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On-site financial costs of soil erosion by runoff from the Mizewa catchment of the Blue Nile basin

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Abstract: This study was conducted in Mizewa watershed which is located in Blue Nile Basin (BNB) to estimate on-site financial cost of erosion in terms of yield reduction taking maize as representative crop. For this purpose, discharge measurement and runoff sampling was made during the rainy season of 2011 at the outlet of three sub watersheds within Mizewa catchment; lower Mizewa (MZ0), Upper Mizewa (MZ1) and Gindenewur (GN0). The samples were filtered to separate the sediment which was subsampled for determination of suspended sediment concentration (SSC), sediment fixed NO_3^-, NH_4^+ and available phosphorous (P) contents. The filtered water was used to assess dissolved nitrate and dissolved phosphate. The on-site financial cost of erosion was estimated based on productivity change approach (PCA) focusing on available NP losses. The result revealed that the SSC and its NP content varied in space and time, in which higher and lower SSC occurred towards the beginning and end of the rainy season, respectively. The mean seasonal discharge was found to be 2.12±0.75, 1.49±0.52 and 0.57±0.20 m^3/sec at MZ0, MZ1 and GN0 stations in that order while the corresponding sediment concentration was 510±370 mg/l, 230±190 mg/l and 370±220 mg/l. This led to the total suspended sediment loss (SSL) of 4 ton/ha/year, 2 ton/ha/year and 3 ton/ha/year from the respective subwatersheds. The on-site financial cost due to N and P lost associated with SSL was estimated to be USD 200/ha, USD 186/ha and USD 227/ha from MZ0, MZ1 and GN0 watersheds, respectively. The study revealed that the economic impacts of soil erosion which is variable based on the characteristics of land resources and management practices are immense and deserve due attention. The result may help in sensitizing both farmers and decision-makers about the risk of soil erosion and in targeting management practices to overcome the challenges.

Keywords: Blue Nile basin, soil erosion, runoff, sediment concentration, Nutrient loss.

Media grab: Information on suspended sediment and plant available nutrients loss in runoff with their economic cost can provide crucial evidence to inform the land users and policymakers to take actions in management of land resources.

Introduction

Blue Nile Basin is heavily affected by land degradation problems. Overpopulation, poor cultivation and land use practices are the major cause, which result in significant loss of soil fertility, rapid degradation of the natural ecosystems, significant sediment and nutrient depositions in lakes and reservoirs (Tamene et al. 2006). To supplement rainfed agriculture with irrigation, a massive surface water harvesting effort has been undertaken in the dry lands of Ethiopia including BNB in the last few years. However, most of the water harvesting schemes is under serious siltation and dry up (Amanuel 2009) due to upstream land degradation mainly soil erosion. Circumstances in turn have led to reduction of productivity because of risky land use exercise and this has significant on-site economic costs to land users and the country as a whole. The cost price of loss of only available N and P, eroded from the 13 small catchments, was estimated at €34.2 million (Haregeweyn et al. 2008) in March 2006 for the Tigray, Northern Ethiopia. Therefore, it is essential to design and implement suitable land management practices for optimum utilization of land resources (soil and water), even if, limited information on financial on-site costs for loss of suspended sediment and plant available nutrients in runoff provide crucial evidence to inform land users and policymakers to take actions. This study tried to estimate productivity losses and corresponding economic and financial costs of suspended sediment and plant available nutrients lost along with runoff in Mizewa catchment as an input to the Nile Basin Development Challenges Program on Water and Food being implemented in the BNB.

Methods

The study was conducted at Mizewa catchment, northwest Ethiopia, drained by Mizewa River, a tributary to the Rib River that feeds to Lake Tana and covering a total area of 2664 ha which is located between latitude 11.88°–11.94°N and longitude 37.78°–37.86°E. Chromic-Luvisols, Chromic-Vertisols and Leptosols are the most common soil types with basaltic rock formation (Setegn et al. 2009). Mixed crop–livestock farming system with maize, rice, finger millet, teff, groundnut and barley are the principal crops grown in the area (Birhanu et al. 2012). Urea and DAP are the commonly used chemical fertilizers. Mizewa lie between 1852 m and 2360 m, dominated by hill to rolling undulating plain land forms and characterized by unimodal rainfall (mean 1204 mm) pattern, peaks around August 20th. Mean annual temperature ranges from 16.73°C to 19.32°C.

