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Quantification of the Temporal Variability of N and Available P Loss in the Eroded Sediment the Case of Mana Watershed Goro District, South Eastern Ethiopia

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Abstract
Human induced changes in the Ethiopian highlands aggravate runoff, sediment and nutrient losses compromising ecosystem services. Soil erosion damages capital that supports economic development and improvements in quality of life. Most studies conducted in Ethiopia are focused on quantification of soil loss in terms of spaces. But this study aims to quantify the temporal variability of N and available P loss in the eroded sediment of Mana Watershed Goro District, South Eastern Ethiopia. The Mana watershed is located in the northeastern part of the Genale Dawa Basin, southeastern Ethiopia. To achieve the identified objective, sampling station was selected at the outlet of the watershed. Depth integrated runoff samples were collected during the Belg season in 2019. Daily runoff samples were collected and filtered to separate the sediment from the water. The result revealed that both N and P concentrations were highly variable in time; in which lower concentration occurred towards the end of the rainy season than at the beginning. The average TN lost associated with the sediment in the rainy season was 584.47 gram per kilogram. From the sample analyzed an average of 369.98 gram of P per kilogram associated with sediment was lost in runoff only during the spring season from the watershed. In addition to the long-term deterioration of land quality, the annual financial loss suffered by farmers is substantial. Therefore, linking traditional and modern SWC measures in the study area is crucial in order to mitigate soil erosion and associated nutrient loss.
Keywords: Mana watershed, nutrient loss, soil erosion
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1.0. INTRODUCTION

Soil nutrients are required by plants for growth development and the production of the harvestable crop itself (seeds, fruit, leaves and stem, roots, etc.). The three main nutrients are nitrogen (N), phosphorus (P) and potassium (K); more commonly known as NPK. Other important nutrients are calcium, magnesium and sulphur. Plants also need small quantities of iron, manganese, zinc, copper, boron and molybdenum, known as trace elements because only small amounts are needed by plants. Plant availability of these nutrients in the soil is affected by land use practices, soil types, climate, relief, soil power of hydrogen (pH), among others (Abate, S. 2011).

The term soil nutrient depletion refers to all nutrient losses from a soil through both natural and human-induced processes. Dynamically, it is the process by which the soil nutrient stock is shrinking because of continuous nutrient mining without sufficient replenishment of nutrients harvested in agricultural products, and of nutrient losses by soil erosion and leaching (Haregeweyin, 2008).

When soil is eroded, basic plant nutrients such as nitrogen, phosphorus, potassium, and calcium are also lost. Eroded soil typically contains about three times more nutrients than the soil left behind on the eroded land. Based on farm plot experiments done by Tully *et, al* , 2015 suggested a ton of fertile topsoil typically contains 1–6 kilogram (kg) of nitrogen, 1–3 kg of phosphorus, and 2–30 kg of potassium, whereas soil on eroded land frequently has nitrogen levels of only 0.1– 0.5 kilogram per ton (kg/t).

Plant productivity is significantly reduced when soil nutrient levels are low. If the soil is relatively deep, such as 300 mm, and 10–20 tons of soil is lost per hectare, the nutrients lost in the eroded soil can be replaced with the application of commercial fertilizers and/or livestock manure (Stoorvogel and Smaling, 1990). However, the loss of nutrients can be expensive for the farmer and nation. For instance, Troeh et al. (1991) estimate that the United States loses $20 billion annually in nutrients because of soil erosion.

Table 1.1. Global nutrient loss rate classes kilogram per hectare per year (kg-1ha-1year).

