} = \text{Nu}_{\text{sed}} + \text{Nu}_{\text{runoff}} \quad \text{Eq.4}$$

11 Where: Nu_{sed} = N or P lost with sediment (g)

12 $\text{Nu}_{\text{runoff}}$ = N or P lost with runoff (g)

$$\text{Nu}_{\text{sed}} = \sum_{di=1}^n \text{SL}_{di} * \text{Con}_{dis} \quad \text{Eq. 5}$$

13 Where: SL_{di} = Soil loss during the ten days interval i (kg ha^{-1})

14 Con_{dis} = Nutrient concentration in sediment during the ten days interval i (g kg^{-1})

$$\text{Nu}_{\text{runoff}} = \sum_{di=1}^n \text{Q}_{di} * \text{Con}_{dir} \quad \text{Eq. 6}$$

16 Where: Q_{di} = runoff ($\text{m}^3 \text{ha}^{-1}$) during the ten days interval i

17 Con_{dir} = Nutrient concentration in runoff during the ten days interval i (g m^{-3})

1 Table 2: Methods and procedures used for the chemical analysis of sediment and water samples

Sample	Parameter	Method	Reference
Sediment	NO ₃ -N & NH ₄ -N	Magnesium Oxide-Devrda's alloy	Maiti, 2004
	Phosphorus	Olsen	Olsen et al. (1982)
Water	Dissolved NH ₄ -N	Phenate method using Spectrophotometer	Patnaik (2010)
	Dissolved NO ₃ -N	Spectrophotometer	
	and Phosphorus		Patnaik (2010)

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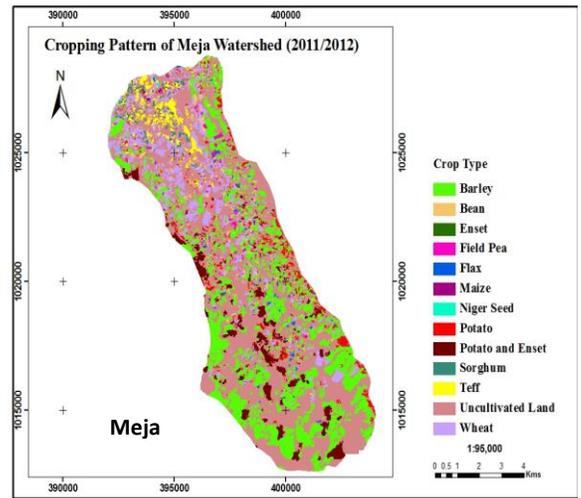
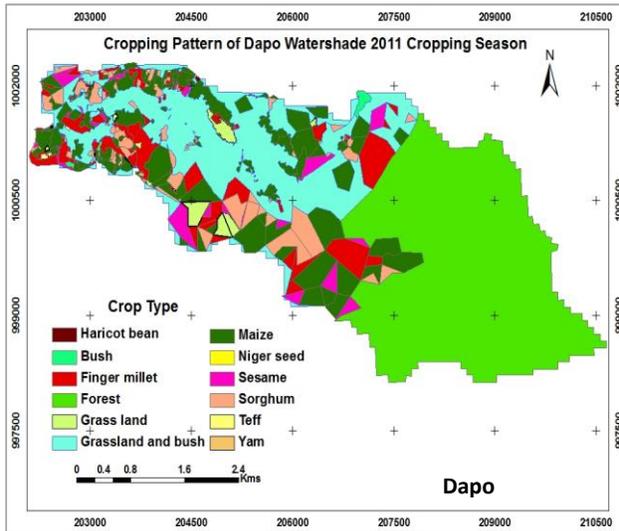
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4 2.6 Estimation of crop yield reduction

5 Assuming that the nutrient losses are even across the watersheds regardless of the land use and
 6 management types (Figure 4) and further assuming that no compensation through fertilization was
 7 made, as it is often the case in the areas, the yield reduction due to soil erosion was estimated using
 8 the response curves developed for the dominant crops and the two nutrients (FAO, 1999). Maize
 9 for Dapo and Mizewa, and potato and barley for Meja were considered as major crops for the
 10 assessment. The response functions were developed (Table 3) based on unpublished secondary data
 11 obtained from the N and P application rates studies conducted on these crops under similar agro-
 12 ecological conditions by the nearest Agricultural Research Centers (Figure 1) including Bako, Adet
 13 and Holeta for Dapo, Mizewa and Meja, respectively.