Flow height (h), surface flow velocity (Vs) measurement and suspended sediment sampling were conducted at the three monitoring stations three times a day at morning, mid-day and evening from 8 July 2011 through 16 October 2011 to calculate discharge (Q), suspended sediment concentration (SSC), suspended sediment loses (SSL), nutrient concentration (NC) and nutrient loss (NL). Data on maize grain yield (GY) response to fertilizer additions were obtained from previous research results under similar agro-ecological conditions. Surface flow velocity was measured using floating approach using a plastic bottle and converted to the average velocity (V) using Graff (1996) method.7 Record of h was converted into flow cross-sectional area (A) using an empirical relationship8 between h and A.

The volume of water (Q) passing a cross section per unit of time was calculated using the area-velocity method[9] (Hudson 1993). Sample runoff sediment was bulked into one as decade (D) according to the date of sampling starting from 8 July 2011 in order to have enough sediment for laboratory analysis and to reduce cost of laboratory. A composite sub-sample of one litter was taken from bulked samples for analysis. In the laboratory, the decade runoff sediment sample was filtered using Whatman No 42 filter paper to have SSC. The filtered water was analysed for dissolved nitrate and phosphate. The sediment left on the filter paper was air dried and weighted to analyse sediment fixed NO^{-}_{3}, NH^{+}_{4} and available P concentration. In laboratory, Gregorich and Ellert (1993) method was applied for NO^{-}_{3} and NH^{+}_{4} analysis and Olsen et al. (1954) procedure was applied for available P. Dissolved nitrate and dissolved Phosphate were determined using spectrophotometer (Bache and Williams 1971).

*7. V = 0.6*Vs.*

8. A = 5.5h2+3.6h for MZ0 ,A=2.9h2+0.95h+0.05 for MZ1 and A=9.95h2+7.44h for GN0.

*9. Q = V*A.*

Load of sediment (SSL), load of dissolved NO_3^- and dissolved PO_4^{3-} load was product of Q (m^3/decade) and their concentration in mg/l. Sediment bounded losses of NH_4^+, NO_3^- and available P was the product of mg/kg of each species with SSL mass in kg/decade. Seasonal losses were the sum of 10 decades of each species. Conversion of NO^-_3 and NH^+_4 to elemental available nitrogen was done using multiplier coefficient 0.23 and 0.78, respectively, while available elemental P and dissolved Phosphate were converted to phosphorous oxide (P_2O_5) using conversion factors 2.29 and 0.75 in order.

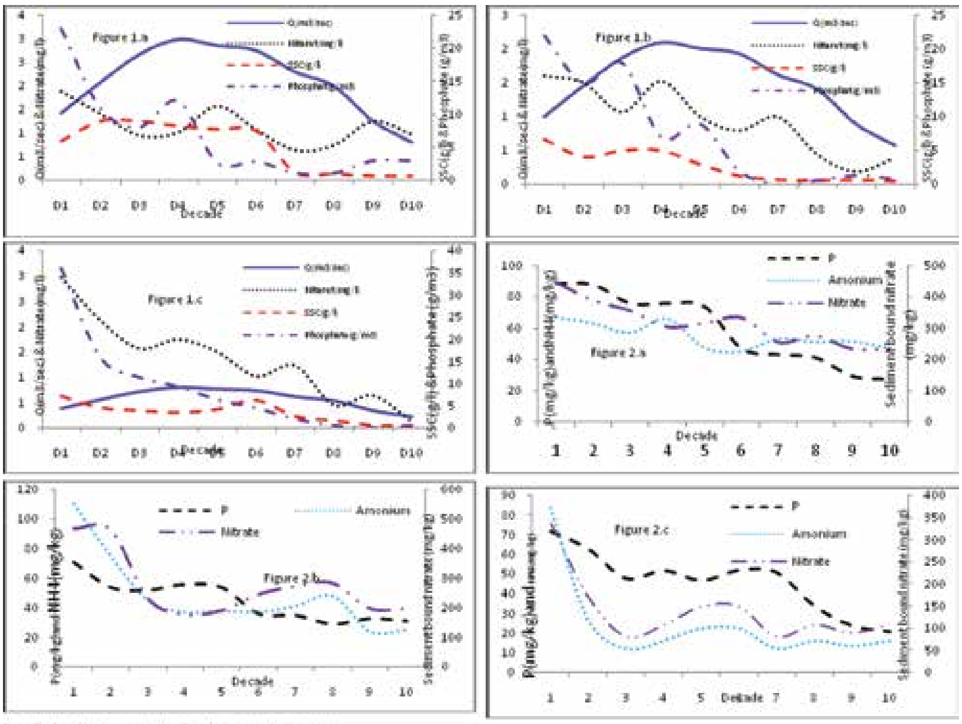
Productivity change approach (PCA) technique Bojo (1995) was used to estimate on-site financial cost of plant available nutrient losses through runoff soil erosion. This was calculated taking the loss of available NP nutrients and put a value on it using the equivalent net maize grain yield loss. Effect on crop yield was simply calculated as the net grain yield lost between potential grain yield due to lost available NP on fitting curve[10] and mean grain yield with no NP fertilizers.