Class	N	P2O5	K2O
Low	<10	<4	<10
Moderate	10-20	4-7	10-20
High	21-40	8-15	21-40
Very high	>40	>15	>40

Source: FAO (1999) as cited in Wudineh et al (2012)

Ethiopia is reported to have the highest rates of soil nutrient depletion in sub-Saharan Africa, with soil erosion estimated to average 42 tons/ha/y on cultivated land (Stoorvogel and Smaling, 1990; Gebremedehin, 2001). Based on plot experiments in different parts of Ethiopia the total loss per hectare in areas of low soil nutrient loss is about 400 birr (46$) and 4,736 birr ($544) per hectare in areas of high soil nutrient loss or about 10-11% of the agricultural GDP (Gebremedehin, 2001). Stoorvogel and Smaling (1990) report for the whole Ethiopia an average N-P-K export through soil loss by erosion of 60 kg ha-1 a-1 which compares very high to the 20 kg ha-1 a-1 which is taken out of the soil by the crops. Haregeweyn et al., (2008) assessed the nutrient export of 13 small catchments in Tigray and found an average sediment nutrient content of 0.15 % ± 0.04 % for N, 8.13 ± 2.75 mg kg-1 for P and 429 ± 164 mg kg-1 for K.

According to Wudineh et al. (2012) nutrient loss experiments the estimated yield reduction of maize due to N and P loss was about 950 and 1420, and 1015 and 665 birr from Dapo and Chekorsa catchments respectively.

Hence, the main aim of this study is to quantify the temporal variability of N and available P loss in the eroded sediment of Mana Watershed Goro District, South Eastern Ethiopia. Meanwhile, the research will contribute for better understanding about the impact of sediment and nutrient loss which in turn gives crucial insight for the temporal variability of nutrient loss in the study area.

2.0. METHODOLOGY

2.1. Description of the Study Area

2.1.1. Location of the study area

Goro woreda is found in Bale zone of Oromia Regional State of Ethiopia with an area of 1339km^2. The woreda is located in the south-eastern part of the country 490 km away from the capital city of Ethiopia, Addis Ababa. Geographically, the woreda is situated at 6029'' N latitude and 40010''40045'' longitudes.

Goro is bordered on the southwest by Guradamole, on the west by Berbere, on the northwest by Sinana, on the northeast by Ginir, and on the southeast by the Somali Region. In the woreda Mount Holachis is the highest point; other important peaks include Mounts Dadimos and Farra. Perennial River includes the Mana, which is lined by forest, and Weyib.

