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Runoff delivery from the hilly catchments of Lake Tana basin

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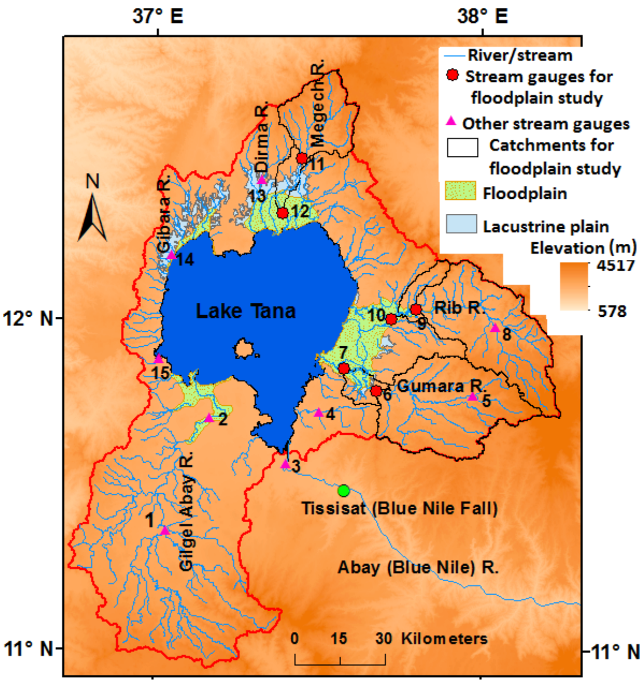
Introduction

The Lake Tana basin comprises hilly catchments and an extensive floodplain (lacustrine plain) adjacent to the lake at its lowland tributaries (Fig.1). Studies by Dessie et al. (2014) indicate that hydrological processes in the floodplains are different from those in the hillslope catchments. This study makes temporal and spatial assessment of runoff discharges of the rivers from the hilly catchments (upstream reaches) of Lake Tana and sediment delivery from such catchments.



Details of numbers shown in the figure

Number	Name of stream gauge	Name of catchment
1	Picolo	Gilgel Abay
2	Chimba	Gilgel Abay
3	Bahir Dar	Tana
4	Gelda	Gelda
5	Gumara	Gumara
6	Wanzaye	Gumara
7	Lower Gumara	Gumara
8	Rib near dam	Rib
9	Rib at Abobahir	Rib
10	Rib at bridge	Rib
11	Megech at bridge	Megech
12	Lower Megech	Megech
13	Dirma	Dirma
14	Gibara	Gibara
15	Kunzila	Tana Beles outlet

Figure 1. Stream gauges, the floodplain (lacustrine plain) and the rest catchments in Lake Tana basin; topographic data from SRTM DEM

Methodology

(1) Water level measurements

Field measurements of river flow stages at gauging stations along main river courses (Fig. 1), upstream just at the edge of the floodplain and downstream within the floodplain, to enable the computation of flow discharges in the hilly catchments and in the floodplain were made in the basin. Water level measurements have been made using automatic water level recorders (every 10 or 20 minutes) and manual readings from a staff gauge (three times a day, at about 7 am, 1 pm and 6 pm).

The automatic water level recorder (or Mini-Diver®) has a pressure sensor to determine water level and a temperature sensor (Fig. 2). It can be set to any desired time interval and the data are retrieved by inserting the Mini-Diver in a USB reading unit connected to a laptop or PC with Diver-Office. For each measurement, the date, time, water level and temperature are stored.