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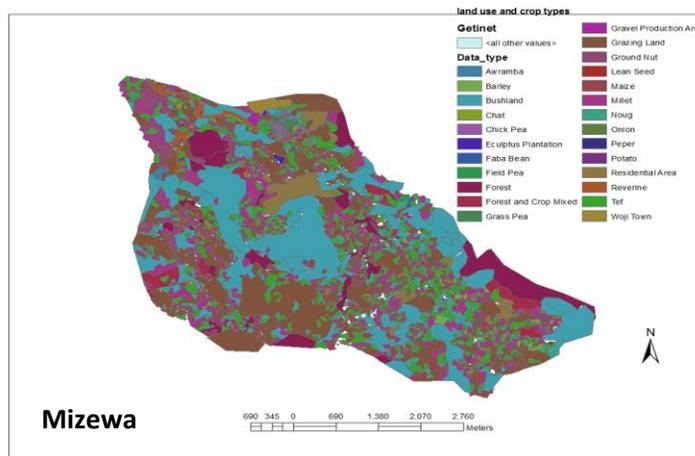
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Figure 4 Crop pattern maps of the study watersheds during the study period (2011)

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1 Table 3: Response equations of selected crops to N and P application rates (kg ha⁻¹) where Y stands for crop
 2 yield (kg ha⁻¹)

Location	Crop type	Response to N		Response to P	
		Equation	R ²	Equation	R ²
Dapo	Maize	$Y = -0.220N^2 + 72.75N + 2483$	0.72	$Y = -1.1(0.436P)^2 + 70.89P + 2483$	0.72
Mizewa	Maize	$Y = -0.290N^2 + 58.60N + 2537$	0.75	$Y = -0.55(0.436P)^2 + 35.84P + 2691$	0.88
Meja	Potato	$Y = -0.001N^2 + 0.31N + 16.15$	0.71	$Y = 0.005P^2 + 0.65P + 16.54$	0.90
	Barley	$Y = -0.412N^2 + 39.94N + 1129$	0.89	$Y = -0.516P^2 + 53.33P + 1209$	0.77

3

4 The functions were used to estimate the yield that could be obtained with and without application of
 5 the nutrients lost as fertilizers and the difference between the two was taken as the net reduction in
 6 yield due to the nutrients loss. The farm gate and local market prices respectively were used for grain
 7 and tuber, and the average price (ETB 100 kg⁻¹) was 350 for maize and potato and 500 for barley,
 8 where the average exchange rate in February 2012 (1 USD = 19.89 ETB) was used for conversion.
 9 The prices of the crops were used to convert the reduction in yield to financial loss incurred by the
 10 farmers.

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1 **3. Results and discussion**

2 **3.1 Runoff and suspended sediment export**

3

4 The total runoff per hectare during the season was highly variable between and within the sites
5 (Table 4), although there was minor difference in terms of the rainfall received during the same
6 period. On average, the highest runoff volume was from Mizewa while the least was from Dapo,
7 which is comparable with that from Meja.