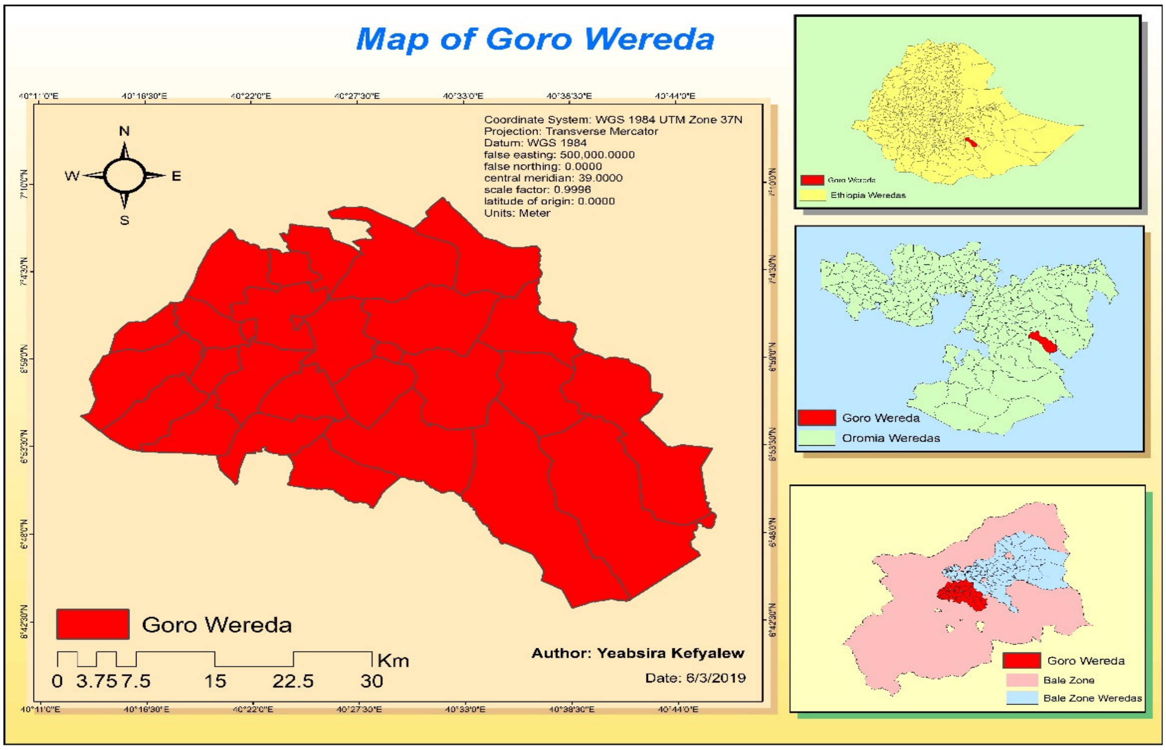

Figure 1.1: Study area map

2.1.2. Soil type

Goro woreda is covered by different soil types such as chromic vertisols which covers the southern part of the woreda; eutric nitosols in the northern part of the woreda; orthic luvisols in the eastern and North-east; and pellic vertisols in the northern west and south-west part (Goro Woreda Agriculture and Rural Development Office Report, 2017). The dominant soil types in Mana watershed are pellic vertisols followed by eutric cambisols.

2.1.3. Research design

The function of research design is to provide methods for the collection of relevant information with minimal expenditure of effort, time and money. Hence, Longitudinal experimental research design was used which is more powerful, especially when researchers seek answers to questions about change and reaction. Both quantitative and qualitative research methods were also used to achieve the objectives identified in this study. The use of mixed research methods help to understand complex research problems other than using single approach alone. Moreover, it has been argued that using a combination of qualitative and quantitative methods of data collection in research improves its overall strength as it gives both depth (qualitative) and breadth (quantitative). Land/soil degradation is the effect of both biophysical condition and the socio-economic history of a given area. Hence, the research design was based on a combination of methodologies like socioeconomic survey (using questionnaire), interview with land-users, understanding of each case was helpful to identify and propose/promote best integrated watershed management approaches in the study catchment.

2.1.4. Data sources

Both primary and secondary data were collected for this study to estimate several parameters. Necessary secondary data for the study was also collected from different sources that were available and from different organizations which work in the watershed. Some of the organizations were Goro woreda agriculture office, Goro woreda land and natural resource management office and National meteorological agency. Moreover, visits to other statistical offices, agricultural bureau, woreda extension centres, farmers associations and important person for the research were undergone and consulted to collect the required data for the study.

2.1.5. Data collection Methods

To combat land degradation across a range of temporal scale, it requires the integration of natural and social scientific methods, such as interviews with land users and expert knowledge. Therefore, to substantiate experiment and bio-physical data, socio-economic data was also collected using tools like household survey, key informants interview and researcher field observation. Such data were used to comprehend the soil loss severity.

2.1.6. Sampling Techniques

The study employed non-probability and probability sampling techniques to select sample kebele and sample population. Purposive sampling technique used to select two sample rural kebeles out of 26 rural and 2 urban kebeles in the Woreda. In order to select and determine the sample kebeles from the woreda: implementation of SWC practices, agro-ecology, livelihood of the residents, transportation access, and proximity to the Mana River and relevance to the research were used as criteria. Fenkel and Chafe Mana were selected accordingly.

2.1.7. Estimating nutrient loss and cost of soil erosion

Nutrient loss was 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 down slope (Keesstra *et al*., 2016). In this study commercial fertilizer is 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 placement 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 organized in composite sampling and analyzed in the laboratory by the same procedures that were used for eroded sediment. This allowed the estimation of their placement value of the commercial fertilizer applied to the surface soil of agricultural farm plots.