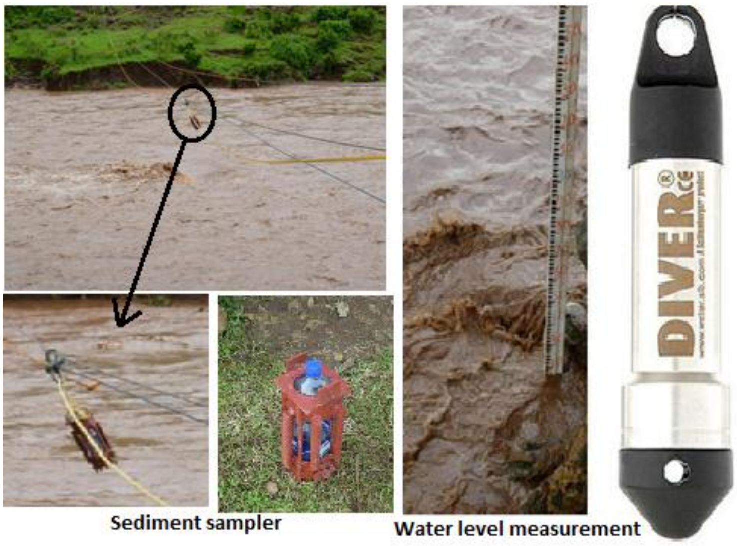


Figure 2. Details of a typical monitoring station installation at Wanzaye (Gumara River) site

A Diver® (with accuracy of 5 cm) measures the water level based on a highly accurate pressure sensor that measures an absolute pressure. This pressure is then related to the height of the water column above the measuring instrument and the prevailing air pressure. A Baro-Diver® was used to record atmospheric pressure.

(2) Discharge rating curves

The discharge of rivers at each gauging station was computed from the relationship between stages and discharge (rating curve). The rating curves (Fig. 3) were produced after the survey of the cross-sections of the river channels and the measurement of flow velocity at different flow stages.

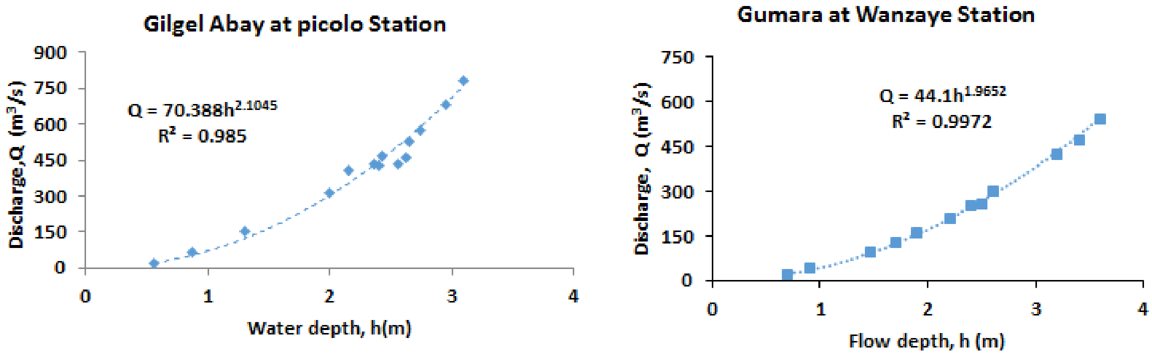


Figure 3. Stage-Discharge relationship (rating curves) for Gilgel Abay at Picolo and Gumara at Wanzaye Stations (after Dessie et al., 2014)

Results and discussion

The 2012 discharge data from the monitoring stations in the hilly catchments shows that there is considerable spatial and temporal variation of runoff in the basin. Generally, the southern catchment of the basin (Gilgel Abay River) produces high amount of runoff (Fig. 4). Nearly 60% of the inflow to the lake is from the Gilgel Abay River (Dessie et al, 2015). Catchment variations in terms of drainage density, topography, lithology, land use, and rainfall were found to affect the summer season runoff depth and runoff coefficients in the Lake Tana basin (Dessie et al, 2014).

On average, 88% of the total runoff observed from the monitoring stations in 2012 occurred in the period of June-September (the rainy season in Ethiopia). The runoff response is smaller at the beginning of the rainy season (June) than towards the end, reaching its climax in August. As shown in Fig, the largest part of the runoff in the majority of the monitored catchments took place in the form of flash floods (average flood duration lasting not more than 3-5 hours).