Statistical comparisons were performed using SPSS 16. Analyses were performed to make comparison within groups of runoff sediment and nutrient loss between sites and decades. Significance differences in sediment load, rate of discharge and nutrient loss between sites was determined by t-test at 95% confidence limit.

Results and discussion

Runoff volume and suspended sediment lost

The average discharge was 2.12±0.75, 1.49±0.52 and 0.57±0.20 m^3/sec with total flow volume of 18.34×10^6 m^3, 12.87×10^6 m^3 and 4.92×10^6 m^3 per season at MZ0, MZ1 and GN0 rivers, respectively. Peak daily discharge was observed in D5 for the three stations (Figures 1.a, 1.b and 1.c) may be due to excess in saturation and full vegetation coverage of land. Mean flow rate was statistically significant between sites ($t = 2.68$, $P \leq 0.025$ between MZ0 and MZ1, $t = 6.58$, $P \leq 0.000$ between MZ0 and GN0, $t = 5.54$, $P \leq 0.000$ between MZ1 and GN0 rivers).



Note: D=decade=ten consecutive days during monitoring season.
D: July 8-July 17
D2: July 18-July 27
D3: July 28-August 6 D4: Aug 7- Aug16 D5:Aug17- Aug 26
D6:Aug27-Sep 5 D7:Sep6- Sep 15 D8:Sep16- Sep 25
D9:Sep26-Oct 5
D10: Oct6 – Oct 15

10. GY = $-0.29N_2+58.6N+2537.3$(R2=0.75) and GY=$-0.55(P_2O_5)2+82.25\ P_2O_5+2690.7$ (R^2=0.88) regression equations between GY of maize to N and P_2O_5.

Figure 1. SSC, soluble NO_3^- and PO_4^{3-};

Figure 2. Sediment bounded available P, NO_3^- and NH_4^+ as a function of time at (a) MZ0 (b) MZ1 and (c) GN0 station during monitoring time.

Mean SSC during the rainy season was 510±370 mg/l, 230±190 mg/l and 370±220 mg/l from MZ0, MZ1 and GN0 stations respectively and significant variations was observed between time and space (Figures 1.a, 1.b and 1.c). In MZ0 mean SSC varied from 67 mg/l to 900 mg/l per decade. SSC coefficient of variation between periods was 73, 82 and 61% for MZ0, MZ1 and GN0 stations, respectively implying that SSC in MZ1 was more variable over time than MZ0 and GN0 rivers. Statistical test for temporal and spatial variability of mean SSC (mg/l) over decades has shown that there is a significant variation between periods ($F = 4.51$ and $p \leq 0.0032$) and sites ($F = 5.61$ and $p \leq 0.013$).

Plant available N and P lost

Significant plant available nutrients were lost in associated with runoff and sediment (Table 1). Mean area specific plant available NP losses were 2.3 kg N/ha and 4.0 kg P_2O_5/ha from MZ0, 1.6 kg N/ha and 4.1 kgP_2O_5/ha from MZ1 and 2.3 kg N/ha and 4.8 kgP_2O_5/ha from GN0 catchments during monitoring period. Statically, there was a clear difference in the concentration of sediment nitrate ($F = 6.23$, $p = 0.006$) and NH_4^+ ($F = 3.85$, $p = 0.034$) across stations during the study period. Figures 2.a, 2.b and 2.c show that; there was no temporal variation in available plant nutrient concentration regardless of the stations except only for soluble phosphate ($F = 10.47$, $p \leq 0.000$). This available nutrient species composition and magnitude varied widely within the watershed which could be caused by several factors that needs further research and detail data to come up the with control variables for these differences among stations.