The on-site costs associated with nutrient loss were calculated by determining the equivalent cost of fertilizer types and quantities needed to replace the lost nutrients using their placement-cost approach (Yitbarek *et al*., 2012). In this case, the capital for replenishment of eroded nutrients is in commercial fertilizer equivalent. Farmers apply commercial fertilizer for the purpose of improving crop yield by restoring surface soil fertility at the crop root zone (Nyssen, *et al*., 2013).

Thus, considering nutrients lost from the topsoil alone is preferable for the estimation of the replacement cost of nutrients in commercial fertilizer equivalent. Based on the percentages of N and P for urea (46:0:0) and diammonium phosphate (DAP; 18:46:0) in fertilizer, urea contains 46% N and DAP contains 18% N and 20% available P (Berhan *et al*., 2009). The values of 1 kg N and P will be calculated as follows:

$V_{Nitrogen}$ = Price 1 kg Urea/ N content of Urea…………………….. Equation 1

$V_{Phosphorus}$= [Price 1 kg DAP – Price of 1 kg N) (N content of DAP)] /Available P Content of DAP……………………………………………… Equation 2

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 (Bewket *et al*., 2009). This study focuses on the time value cost due to Fenkel and Chafe Mana gully for farmers living above and below the gully.

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)…………………………….. Equation 3

The other cost of gully erosion arose due to losses of animals and perennial trees (Moges and Holden 2009). A number of animals were killed after being trapped in the gully during the rainy season. Animals killed were valued at their potential sales price (the replacement cost of lost animals) (Bewket *et al*., 2009).

Finally, the total cost of soil erosion was calculated by summing the value of resources lost in 2019.

2.1.8. *Data Analysis*

For data gathered through questionnaire and experiment, data analysis was carried out by use of mean, percentage and regression, by use of computer software application Statistical Package for Social Sciences (SPSS) Version 22. The qualitative data that are gathered through key informant interviews will be analyzed using content analysis by describing and interpreting the situation deeply and contextually so that the socio-economic factors will be distinguished.

Suspended sediment concentrations (SSC) will be determined gravimetrically by vacuum filtration of 100 mL of sample through a pre-weighted 0.45-μm filter paper, followed by oven drying at 105 ^{0}C for 24hand re-weighing with a high precision balance for further chemical analysis.

Due to constraints like finance, transportation and adequate sample for analysis, the 15 consecutive day's samples were bulked in to one large jerry can. Then, a composite subsample of two liters was taken from bulked samples for lab analysis.

Table 2.1. Methods and procedure used for the chemical analysis of sediment.

Sample	Parameter	Method	Reference
Soil	Nitrogen	Kjeldahl digestion	Walkely and Black 1934
Soil	Phosphrous	Alkaline Extraction of Olsen	Olsen and co-worker (1954)

