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Sediment and nutrient lost by runoff from two watersheds, Digga district in Blue Nile basin, Ethiopia

Alemayehu Wudneh[1]*, Teklu Erkossa[2] and Prhaba Devi[3]

[1]Natural Resource Management Course Team, Madawalabu University, P.O. Box 247, Robe-Bale, Ethiopia,
[2]International Water Management Institute, Regional office for East Africa and Nile Basin, P. O. Box 5689, Addis Ababa, Ethiopia.
[3]Ambo University, Biology Course Team, Ambo, Ethiopia.

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The study was conducted in two sub watersheds in the Upper Blue Nile Basin in Ethiopia to determine the quantity, quality of sediment lost and its onsite costs in terms of crop yield. Two monitoring stations at the outlets were selected. Discharges were estimated and depth integrated daily runoff samples were collected during the rainy season in 2011. The sediment concentration and nitrogen (N) and phosphorus (P) content was analyzed and related to crop yield using a nutrient response equation for maize (*Zea mays*). The result shows statistically significant differences in sediment concentration of the two watersheds. Suspended sediment concentration was strongly correlated with the discharge from Chekorsa River (R^2 = 0.7) but it was very weak for Dapo. There was higher concentration of nutrients in the sediment than the surface soil in both watersheds. Particularly, sediment enrichment ratio of available P was 2.7 and 9 for Dapo and Chekorsa Rivers, respectively. The estimated yield reduction of maize due to N and P loss was about 950 and 1420, and 1015 and 665 kgha^{-1} from Dapo and Chekorsa catchments, respectively. Such results are equivalent to an onsite cost to farmers of about 190 and 285 USD ha^{-1} for Dapo, and 203 and 133 USDha^{-1} for Chekorsa catchments in that order. This monetary value can alert farmers and decision makers to take soil and water conservation measures.

Key words: Soil loss, enrichment ratio, nutrient depletion, Blue Nile Basin, sediment.

INTRODUCTION

Soil erosion is a worldwide problem and has become a major global concern since its severe impacts on agriculture and environment (Le Bas and Kozak, 2007; Tenaw and Bekele, 2009). Pimentel et al. (1995) indicated that about 80% of the world's agricultural land suffers moderate to severe erosion. Soil erosion is among the major causes of nutrient depletion and, shortage of basic plant nutrients (Wortmann, 2006; Pimentel et al., 1995) with a devastating impact on overall soil organic matter levels (Van-Camp et al., 2004). According to FAO (1999), Ethiopia is among the countries with high rate of erosion and nutrient depletion rate. Studies showed soil erosion in Ethiopia is more severe in the highlands. Henao and Baanante (1999) reported NPK loss of more than 60 kgha^{-1} based on their study between 1993 and 1995 in Ethiopia and losing fertile topsoil that exacerbated impacts of dry spells and drought in the Upper Blue Nile Basin (Getnet et al., 2009).

Water is the main cause of soil erosion in the highlands of Ethiopia (Dubale, 2001) removing about 1493 Mtyr^{-1} (Hurni, 1993) whereas in the Abay Basin (the Ethiopian part of the Blue Nile Basin) loss of soil was about 303 Mtyr^{-1}(Hagos et al., 2009). Nearly 50 and 34% of the total soil loss was estimated to come from cultivated fields in the central highlands of Ethiopia and Abay Basin, respectively (Hagos et al., 2009; Hurni, 1993).

According to Gruhn et al. (2000), and Desta et al., (2000) soil fertility loss by erosion are the main ways for nutrient outflow from a watershed. Eroded soil was often significantly enriched by plant nutrients than the soil left behind with enrichment ratios ranging from 1.2 to 2.3 (Fenli et al., 2005). It is the characteristics of watershed that influence river nutrient enrichment ratio. Eroded soil by runoff constitutes a large proportion (>60%) of the P transported in surface runoff from surface soil, with enrichment ration greater than 1 (Scalenghe et al., 2002). The enrichment ratio greater than 1 is related to the high P content in the top 5 cm of the surface soil and the fact that runoff preferentially erodes finer particles including clays with which P is associated (Sharpley et al., 2000).

The losses of the nutrients can limit crop growth and productivity. Soils in all major maize growing regions of Ethiopia are depleted of NPK nutrients, thus demanding high soil amendments (Kebede et al., 1993). Decline in soil fertility due to depletion of NPK nutrients in the country is therefore eradicating production including maize production. Nitrogen is the most limiting nutrient for maize productivity (Kogbe and Adediran, 2003; Alley et al., 2009). As a result of water erosion, organic matter content is highly reduced since its largest part is found in the fertile topsoil and cause decline of production because of low physical structure (Helmecke, 2009).

All physical and economic evidence shows that agricultural land productivity decline is a severe problem in Ethiopia (Berry et al., 2003) and in Africa in general, for example, about 86% of the countries in Africa lose more than 30 $kg^{-1}ha^{-1}yr$ of NPK (Henao and Baanante, 1999). This severe erosion is reducing agricultural land productivity (Berry et al., 2003) particularly, in the Blue Nile basin (Tenaw and Bekele, 2009; Dubale et al., 2009) in which soil erosion is among the major threat (Desta et al., 2000; Bekele and Holden, 1998; Ashagrie, 2009).

Most soil erosion research in Ethiopia focused on its physical, chemical and biological effects (Gorlach et al., 2004) and limited to farm plots (Berry et al., 2003). In Ethiopia, farmers and other decision makers at grass-roots level cannot easily understand estimated soil and nutrient losses by runoff in terms of scientific units. However, converting the lost soil nutrients by runoff from watersheds into monetary value can easily make them aware of the severity of soil erosion. In other words, the monetary value of lost nutrients can induce and initiate farmers and policy makers to implement land and water management practices. The cost of soil erosion to farmers can be related to loss of productivity due to the lost of nutrients or the cost of fertilizer to compensate for the lost nutrients (Gruhn et al., 2000).

Yield reduction cannot be because of soil nutrient depletion alone but also affected by other physical and biological factors and conditions such as land management, nutrient status, soil microbs, soil depth, etc. To estimate financial cost of lost soil nutrients, it is necessary to consider those factors and conditions prevailing in the specific area (Pimentel et al., 1995). As a result, productivity lost method was preferred to replacement cost for this study.