Table 1. Soluble and sediment fixed plant available nutrients looses

Station	Loss	Q (10^6 m^3)	SSC (mg/l)	Plant available N and P (kg)	
				N	P_2O_5
MZ0	Total	18.34		5967	3,635
	Mean	1.83	510	597	363
	Loss/ha		4	2.3	4
MZ1	Total	12.87		2590	1005
	Mean	1.29	230	259	101
	Loss/ha		2	1.6	4.1
GN0	Total	4.92		1627	551
	Mean	0.49	370	163	55
	Loss/ha		3	2.3	4.8

On-site financial costs

In this study, plant available N and P lost through runoff suspended sediment was responsible for significant economic on-site costs and this was reflected in maize grain yield reduction (Table 2) during monitoring season. Regression equations between maize grain yield and additional N and P_2O_5 application based on Tilahun Tadesse et al. (2007) data source was used as a bridge to link soil nutrient lost with grain yield loss of maize crop. Coefficient of determination in the equations shows a wide variation of yield response to the almost equivalent amount of fertilizer level. This shows that mean grain yield with no P and N fertilizers were 2691 kg/ha and 2537 kg/ha, respectively. Correspondingly, the lost net maize grain yield due to the loss of available NP were 453 kg/ha from MZ0, 421 kg/ha from MZ1 and 453 kg/ha from GN0 watersheds.

Table 2. Estimated monetary value of available N and P loss in Mizewa watersheds

Cost estimation procedure	MZ0			MZ1			GN0		
	N	P2O5	Total	N	P2O5	Total	N	P2O5	Total
Total loss (kg/ha)	2.3	4		1.6	4.1		2.3	4.8	
Potential grain yield response (t/ha)	0.267	0.301		0.263	0.302		0.267	0.307	
Grain yield with no NP fertilizers (t/ha)	0.254	0.269		0.254	0.269		0.254	0.269	
Net grain yield loss (kg/ha)	134	320	453	93	328	421	134	382	515
Price of net grain yield loss (USD/ha)	59	141	200	41	145	186	59	168	227

Price of grain maize in July 2011 (USD 0.44/kg).

According to Central Statistical Agency report of Ethiopia in 2011, average maize grain yield productivity in the study area was 2 t/ha. Therefore, the lost maize yield due to available N and P_2O_5 accounts 23, 21 and 26% of the total yield from MZ0, MZ1 and GN0 watersheds correspondingly. This effect of soil erosion on grain yield is above the reported figures of Helmecke (2009) who estimated 10, 5 and 12% for cereals pulses and root crops, respectively, at global scale. As a result, a farm enterprise having a hectare of land with maize cultivation in the study area has a profit loss of about USD 200/ha from MZ0, USD 186/ha from MZ1 and USD 227/ha from GN0 watershed in consequence of plant available N and P lost through runoff soil erosion process only in one particular rainy season.

Conclusions and recommendations

During the monitoring period $18.34 \times 10^6\,m^3$, $12.87 \times 10^6\,m^3$ and $4.92 \times 10^6\,m^3$ of water was lost with mean SSL of 4 ton/ha, 2 ton/ha and 3 ton/ha in association with (2.3 kg available N/ha and 4 kg P_2O_5/ha), (1.6 kg available N/ha and 4.1 kg P_2O_5/ha) and (2.3 kg available N/ha and 4.8 kg P_2O_5/ha) from MZ0, MZ1 and GN0 watersheds, respectively. This study also conclude that a reduction in maize gain productivity of 23, 21 and 26% and equivalent financial cost of USD 200/ha, USD 186/ha and USD 227/ha from MZ0, MZ1 and GN0 catchments in that order was estimated. The lost runoff from each watershed has a potential to irrigate a significant hectare of land, so that one could understand the valuable benefits gained by farmers if this water was used during dry season through water saving technologies though it needs detail study for recommendations to assess runoff lost with its on-site financial cost. The sediment lost did not consider bed-load transport, which might be important in the Mizewa catchments. Hence, measuring bed load in future is important in order to obtain more realistic total sediment and nutrient load calculation. In order to obtain a better picture of erosion impacts in the area, studies on other nutrient losses like calcium and magnesium and off-site effects of erosion need to be considered. This will benefit the understanding of the problem by land users and/or policymakers, letting them see the need to promote and/or implement soil conservation measures, as that is the language that they usually understand best. Therefore, the researchers recommend considering cost of soil erosion in national economy accounting to show significance of soil erosion to policymakers and to land users.

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