3.0. RESULT AND DISCUSSION

3.1. The Temporal Variability of N and Available Phosphrous in the Eroded Sediment

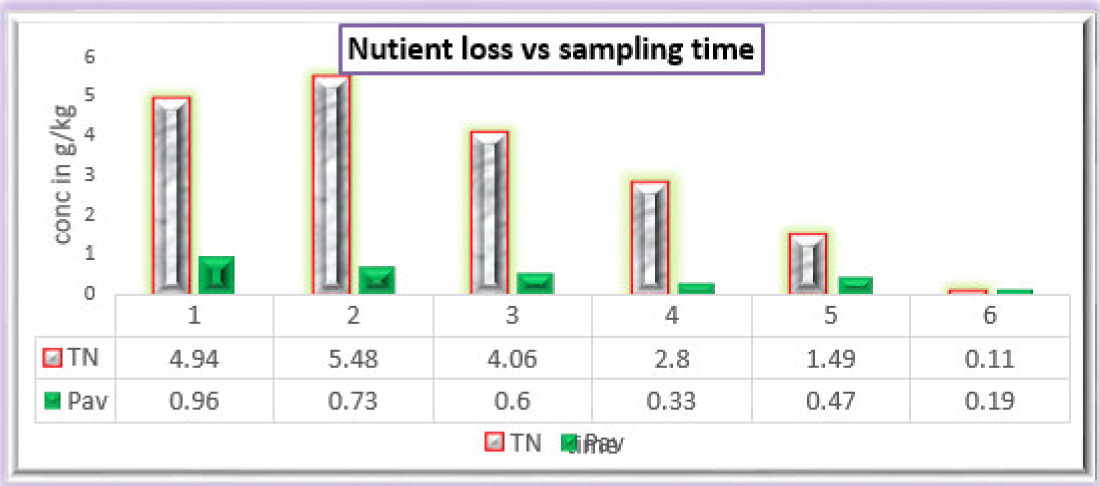

Figure 3.1: Temporal variation of nutrient loss

As described in (Figure 3.1), the average TN lost associated with the sediment in the rainy season was 584.47 gram per kilogram. The loss of Pav in sediment also is a challenge for the crop water productivity in the watershed. From the sample analyzed an average of 369.98 gram per kilogram associated with sediment was lost in runoff only during the spring season from the watershed. These concentrations in sediments provide a useful context for the severity of nutrient depletion in the watershed. Therefore, In addition to soil loss, nutrient loss is challenging the productivity of the watershed.

Analysis of sediment revealed that there was a significant amount of plant nutrients lost with the sediment mainly total nitrogen (TN) and Available phosphorus (Pav).

There was also temporal variation in the nutrient concentration during the rainy season. From the general trend, highest concentration was at the first month of the rainy season and lowest concentration in third month

(Figure 3.1.). This was associated with limited in supply meaning, in the watershed chemical fertilizers commonly urea and DAP were being intensively used to grow crops by the farmers in their agricultural fields at the time of sowing. This results are supported by (Bamlaku et al., 2012; Wudneh et al, 2012; Erkossa et al., 2015). They suggest that nutrient concentration measurements reflect the nutrient losses related to the application of commercial fertilizer.

The dissolved nutrient yield in the discharge peaked in at the end of April and at the beginning of May (Figure 3.1.). The loss of nitrogen was higher than phosphorus concentration which is supported by the results of (Bamlaku et al., 2012; Wudneh et al, 2012; Erkossa et al., 2015). The magnitude of loss of nutrient yield on June was much lower than May. This is due to decreasing of the intensity of the rainfall and crop coverage of the fields. Sediment associated nutrient concentration for the whole Mana watershed was higher at the end of April and early May 2019. Therefore, catchment condition and time of commercial fertilizer application were the two most important determinants for the nutrient variability in stream discharge (Desalegn B., 2012). On contrary to the above, Gessesse et al. (2016) has stated that nutrient loss was not only dependent on the sediment loss, but the soil condition of the land where nutrients losses can also influence. The total mass of nutrients depleted depends on the sediment yield (Erkossa et al., 2015; Tesfaye, 2014). Soil and nutrient losses significantly reduced by application of soil conservation and management practices such as soil bund on cultivated land (Haile, et al., 2012). According to Joy (2005) nutrient loss rates vary between the land use types and the land management practices.

3.2. Rate of nutrient losses

Table 3.2. Rate of nutrient losses from the Mana watershed in 2019

N loss (kg/ha/y)	cost of N loss (Birr/ha/y)	P loss (kg/ha/y)	Value of P loss (/ha/y)	Total value of loss (Birr/ha/y)
16.82	488 birr	8.78	562	1050

Stoorvogel and Smaling (1990) also reported that Ethiopia had among the highest rates of nutrient depletion in sub-saharan Africa with nitrogen loss reaching 30 kg ha^{-1} and phosphorus loss of 15-20 kg ha^{-1}. Haileslassie et al. (2005) estimated Ethiopia's nutrient rates of 122 kg N and 13 kg $ha^{-1}y^{-1}$. Similarly, Mitiku. (2006) estimated 47.8 kg N, 0.60 kg P, $ha^{-1}y^{-1}$ through soil erosion alone in the central highlands of Ethiopia.