Depending on the characteristics of watershed, suspended sediment concentration related to discharge can produce different shapes of hysteresis loops (Baca, 2002; Sander et al., 2011). These relationships are normally not homogenous in time, neither within nor between events (Baca, 2002). The most common shapes of the hysteresis effects are clockwise and counter clockwise loop (Sander et al., 2011; Ahanger et al., 2013). The characteristics of watershed that produce hysteresis effects are source of sediment which could be from distant hill slope, or channel or nearby sources, higher rainfall intensities at the beginning of storms, sediment availability, increasing of base flow supply to the river, the duration and interval of storm events (Eder et al., 2010; Baca, 2002; Slattery et al., 2002; Lefrançois et al., 2007)

In this context, the objectives of the research were to estimate the sediment concentration at the outlets of Dapo and Chekorsa watersheds and patter of sediment hysteresis loop, to analyze soil nutrients lost by runoff and consequently river nutrient enrichment ratio, and to estimate the financial cost due to soil erosion at the study

*Corresponding author. E-mail: alexowudneh86@gmail.com.

Abbreviations: AVP, Available phosphorus; **BARC,** Bako Agricultural Research Center; **C/N,** carbon/nitrogen; **CR,** Chekorsa River; **CRC,** Chekorsa River Catchment; **d,** ten consecutive days/decade; DDS, Dapo downstream; **DFA,** discriminate function analysis; **DR,** Dapo River; **DRC,** Dapo River catchment; **DUS,** Dapo upper stream; **ER,** enrichment ratio; **FAO,** Food and Agricultural Organization; **GDP,** gross domestic product; **gm/L,** gram per liter; **INM,** integrated soil nutrient management; **IWMI,** International Water Management Institute; **kg/ha/yr,** kilogram per hectare per year; **L,** liter; **LD,** Lelisa Dimtu; **m.a.s.l,** meter above sea level; **Mg,** mega gram; **Mha,** million hectare; **Mm^3/d,** mega metric cube; **$Mt^{-1}yr$,** million tons per year; **NBDC,** Nile Basin Development Challenge; **NH_4-N,** ammonium nitrate nitrogen; **NO_3-N,** nitrate nitrogen; **NPK,** nitrogen, phosphorus and potassium; **OC,** organic carbon; **$PO4^{-3}$,** phosphate ion; ppm, parts per million; **Q,** discharge; **SPSS,** Statistical Package for Social Science; **SSC,** suspended sediment concentration; **SSL,** suspended sediment load; **SWC,** soil and water conservation; **t/ha/d,** tonnes per hectare per decade; **TKN,** total Kjeldal nitrogen; **tons/ha/yr,** tonnes per hectare per year; **USLE/RUSLE,** revised/universal soil loss equation; **WAO,** Woreda Agricultural Office.

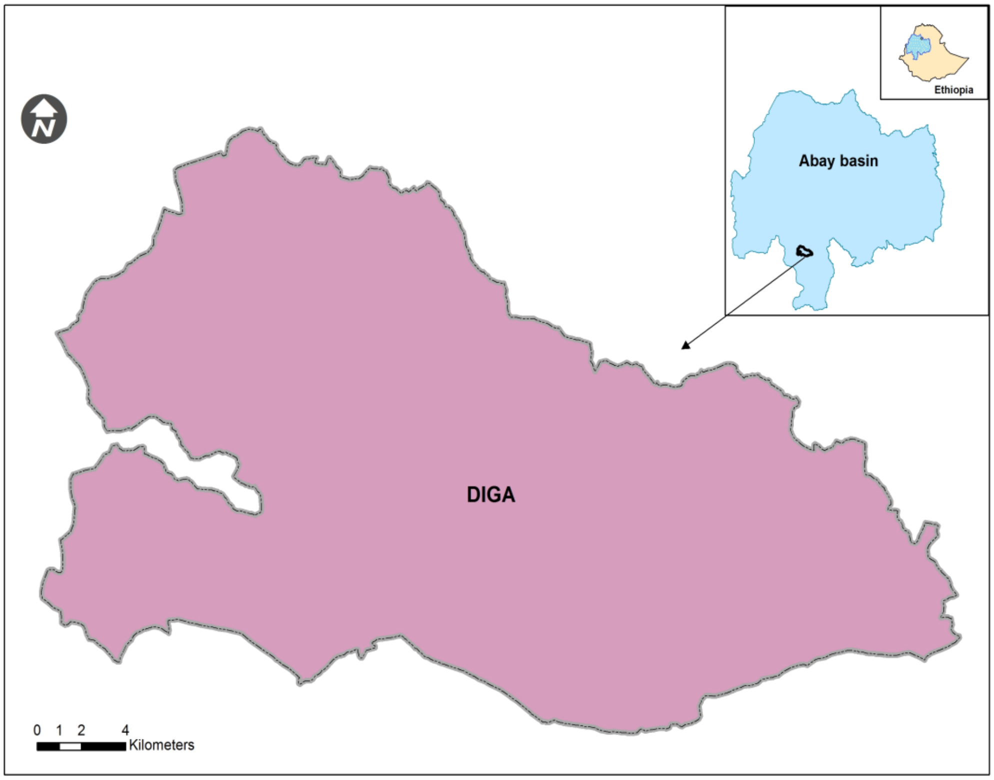

Figure 1. Study location map.

region.

MATERIALS AND METHODS

Description of the study area

The study was conducted in two sub watershed located in Diga district in East Wollega Zone of Oromia Regional State, Ethiopia (Figure 1) from March 2011 to October 2012. The area is characterized by an average annual mono-modal rainfall of 1707 mm which begins late April, and ends in early September, with annual minimum and maximum temperature of 14 and 30°C, respectively (Joshua et al., 2010). Information from Diga District Water Resource Office in 2010 shows that the major livelihood is mixed crop-livestock rain fed agriculture. In middle altitude of the study area, the dominant soil color is red whereas black in the low land (Birhanu Z, 2012) and according to soil map developed by Seleshi et al. (2009) which are classified as Acrisols and Alisols.