8 Table 4: Average runoff and sediment loss during the season from the catchments

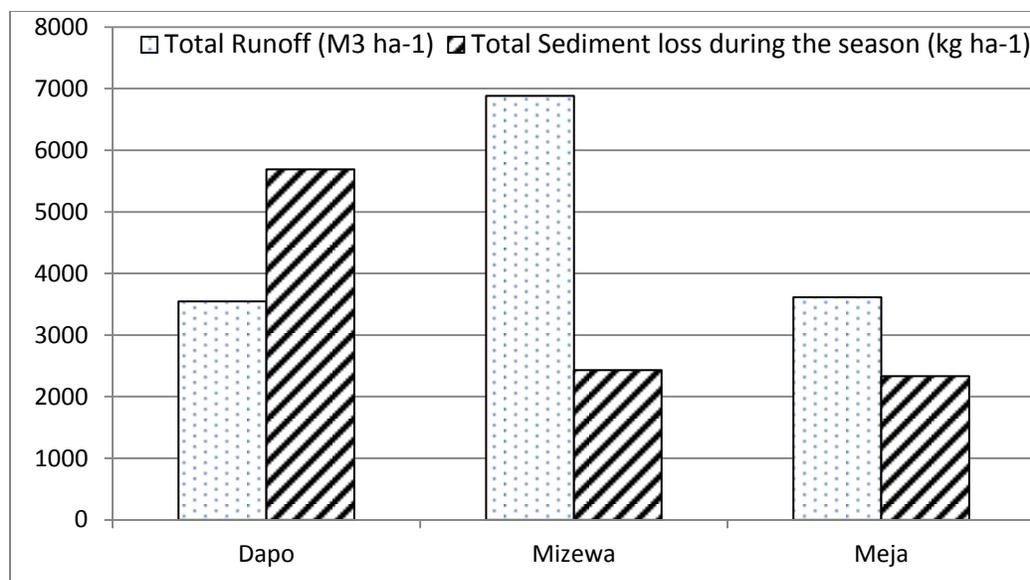
Catchment	Sub catchment	Area (ha)	Runoff (M ³ ha ⁻¹)	Sediment loss during the season (kg ha ⁻¹)
Dapo	Dapo	1620	3196	4072
	Chekorsa	560	3900	7306
	Average		3548	5689
Mizewa	Lower Mizewa	2664	6885	3173
	Upper Mizewa	1870	6882	1599
	Gindenewur	715	6882	2520
	Average		6883	2431
Meja	Melka	9200	2707	2675
	Kollu	250	8079	1847
	Gallessa	160	60	2481
	Average		3615	2334

9

10 The runoff from the watersheds and the sub-watersheds seems to have been influenced by factors
11 such as topographic characteristics, land use and management practices implemented (Gary and
12 Carmen, 2007; Hartanto et al., 2003). For instance, runoff from Kollu sub-catchment at Meja was
13 135 times higher than that from Gallessa. A large proportion of Gallessa is flat and waterlogged,
14 and a major part of it is used for grazing or cultivation of potatoes that are often planted early in the

1 season on contours to cover the land during the peak season, thus increasing water infiltration. In
2 contrast, Kollu is characterized by steep slopes and largely cultivated to cereals that are planted late
3 in the season exposing bare land to erosive force of rainfall and runoff. Therefore, improving land
4 use and management practices, such as growing permanent crops on the steep slopes (Hartanto et
5 al., 2003), contour cultivation (Quinton and Catt, 2004) and early planting to ensure sufficient land
6 cover during the peak rainfall season and implementing soil conservation practices such as soil
7 bunds stabilized with vegetative materials may allow more infiltration of water (Cerdà 1998) that can
8 be used by the crops during the dry season and reduce loss of soil and water.