4. CONCLUSION

Accelerated erosion in the form of sediment and plant nutrient loss pose a serious threat to Soil and Water Conservation sustainability and crop water productivity in Mena watershed due to natural and anthropogenic factors. There was a significant amount of plant nutrients lost with the sediment mainly total nitrogen (TN) and Available phosphorus (Pav). Hence, there was also temporal variation in the nutrient concentration during the rainy season.

Meanwhile, from the general observation; Suspended Sediment Concentrations were highly variable in temporal situations. The general trend is lower towards the beginning of the rainy season. Generally, the sediment samples indicated that there was a significant amount of plant nutrients lost mainly nitrogen and available phosphorus (Pav) as well as organic matter. Nutrients concentration varies temporally. The rate of phosphorus loss was 9 times in the sediment than that of the surface soil.

5. RECOMMENDATION

Based on the results of the onsite economic cost estimation the that

- ❖ Nutrient loss should give due attention along with soil loss through awareness creation for land users in any watershed management interventions in simultaneously reverse the land degradation;
- ❖ Runoff water harvesting should be an opportunity for enhancing rural livelihoods and food security and at the same time minimize the risk of erosion in the watershed and the basin;
- ❖ The data can also be used to calibrate, validate, and evaluate models to provide valuable information in evaluating land management alternatives to help find solutions for land degradation of the watershed; and
- ❖ Further work is therefore needed to determine the dynamic watershed response of runoff and erosion process to specify different land use scenario especially for eucalyptus plantations on their land.

REFERENCES

Abate, S. 2011. Estimating soil loss rates for soil conservation planning in the Borena Woreda of South Wollo highlands, Ethiopia, Journal of Sustainable Development in Africa, 13, 87–106.

Berhan, G. and Mekonnen, K. 2009. Estimating soil loss using Universal Soil Loss Equation for soil conservation planning at Medego watershed, northern Ethiopia, Journal of American 25 Sciences, 5, 58–69.

Bewket W, Teferi E. 2009. Assessment of soil erosion hazard and prioritization for treatment at the watershed level: case study in the Chemoga watershed, Blue Nile Basin, Ethiopia. Land Degradation & Development 20: 609–622. DOI:10.1002/ldr.944.

Deore, S.J. 2005. Prioritization of Micro-watersheds of Upper Bhama Basin on the Basis of Soil Erosion Risk Using Remote Sensing and GIS Technology. PhD thesis, University of Pune, Pune.

Desalegn B., Erkossa T. and Devi P. 2012. Characterization and cost estimation of erosion in abay basin: the case study on Meja watershe. Ambo, Ethiopia.

Erkossa T, Wudneh A, Desalegn B, Taye G. 2015. Linking soil erosion to on-site financial cost: lessons from watersheds in the Blue Nile basin. Solid Earth 6: 765–774. DOI: 10.5194/se-6-765 2015.

GebreMedhin, W. 2001. Country Profile of Potato Production and Utilization: Ethiopia. Ethiopian Agricultural Research Organization, Holeta Agricultural Research Center, National Potato Program.

Gessesse B, Bewket W, Bräuning A. 2016. Determinants of farmers' treeplanting investment decisions as a degraded landscape management strategy in the central highlands of Ethiopia. Solid Earth 7: 639–650. DOI: 10.5194/se-7-639-2016.

Goro Woreda Administration Office Profile. 2018.

Goro Woreda Administration Socio-Economic Profile. 2017.

Goro Woreda Agriculture and Rural Development Profile. 2017.