Two sub watersheds (Dapo and Chekorsa) were selected by the Nile Basin Development Challenge Program (NBDC) for rainwater management research in the Blue Nile Basin. Zemadim et al. (2010) indicated that the two catchments have an area of 18 and 5.60 km^2, respectively with their altitude ranging between 1,347 - 2,011 m (Dapo) and 1,266 - 1,430 m (Chekorsa).

Both Dapo River (DR) and Chekorsa River (CR) are tributaries of Didesa River, the largest tributary to the Blue Nile River, in terms of water volume (MWRE, 2010). Both Rivers are supplied by numerous first and second order streams. Similar to Chekorsa River Catchment (CRC), the physiographic, land use and land cover condition in the downstream of Dapo River Catchment (DRC), around the water level gauging site, consists of mango trees and sparse natural vegetation, maize and grazing areas(Figure 2) (Zemadim et al., 2012). Coupled with the intensive rainfall, Dapo River has cultivation in steep slopes that aggravates soil erosion and plant nutrient depletion (Zemadim et al., 2010). Depleted soil fertility caused by soil erosion and crop uptake is a major limiting factor for crop production and productivity in both catchments (Negassa et al., 2005). In response to the productivity decline, farmers open a new agricultural land which increases deforestation. Maize, sesame and finger millet are the dominant crops in DRC while about one third of the watershed area is covered by forest, mainly located at the most upper land (Figure 3), but no significant forest is left in Chekorsa catchment.

Methods

Selection of runoff sampling site

Hydrologists of the International Water Management Institute (IWMI) selected the bridge on the main highway that goes from Diga to Ghimbi for DRC and the bridge from Arjo Gudatu to Lalisa Dimtu for CRC, where flow monitoring stations where established. The bridges are 4.5 and 3.5 m wide through which Dapo and Chekorsa river flows respectively, and all flows were contained inside the culvert of the bridges.

Discharge measurement

Discharge measurement and sampling was started from the beginning of major runoff in July, 2011 and ended in early September, 2011 when the rainfall ended. Based on Gierke (2002), the flow rate of the river at the outlet was determined using current

Figure 2. Dapo watershed outlet (a) and land use and land cover condition around the outlet (b), at the Diga district, Ethiopia. Photo credit (Brihanu Zemedin, 2011).

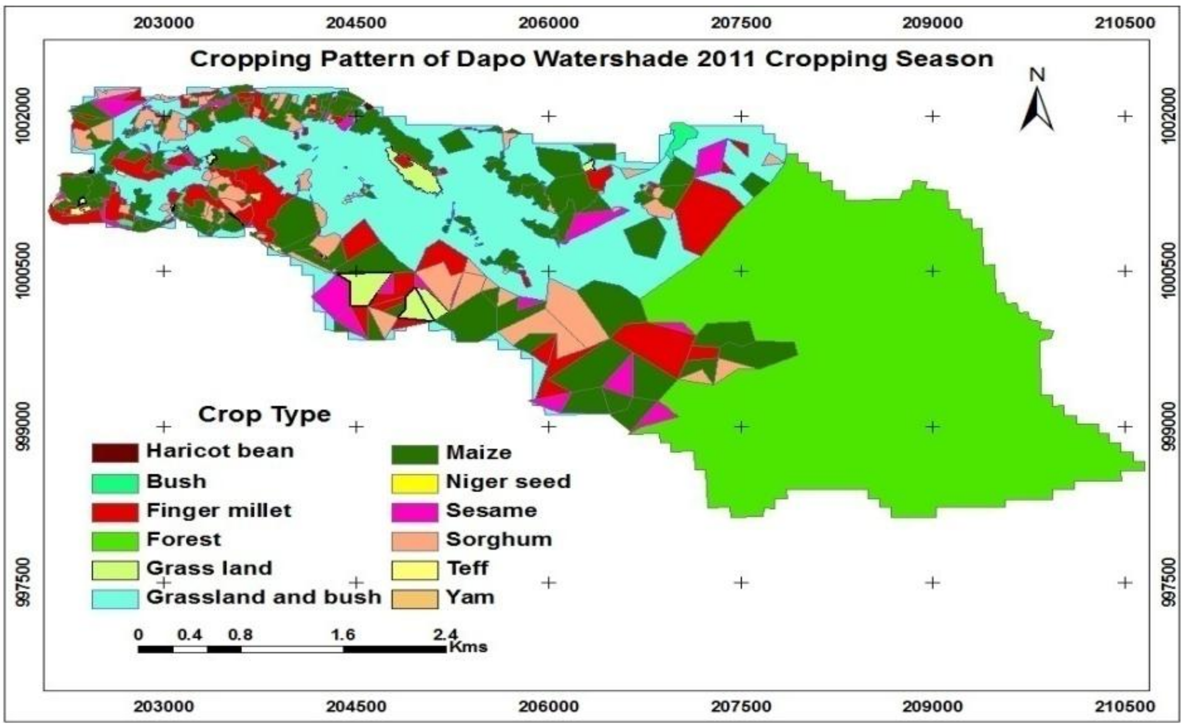

Figure 3. Land use and land cover of Dapo watershed. Source: IWMI (2012).

meter (Model 0012B Surface Display Unit and Model 002 Flow Meter (Figure 4A and B)); the depth of the rivers at the cross-section was measured using 1.5 m wading rod (Figure 4E), and the flow rates and depths (h) were measured across the rivers simultaneously at 9 points spaced at 0.5 m intervals for DR and at 5 points at 0.75 m interval for CR. The cross sectional area of the flow was calculated using the depth records and the average flow rates at each point (Equation 1). Discharge (Q) passing the outlet of the watersheds was calculated using Equation 2.

$$qi = vi*ai \; (a) \quad Q = \sum_{i=0}^{n} qi \; (b) \qquad (1)$$

Where:

qi = discharge at each cross sectional area (m^3sec^{-1}); vi = flow velocity at each cross sectional area ($msec^{-1}$); ai = cross sectional area at each point (m^2); Q = total discharge (m^3sec^{-1}).

$$Q = c\,(h + a)^{b} \qquad (2)$$

Where: Q = discharge (m^3sec^{-1}); h = measured water level (m); a = water level (m) corresponding to Q = 0; c = coefficients derived for the relationship corresponding to the station characteristics; b = coefficient derived for the power in relation to the station characteristics.