9 The average sediment lost during the study period ranged from 2334 kg ha⁻¹ at Meja to 5689 kg ha⁻¹
10 at Dapo (Figure 5), and this is lower than most estimates for the Ethiopian highlands where the
11 estimated annual soil erosion rates range from as low as 16 t ha⁻¹ (Gizachew, 1995) to as much as
12 300 t ha⁻¹ (Herweg and Stillhardt; 1999 Hurni, 1993). As explained earlier, in all the sites, rainfall
13 started in May, but runoff measurement and sampling began in early July after the most sensitive
14 time in terms of soil erosion has passed. At all the sites, intensive tillage for land preparation which
15 keeps the soil surface bare and vulnerable to the detaching forces of raindrops and runoff starts in
16 April and May depending on the onset of rainfall (Erkossa et al., 2009). Therefore, the sediment loss
17 reported here is only a portion of the total loss. For instance, a modeling effort for the same year
18 using RUSLE revealed an estimated annual soil loss rate of 10 tons ha⁻¹, 4 tons ha⁻¹ and 5 tons ha⁻¹
19 for Lower Mizewa, Upper Mizewa and Gindenewur sub-catchments, respectively (Getnet, et al.,
20 2013). In addition, not all the sediment that is lost from the upstream fields is delivered to the outlet
21 since part of it is deposited on its way (Pathak et al., 2004). Consequently, the data may not show the
22 full picture and should be interpreted only in relative terms.



1

2 Figure 5: Average runoff and sediment loss during the measurement period at the study sites

3 In contrast to its lowest runoff, Dapo exhibited the highest sediment loss per unit area during the
 4 study period. This may be related to the high rate of active deforestation that exposes topsoil on
 5 sloping land to the detaching forces of raindrops and the high transport capacity of runoff created
 6 by the steep slope gradient. This is particularly true for Chekorsa sub-catchment in which the peak
 7 sediment concentration coincided with the peak runoff (Wudneh et al., 2014). Mizewa revealed
 8 lower soil loss than Dapo, despite its highest cumulative runoff. According to Pathak et al (2004),
 9 several factors such as storm size, duration and intensity, changes in crop canopy during the season,
 10 tillage timing, and changes in grass waterway conditions explain the major parts of the variation in
 11 sediment concentration among sub-watersheds. In addition, the lower soil loss from Mizewa can
 12 partly be attributed to a longer history of its exposure to accelerated soil erosion which might have
 13 led to the armoring effect due to the selective soil erosion by water (Charles and Black, 2001), in
 14 which case detachment instead of transportation would be the limiting factor.

15

1 3.2 N and P export

2 The buildup and depletion, respectively, of plant nutrients from agricultural soil has been a problem
3 in developed and developing countries. Soil erosion and leaching are among the major factors
4 responsible for nutrient depletion from agricultural lands in humid tropical areas in Africa (Hena
5 and Baanante, 1999). The rate of N and P loss due to erosion is often related to the rate of runoff
6 and soil erosion (WU et al., 2012). This study revealed that N and P loss was strongly related to the
7 soil loss in which, the highest N (14 kg ha^{-1}) and P (6.8 kg ha^{-1}) was from Dapo where the sediment
8 loss was the highest (Table 5). However, while the sediment loss at Dapo was 2.3 times higher than
9 that from Mizewa (the lowest), the N and P loss was even higher (6.7 and 3.6 times, respectively)
10 compared to that from Mizewa. In part, this may be related to the fact that Dapo is experiencing
11 active expansion of agriculture to forested areas that are rich in these nutrients. Therefore, limiting
12 land use change from forest to agriculture by intensifying productivity in areas already under
13 cultivation may mitigate the loss of sediment and nutrients.

14 3.3 Effect of N and P loss on crop yield

15 The impact of soil erosion on the productive potential of agricultural lands is well known (Pathak et
16 al., 2004), but the magnitude depends on local circumstances. In the study areas, the loss of the
17 essential plant nutrients N and P in association with the suspended sediments and runoff during the
18 measurement period and the attendant yield and income losses suffered by farmers were remarkable.
19 Predictably, the maximum yield reduction and resultant financial loss due to the two plant nutrients
20 considered was from Dapo (Table 5) which corresponds to the highest loss of these nutrients while
21 the least was from Meja. Compared to Meja, the estimated yield reduction due to N and P loss from
22 Dapo was 11 and 7 times higher while the corresponding financial loss was 7 and 5 times higher,

1 respectively. The relatively lower financial loss from Dapo is related to the lower market price of
2 maize as compared to barley and potato, which are dominant at Meja.