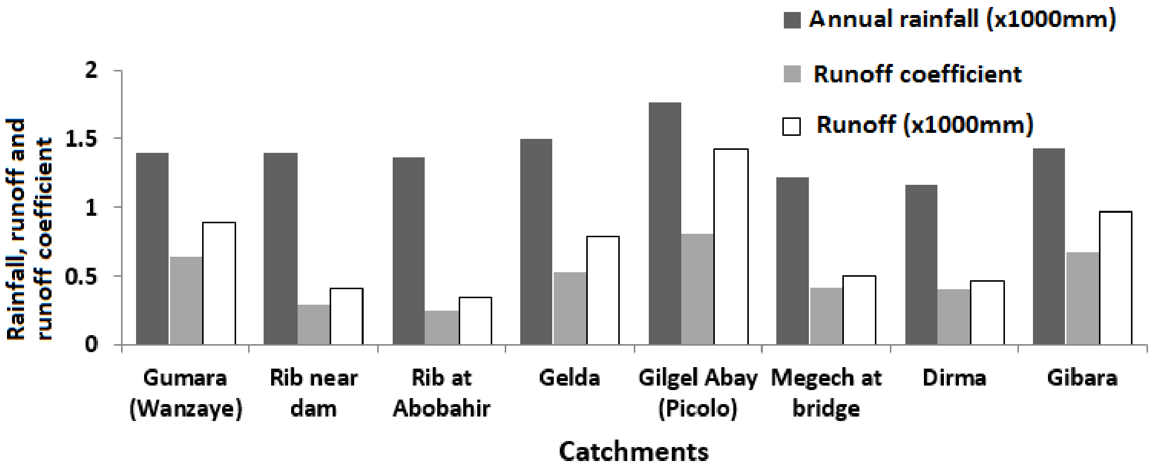


Figure 4. Annual rainfall, runoff and runoff coefficient for the hilly catchments in the Lake Tana basin. Refer to Fig. 1 for location of stations. (After Dessie et al., 2014)