Discharge rating curves were developed by fitting the measured gauge to discharge into power curve (Equation 4) for the two rivers. And having water levels measured throughout the study period by the staff gauge (Figure 4E), the discharge for each was calculated from the equations of the curves.

Runoff sampling and storage

Depth integrated runoff was collected manually from catchments using one liter plastic bottle three times a day. The daily samples were mixed and two litters were sub sampled and bulked in a 20 L plastic jar for 10 consecutive days. The bulked samples were kept

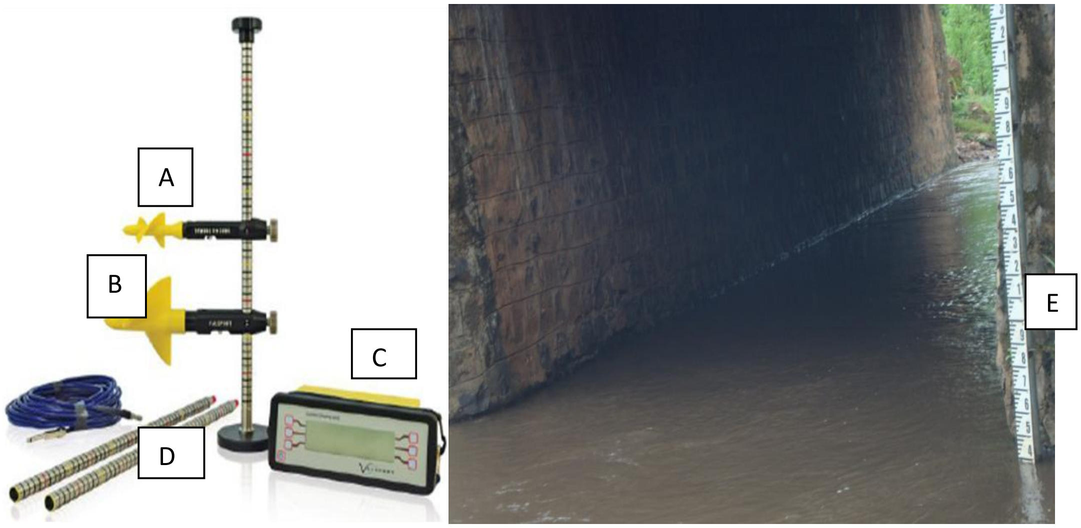

Figure 4. Current Meter model used for measuring river flow and staff gauge (E) at DR monitoring station. Photo Credit: Brihanu Zemedin (2011).

Table 1. Methods and procedure used for the chemical analysis sediment and water.

Sample	Parameter	Method budget	Reference
Soil	OM	Wet oxidation/Walkley-Black	Jackson (1967)
	TKN	Modified Kjeldahl digestion	Dalal et al (1984)
	NO_3-N NH_4-N	Magnesium oxide-Devrda's alloy	Maiti (2004)
		Magnesium oxide-Devrda's alloy	Maiti (2004)
	P_2O_5	Alkaline Extraction of Olsen Method	Olsen and Sommers 1982
	Texture	Hydrometer	Bouyoucos (1962)
Water	Dissolved ammonia	Phenate method using Spectrophotometer; Modele Eleco SL-160 double beam UV	Patnaik (2010)
	Dissolved nitrate and phosphorus	Spectrophotometer; Modele Eleco SL-160 Double beam UV	Patnaik (2010)

in the refrigerator at 4°C in a soil laboratory to minimize further chemical and physical changes.

Estimation of sediment load and chemical analysis

Sediment in water sample collected for each consecutive 10 days was allowed to settle down before the clear water at the top was decanted into laboratory beakers. The turbid water remaining at the bottom containing most of the sediment was filtered using filter papers and air dried. Soil loss was calculated based on the sediment concentration and discharge per 10 consecutive days at the gauged sites. The water collected after filtration and that which was stored after decantation were mixed proportionally for chemical analysis (Table 1).

Estimates of nitrogen and phosphorus loss

The quantity of N and P delivered to the outlet of the watersheds with water and suspended sediment was estimated using Equations 3 and 4, respectively. The total N and P lost was estimated by summation of the amount lost with water in dissolved form and by the quantity lost with suspended sediments (Equation 5). The maize yield loss due to the two essential plant nutrients was estimated according to FAO (1999) method.

$$\mathrm{Nwi} = \mathrm{Ncwi} * \mathrm{qi}(a) \text{ and } \mathrm{TNw} = \sum_{i=1}^{9} \mathrm{NLi} \quad (b) \tag{3}$$

$$\mathrm{Nsi} = \mathrm{Ncsi} * \mathrm{SSL} \text{ and } \mathrm{TNs} = \sum_{i=1}^{9} \mathrm{Nsi} \quad (b) \tag{4}$$

$$(\mathrm{TNw} + \mathrm{TNs})/\mathrm{AGTN} = (\mathrm{TNw} + \mathrm{TNs})/\mathrm{A} \tag{5}$$

Where, Nw: nutrient loss with water per ten consecutive days (gm/d) (nitrogen or phosphorus); Ns: nutrient loss with suspended sediment per ten consecutive days (gm/d) (nitrogen or phosphorus); Ncw: nutrient concentration in water (gm/L) ((nitrogen or phosphorus); Ncs: nutrient concentration in suspended sediment (gm/kg) (nitrogen or phosphorus); SSL: suspended sediment loss (Kg); q: discharge of the rivers per ten consecutive days (L/d); A: area of the catchments (ha); i: ten consecutive days; TN: total nutrient loss (Kg) (nitrogen or phosphorus); grand total nutrient loss (Kg/ha) (nitrogen or phosphorus).