3 Despite the apparent under estimation of the impact since the major part of sediment and nutrient
4 loss was not captured, compared to the average income of the subsistent farmers (60 USD ha⁻¹)
5 (IFPRI 2010), the estimated yield reduction and loss of income due to the loss of the two essential
6 nutrients can be considered high, regardless of the location considered. The estimate assumes no
7 substitution of the nutrients lost either through external inputs or internal regeneration. However,
8 the use of technologies for compensating the nutrients such as applying more nutrients and using
9 management practices increases production costs, which can still reduce net farm income. However,
10 using soil and water conservation practices that control erosion, these costs can be minimized, which
11 improves the sustainability of the agriculture sector (Montgomery, 2007; Lal, 2006). Soil erosion also
12 brings about a loss of soil quality (Blaschke et al., 2000) including its physical deterioration, which
13 has repercussions both on its nutrient and water holding capacity and thereby on productivity.

14
15 In addition to the reduction in crop yield that directly affects the land user, both N and P contribute
16 to eutrophication of freshwater bodies that are essential for various ecosystem services (Lewis et al.,
17 2011; Conley et al., 2009), affecting the society at large. Consequently, maintaining or improving
18 water quality in lakes, ponds etc. that may experience-man-made eutrophication requires reducing
19 inputs of the nutrients to the water bodies, especially from agricultural lands, where these nutrients
20 are needed by crops in large quantities. Therefore, although controlling runoff and soil erosion
21 should be done on farm lands, farmers need some incentives in addition to reducing yield loss.
22 Other stakeholders that benefit from the avoided risk of damage to the quality of water need to
23 support them through various frameworks such as payment for environmental services, which
24 requires establishment of upstream and downstream institutional linkages.

1 Table 5: N and P export with suspended sediment and dissolved in runoff during the season from the sub
 2 catchments and the corresponding yield and financial loss (at an average exchange rate in February
 3 2012 of 1 USD = 19.89 ETB)

Catchment	Sub catchment	Nutrient loss (kg ha ⁻¹)		Estimated yield loss (kg ha ⁻¹) due to		Crop type	Financial loss (USD ha ⁻¹ year ⁻¹)*	
		N	P	N	P		N	P
Dapo	Dapo	13.6	9.3	949	1421	Maize	171	263
	Chekorsa	14.3	4.2	1013	664		188	123
	Average	14.0	6.8	981	1043		179	193
Mizewa	Lower Mizewa	2.3	1.8	134	320		58	138
	Upper Mizewa	1.6	1.8	93	328		40	142
	Gindenewur	2.3	2.1	134	382		58	165
	Average	2.1	1.9	120	343		52	148
Meja	Melka	9.0	6.0	32	47	Barley	13	19
	Kollu	17	5.0	25	43		10	17
	Galessa	3.0	3.0	210	340	Potato	50	81
	Average	9.7	4.7	89.0	143		24	39

4

5

6 4. Conclusion and recommendations

7 Despite the limited data availability, the study demonstrated that soil erosion causes an immediate
 8 harm to the income of farm households. The magnitude of the effect is higher in areas with more
 9 fertile soil than those that have experienced sever degradation. This suggests that priority in soil and
 10 water conservation planning relative priority should be given to the 'high potential' areas where
 11 productivity should be maintained. However, farmers in such areas may be reluctant to take actions
 12 since the effect may not be apparent in the short term. Empirical evidences showing the cost of no
 13 action in financial terms may be use to alert the land users and policy makers alike for action. In
 14 quantifying the paybacks of conservation measures, the inputs required and the negative impacts of

1 the measures such as land taken out of production due to the physical structures need to be
2 considered. Although this and many other studies reveal economic justification for land users to
3 implement improved land and water management, a mechanism through which the other
4 stakeholders that benefit from the improvement should be in place. Such mechanism enhances the
5 coordination between upstream and downstream land and water users towards avoiding the negative
6 impacts of no action.

7

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