Goro Woreda Metrological Sub-Station. 2018.

Haile, G. W. and Fetene, M. 2012. Assessment of soil erosion hazard in Kilie catchment, East Shoa, Ethiopia, Land Degrad. Dev., 23, 293–306, 2012.

Haregeweyn N, Poesen J, Deckers J, et al. 2008. Sediment-bound nutrient export and associated costs from micro-dam catchments of Northern Ethiopia. Land Degradation and Development 19: 136–152.

Keesstra SD, Bouma J, Wallinga J, Tittonell P, Pete S, Cerdà A, Montanarella L, Quinton JN, Pachepsky Y, van der Putten WH, Bardgett RD, Moolenaar S, Mol G, Jansen B, Fresco LO. 2016.The significance of soils and soil science towards realization of the United Nation Sustainable Development Goals. The Soil 2: 111–128. DOI: 10.5194/ soil-2-111-2016.

Mitiku H., Herweg K., and Stillhardt B. 2006. Sustainable Land Management: A New Approach to Soil and Water Conservation in Ethiopia. Land Resources Management and Environmental Protection Department Mekelle University, Ethiopia, and Centre for Development and Environment (CDE), Swiss National Centre of Competence in Research (NCCR) North-South University of Bern, Switzerland.

Moges, A. and Holden, N. M. 2008. Estimating the rate and consequences of gully development: a case study of Umbulo Catchment in Southern Ethiopia, Land Degrad. Dev., 19, 574–586.

Morgan, R. P. C. 2005. Soil Erosion and Conservation (3rd. Ed.). Malden, Mass.: Blackwell Publishing.

Nyssen, J.; Haregeweyn, N.; Descheemaeker, K.; Gebremichael, D.; Vancampenhout, K.;Poesen, Haile, M.; Moeyersons, J.; Buytaert, W.; Naudts, J.; Deckers, J.; Govers, G. 2006. Comment on "Modelling the effect of soil and water conservation practices in Ethiopia" (Agriculture, Ecosystems and Environment 105: 29-40), Agriculture, Ecosystems and Environment.

Stoorvogel, J.J. and E.M.A. Smaling. 1990. Assessment of soil nutrient depletion in sub-Sahara Africa: 1983-2000, 4 Volumes. *Report 28*. The Winand Staring Centre for Integrated Land, Soil and Water Research, Wageningen, The Netherlands.

Telles, T. S., de Fátima, G. M., & Dechen, S. C. F. 2011. The costs of soil erosion [Os custos da erosão do solo]. Revista Brasileira de Ciencia do Solo, 35(2), 287–298.

Tesfaye A, Negatu W, Brouwer R, Zaag P. 2014. Understanding soil conservation decision of farmers in the Gedeb watershed, Ethiopia. Land Degradation & Development 25: 71–79. DOI:10.1002/ldr.2187.

Tilahun, S.A., Guzman, C.D., Zegeye, A.D., Steenhuis, T.S. 2015. Distributed discharge and sediment concentration predictions in the sub-humid Ethiopian Highlands: the Debre Mawi Watershed. Hydrol. Process. 29, 1817–1828. DOI: 10.1002/hyp.10298.

Tully K, Sullivan C, Weil R, Sanchez P. 2015. The state of soil degradation in sub-Saharan Africa: baselines, trajectories, and solutions. Sustainability 7: 6523–6552. DOI: 10.3390/su7066523.

WMO. 2005. Climate and land degradation.

Wudneh A., Erkossa T. and Devi P. 2012. Characterstics and onsite costs of the sediment lost by runoff from dapo and chekorsa watersheds, digga district. Ambo. Ethiopia.

Yitbarek, T. W., Belliethathan, S., and Stringer, L. C. 2012. The on-site cost of gully erosion and cost-benefit of gully rehabilitation: A case study in Ethiopia, Land Degrad. Dev., 23, 157–166. http://www.wmo.int/web/wcp/agm/agmp.