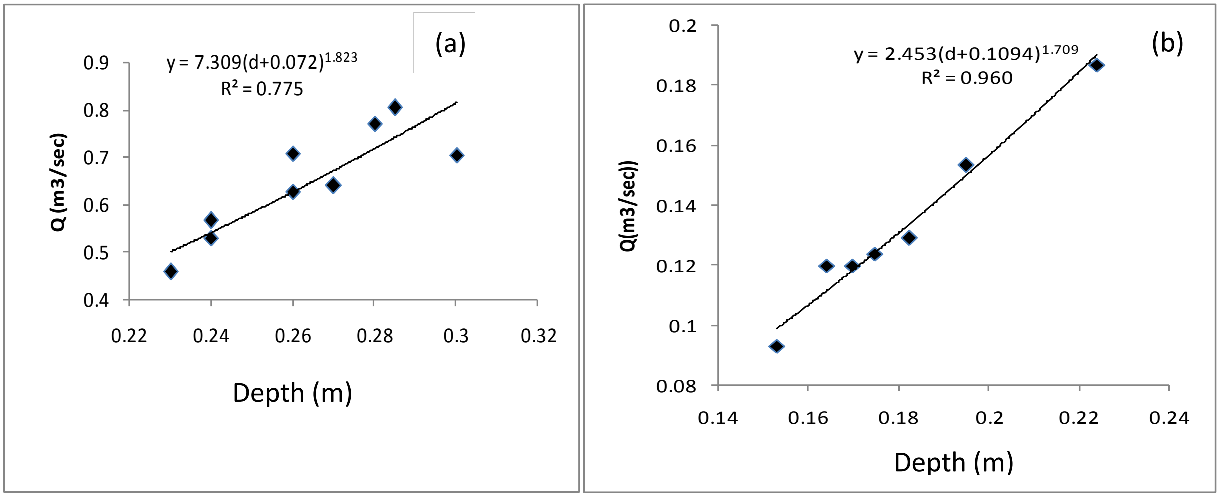

Figure 5. Discharge rating curve for DR (a) and CR (b).

Table 2 Discharge, total suspended sediment and sediment concentration from Dapo River and Chekorsa River.

Parameter	Dapo River				Chekorsa River				t value	p-value
	Mean	SD	CV	R^2	Mean	SD	CV	R^2		
Discharge (Mm^3/d)	0.64	0.17	26.7	1	0.24	0.043	18.09	1	6.83	0
TSS (tons/d)*	747.86	379	50.7	0.7	434	217	49.82	0.85	2.16	0.05
SSC (gm/L)	1.12	0.36	32	0.3	1.74	0.597	34.29	0.73	2.66	0.02
Soil loss (t/ha/d)	0.42	0.21	50.7	0.7	0.75	0.335	44.82	0.79	2.52	0.023

*TSS: Total suspended sediment loss in tons per 10 consecutive days.

Crop yield reduction due to the loss of nitrogen and phosphorus

Since maize is a major crop in both watersheds, reported research data of maize grain yield response to N and P under similar agro-ecological conditions were obtained from Bako Agricultural Research Center. The yield response curve for N and P was developed by fitting the data into quadratic relation (Rosas, 2011; Naher et al., 2011). The yield reduction due to loss of available N and P were estimated using their respective response curves (Equation 6).

$$Y = ax^2 + bx + C \quad (6)$$

Y: Maize yield per hectare; X: nutrient (N and P) per hectare; a, b and c: constant of quadratic equation.

The local market price of maize which was 3.5 $BirrHa^{-1}$ (1birr = 17.50USD)) was used to convert the reduction in grain yield to financial loss incurred by the farmers.

Data analysis

The data was analyzed using SPSS and presented using Sigma-plot software (version 10). Linear regression analysis was carried out for suspended sediment load (SSL) and suspended sediment concentration (SSC) with hydrological parameters. T-test at 95% confidence limit was used to analyze the differences in sediment load between the two monitoring stations. Pearson correlation analysis between soil texture percentage and nutrients were also determined.

RESULTS AND DISCUSSIONS

Discharge

Water levels or depth across the width of the rivers and corresponding flows of water resulted in power curves (Figure 5). According to Braca (2008), continuous measurement of flow past a river section is usually time consuming, impractical during flood event and prohibitively expensive. The average discharge estimated using the stage-discharge relationship curve was 0.64 DR and 0.24 Mm^3/d for DR and CR, respectively (Table 2).

Suspended sediment and its interaction with discharge

Eroded soil by runoff from watersheds is mostly

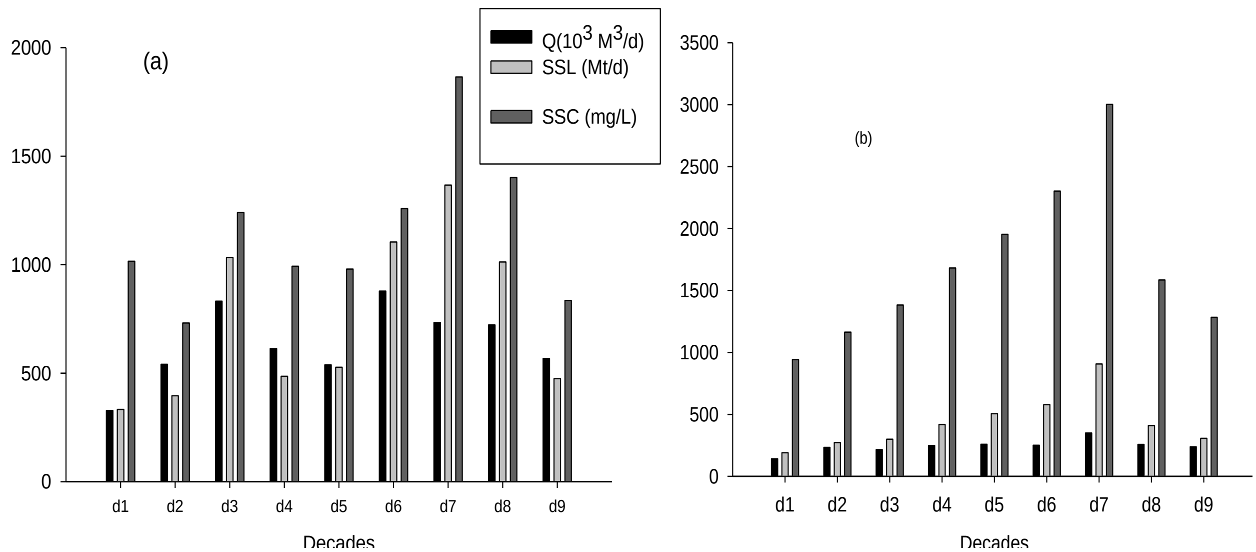

Figure 6. Average discharge and SSC, SSL of Dapo (a) and Chekorsa Rivers (b).

transported by river flow in suspension (Sileshi et al., 2008). The sediment concentration increased with increasing discharge throughout the measurement period for CR (Figure 6b). For DR, the maximum concentration occurred during day 7 after the maximum discharge occurred (Figure 6a).The regression analysis showed SC is strongly related to discharge at CR (R2=0.73) but it was weak at DR weak (R2=0.29) (Table 2). SSC of DR did not remain high with all the discharges throughout the study period. This may be because of the quantity of sediment on a river bed, limited and less sediment availability from the watershed (Ongley, 1996).

Consequently, although the total discharge from DR was about three times greater than that from CR, the amount of sediment lost from the two catchments was similar.

Some possible causes of these variations are soil erodibility, proximity to the waterways, and the difference in riparian zones vegetation (Figure 8), catchments dimensions, land use and cover (GLCUS, 2008), sediment availability (Baca, 2002) and population density, turbulent fluctuations of stream velocity. As shown in Figure 6a, sediment becomes readily available for transportation following the peak discharge that occurred during day 6.

Temporal variability of suspended sediment with discharge

There is significant difference in discharge and sediment transport between ten consecutive days. The discharge to SC (Q-SC) hysteretic loops identified for the two catchments were different (Figure 7a and b) such as it was characterized by anti-clockwise for DR but clockwise for CR. However, since short-term storm events are important determinants of sediment concentration (Eder et al., 2010), and single events hysteresis analysis must be conducted to confirm this interpretation.

The counter clockwise hysteresis in SC for Dapo watershed may be related to the reduced rainfall and the attendant decrease in discharge up to the fifth ten consecutive days, the delay in sowing time of the major crops in the upstream part as compared to those in the downstream part of the watershed. The eroded sediment from cultivated field had been trapped to its maximum at the riparian zone and then detached and transported after the peak discharge event when the supply of sediment was limited (Figure 8) corroborating the findings of Baca (2012) who conducted a similar study in Slovakia.

The clockwise hysteresis is attributed to the rapid displacement of sediment from source close to the stream. The size of CRC is less than a third of Dapo watershed. Similar result where found by Vanmaercke et al. (2006) in Geba River Catchment of Northern Ethiopia. Clockwise loops most commonly occur when the sediment peak occurs before the water discharge peak and when there is a source of easily erodible sediment which can be rapidly depleted (Hudson, 2002; Picouet et al., 2001; Baca, 2010).

Plant nutrient loss and enrichment ratio

In Chekorsa River, N loss increased towards the end of the rainy season up to three times as compared to at the beginning of the study, whereas P loss increased up to 2 times (Figure 9) although increase in discharge was not significant (Figure 9). On the other hand, it is vice versa

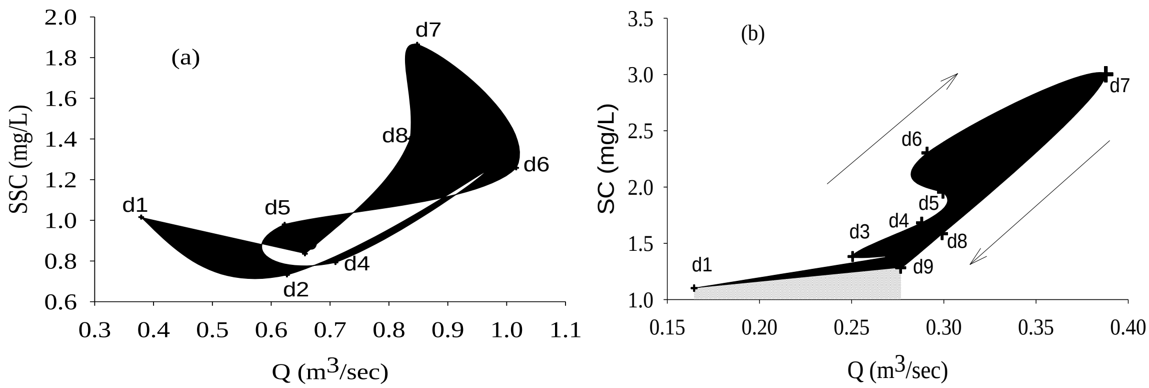

Figure 7. Changes of SSC with decade average discharge of Dapo (a) and Chekorsa Rivers (b).

Figure 8. Accumulated sediment at the edge teff field (a) and vegetation along DR (b).

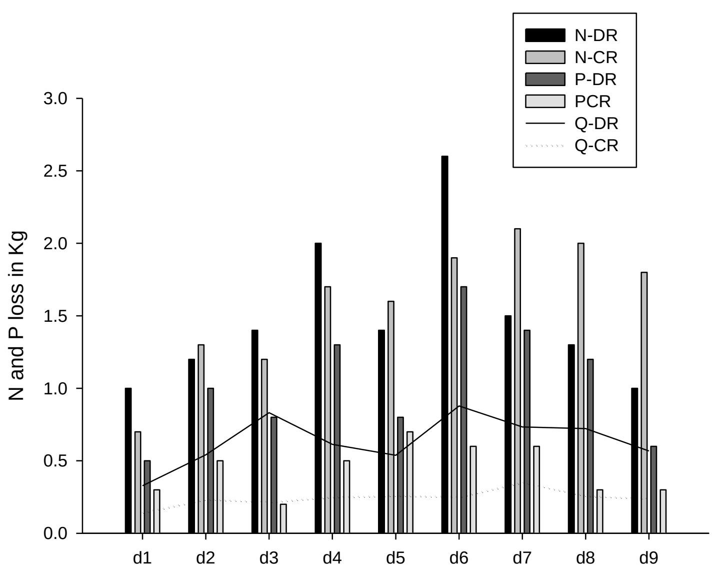

Figure 9. Amount of N and P loss (kg) and discharge ((Q) in Mm^3/d) in each decade from DR and CR during the study period.

Table 3. Mean nutrient content of the surface soil of the catchments, and sediment (kg/ton) and enrichment ratio.

Sub areas	Surface soil			Enrichment ratio (: s)		
	Total N	OC	P	Total N	OC	P
Dapo downstream	4.19	57.06	0.013	0.89	1.18	2.69
Dapo upper stream	2.74	26.49	0.022	1.36	2.54	1.62
Chekorsa catchment	2.58	20.47	0.002	0.95	1.5	8.99
DR (Suspended sediment)	3.73	67.2	0.04			
CR (Suspended sediment)	2.44	30.78	0.02			

Table 4. R^2 regration analysis of nutrient with particle size distribution percentage in the sediment for CR and DR.

TKN	OC			P	Sand (%)		Silt (%)		Clay (%)	
	CR	DR	CR	DR	CR	DR	CR	DR	CR	DR
TKN	0.485	0.43	0.621	0.278	0.074	0.39	0.997	0.14	0.672	0.936
OC			0.981	0.989	0.251	0.1	0.428	0.34	0.964	0.539
P					0.142	0.11	0.565	0.35	0.997	0.523
Sand (%)							0.107	0.91	0.107	0.17
Silt (%)									0.617	0.016
Clay (%)										

TKN, Total Kjeldal nitrogen; OC, organic carbon; CR, Chekorsa River; DR, Dapo River; P, phosphate.

for Dapo River, which is quite similar result found by Liu et al. (2012). The loss of P and particularly N from CR is as higher as that of DR (Figure 9) though the average discharge of CR is as about three times less than DR (Figure 9). It was probably because of an effect remarked by Arheimer and Lide (2000), that is, contribution from rural point sources such as the traditional manuring, the availability of nutrients in the lower parts of a catchment (Chekorsa River catchment is more arable land and dense population), and water has easy access to the rivers and dilution effects by water from upper part of the catchment.

Similarly, the ground water which came as base flow from the upper region of DRC (covered by natural dense forest increase infiltration of rain water into ground water) probably diluted the river. Clay particles have been washed away from both catchments in greatest percentage. For example, if washing of clay particles continues in such a way (Table 4), it would exacerbate pressure on production, since soils with higher clay content have more favorable chemical properties (Hutton et al., 2008) than coarser textured soils.

The concentration of OM, TKN and available P in the eroded sediment were greater than the surface soil. The concentration of available P reaches up to greater than 2.7 and 9 time its initial concentration in some areas of the watershed in the DRC and CRC (Table 3), respectively. This indicates that surface runoff is washing P in large amount to the water body. This may be because of the largest concentration of P in the soil surface layers, and concentrated hydrologic energy on the soil surface (Zaimes and Schultz, 2002). This high P ER coincides with high clay transport by the rivers, (for example: r^2 of 0.997) (Table 4). Scalenghe et al. (2002) indicated the highest accumulation of clay has strong relation with P ER because of the preferential loss of P with finer clay sized particle.

Soil erosion selectively washes fine particles such as clay and organic matter leaving coarse sand behind. Sand and silt are comparatively inert and act only as diluents to the more active clay (Page, 1950). Therefore, the higher the clay fraction the greater is the surface area of the soil available for sorption (Hutton et al., 2008).

Surface soil of DRC has greater soil fertility and hence loses much more nutrient than CRC (Table 3). This result also supports why soils with higher fertility status lose much more nutrients relative to those with a lower fertility status. Evans (2006) showed that the amount of nutrient lost was found to be strongly dependent on the nutrient status of the soil.

The severity of nutrient loss

The classifications were based on FAO (1999) calcification for available nutrient loss. The result of classification signifies how much soil erosion alone is contributing for the very high nutrient loss (FAO, 1999; Henao and Baanante, 1999). However, the classification in the report had been based on the nutrient removal including other major means of nutrient removal such as crop residue removal, leaching evapo-transpiration, grazing, etc.

Regarding nitrogen, Table 5 indicates only 35 and 30%

Table 5. Severity classes of the loss available nutrients.

Available	Dapo catchment		Chekorsa catchment		Loss left behind to be classified as high nutrient loss class (%)	
	Total loss	Severity class	Total loss	Severity class	DRC	CRC
N	13.58	Moderate	14.3	Moderate	35.4	30.6
P	9.31	High	4.20	Moderate	---*	47.5

Table 6. Estimated monitory value of available nutrient loss by the two Rivers.

Step	Estimated	Dapo catchment		Chekorsa Catchment	
		N	P	N	P
1	Total Lost/ha	13.6	9.3	14.3	4.1
2	Potential grain yield response (Kg/Ha)	3338.1	3905.1	3402.4	3147.6
3	Mean grain yield with no P and N fertilizer*	2389.3	2483.7	2389.3	2483.7
4	Net yield (Kg/ Ha)	948.8	1421.4	1013.1	663.9
5	Total price (Birr/ha)**	3320.8	4974.9	3545.9	2323.7

*Using Figure 12 and 13 equations accordingly. **Since market price of maize at Nekemte is 3.5 birr Ha^{-1} (1 birr = 17.50 USD).

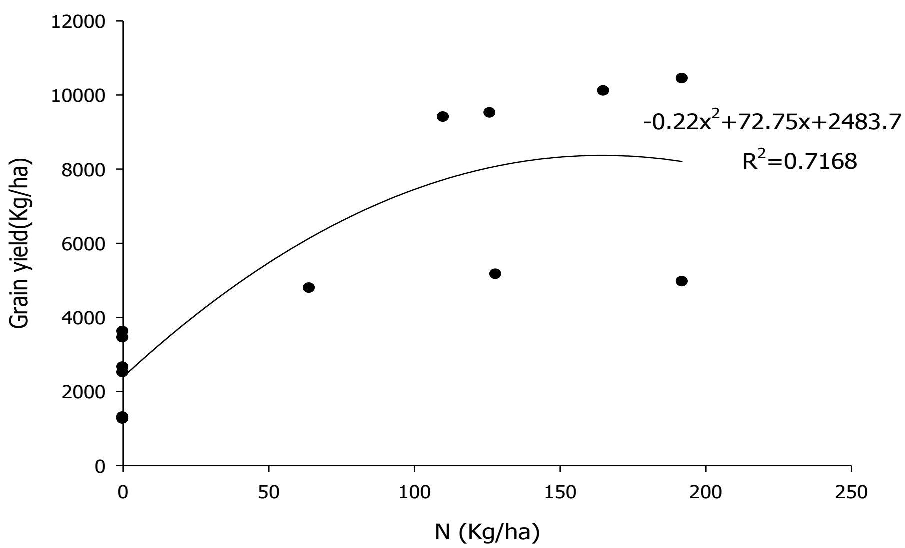

Figure 10. Response of maize grain yield to nitrogen application rate.

of high nutrient loss rate class stated by FAO (1999) was left behind in DRC and CRC, respectively, to fall in the high nutrient loss rate class. The soil nutrient loss due to soil erosion alone contributed about 65 and 69% high nutrient loss rate class by FAO (1999). According to FAO (1999), if P_2O_5 losses from cultivated land are between 4 and 7 $kg^{-1}ha^{-1}yr$, such value are considered as high losses. Only by soil erosion, P_2O_5 has already attained the high soil nutrient depletion rate class for Dapo (Table 5). On the other hand, in the CRC, 52.53% has already attained the minimum amount of P_2O_5 loss to be classified as high losses.

Costs of nutrient loss

The estimated macro nutrients (Table 6) and the yield response curve (Figures 10 and 11) were used as a tool to the estimated monetary value of onsite economic cost of the lost nutrients in Table 6. However, estimating total monetary cost of erosion presents many difficulties (GLCUS, 2008) since it involves many different factors (Derek, 1996).

R^2 of Figure 10 shows a wide variation of yield response to the almost equivalent amount of fertilizer rate; that is, 2.3 to 6.5 tha^{-1}. Similarly, Negassa et al.

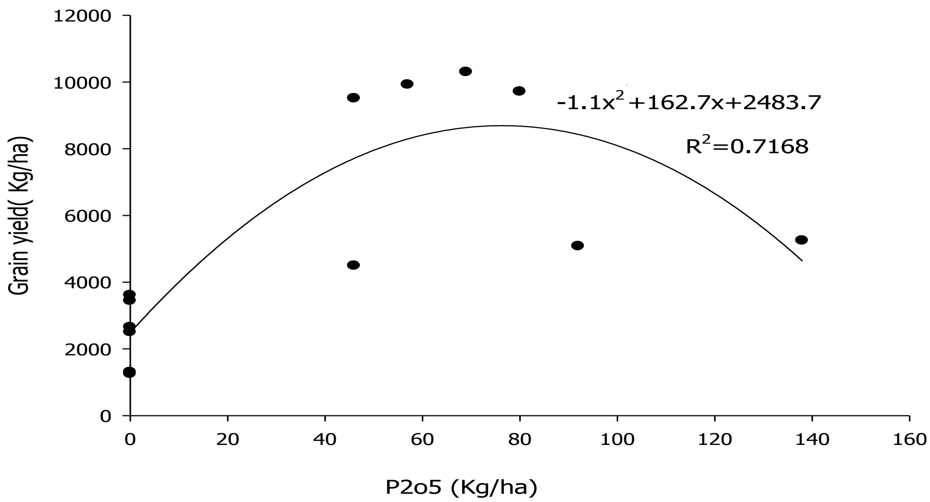

Figure 11. Grain yield response curve of maize to phosphorus rate.

(2005) indicated high variation of maize yields on farmers' fields in the study areas ranging from <1.0 to almost 6.0 t ha^{-1}.

Equations of Figures 10 and 11 represents the yield response curves showing the trend of yield increment for different rates of additional N and P application. Mean grain yield with no N and P fertilizers were 2,389 and 2,484 $Kgha^{-1}$, respectively (Table 6). Therefore, lost net maize grain yield due to the loss of available N and P_2O_5 by runoff were about 949 and 1,421 $kgha^{-1}$ from DRC whereas 1,013 and 664 $kgha^{-1}$ from CRC (Table 6). Farmers in the study area lost about 190 and 284 USD/ha from Dapo catchment and 203 and 133 USD/ha from Chekorsa catchment due to the loss of N and P, respectively.

Yield decline due to erosion follows a curvilinear, negative exponential (FAO, 1999). Therefore, eventually the current decline of yield can gradually reach a worst period in the future where there is no observation in yield decline. Negassa et al. (2005) also found that the relatively common practice of sole application of low rate of N and P fertilizers has not sustained maize production and productivity in the region because of severe nutrient loss. Therefore, combined application of these nutrients with manure/compost gives a better yield.

Conclusion and recommendations

The results revealed that suspended sediment concentration is strongly related to discharge or flood events for both catchments. The quality of the sediment lost from both sites is similar, though the catchment size and total discharge from Dapo River is about three times greater than Chekorsa, once sediment concentration of the Chekorsa River (varies from 942 to 3,002 mg/L) is higher than one at the Dapo River (ranging from 731 to 1,865 mg/L).

Suspended sediment concentration increases directly coincide with the surge in discharge for Chekorsa River but not for Dapo River. Discharge-suspended sediment concentration produced two types of hysteretic loops, an overlapped anticlockwise hysteresis for Dapo River Catchment and clockwise hysteresis relationships for Chekorsa River. The study reveals the loss of productivity as a result of both dissolved and sediment-sorbed N and P nutrient transported in overland flow delivered to the monitoring station.

In addition, from the result of the study, it is possible to conclude that:

1. Nitrogen and phosphorus losses due to soil erosion are elevated;
2. Clay has eroded more than silt and sand;
3. There is a strong correlation between percentage of clay with phosphate and TKN;
4. The rate of phosphorus loss was nine times in the sediment than that of the surface soil;
5. The monetary value of the lost nutrient may persuade farmers to implement sustainable nutrient practices and soil conservation activities;
6. As recommendation, similar studies must continue in the catchment including event based sediment hysteresis assessment in order to compare it with the weekly based sediment hysteresis.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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