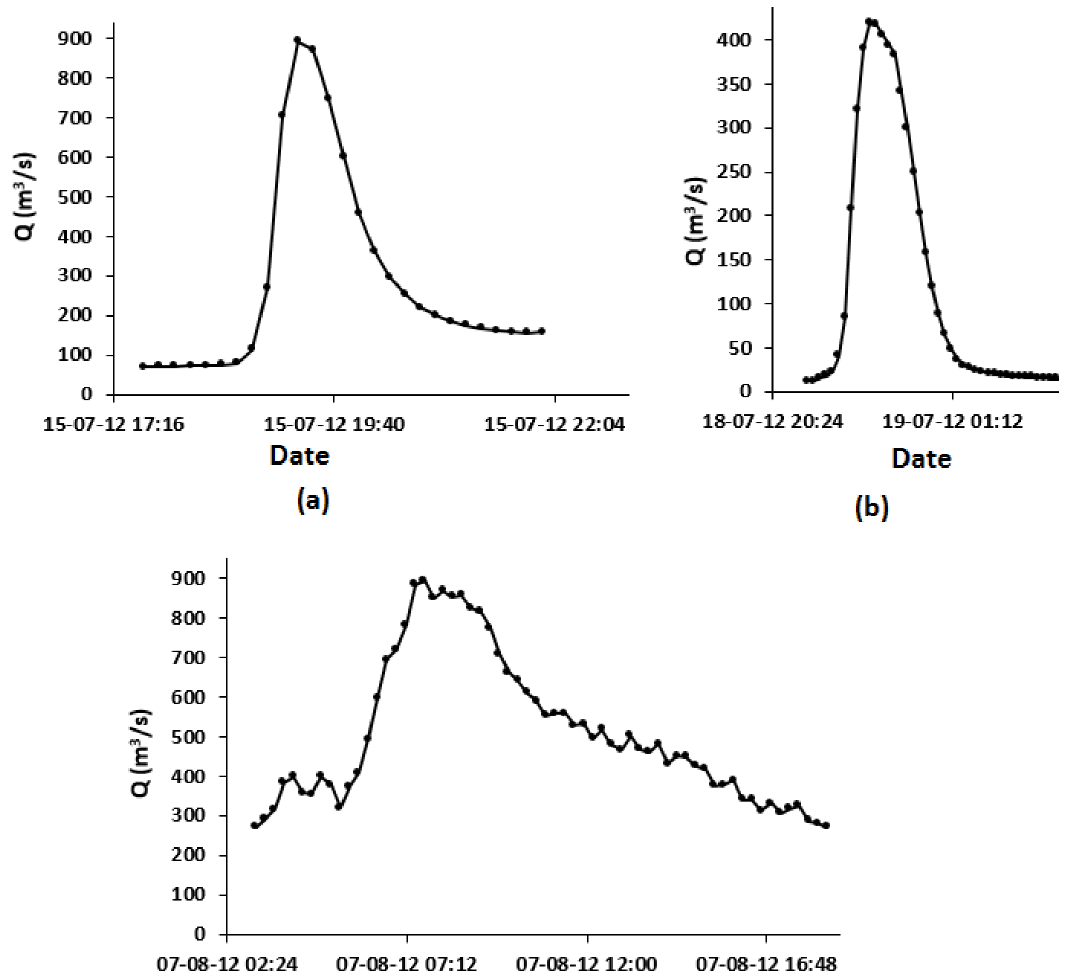


Figure 5. Typical flood hydrographs for (a) Gumara R. at Wanzaye station, (b) Gelda R. and (c) Gilgel Abay R. at Picolo station (After Dessie et al., 2014).

Conclusions

The runoff in the hilly catchments of the Lake Tana basin is characterized by significant spatial variations (the southern catchment of the basin (Gilgel Abay River) produces high amount of runoff). On average, 88% of the total runoff observed from the monitoring stations in 2012 occurred in the period of June-September (the rainy season in Ethiopia).

References

Dessie, M., Verhoest, N.E.C., Admasu, T., Pauwels, V.R.N., Poesen, J., Adgo, E., Deckers, J., Nyssen, J., 2014. Effects of the floodplain on river discharge into Lake Tana (Ethiopia). Journal of Hydrology, 519: 699-710. DOI: 10.1016/j.jhydrol.2014.08.007.

Dessie, M., Verhoest, N.E.C., Pauwels, V.R.N., Adgo, E., Deckers, J., Poesen, J., Nyssen, J., 2015. Water balance of a lake with floodplain buffering: Lake Tana, Blue Nile Basin, Ethiopia. Journal of Hydrology 522: 174-186. doi:10.1016/j.jhydrol.2014.12.049.

Sediment budget of Lake Tana and the role of lacustrine plains

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1. Introduction

The shallow Lake Tana is at high risk of siltation due to the wide-ranging land degradation in the basin. Research efforts made so far in the basin on its sediment budget are scanty and all attempts are constrained by limited data availability and reliability. Moreover, part of the lacustrine plains is subjected to periodic flooding and sediment deposition (Poppe et al., 2013; SMEC, 2008). Overbank sedimentation on these river floodplains can result in a significant reduction of suspended sediment load transported by a river and thus represents an important component of the sediment budget (Walling et al., 1998). Despite its crucial importance in the sediment budget, floodplain sedimentation is not studied so far in the basin or at country level (Abate et al., 2015; Nyssen et al., 2004). This study attempts to quantify the amount of sediment transported into the lake, stored on the floodplains, delivered out of the lake and stored in the lake annually in order to establish a sediment budget for Lake Tana.

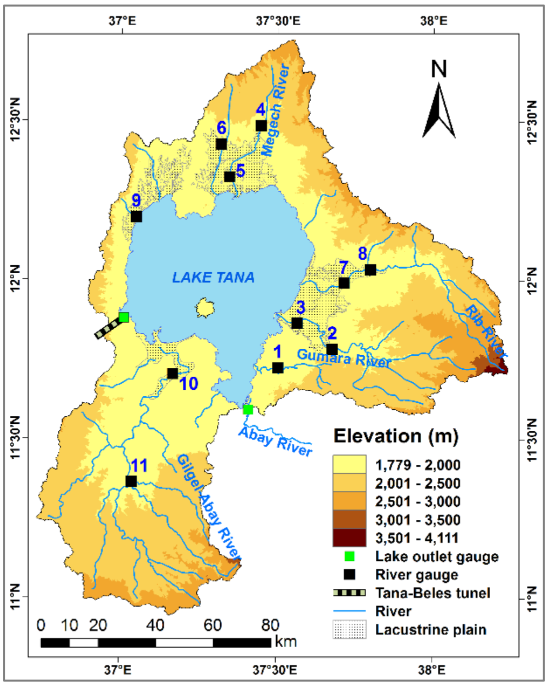


Figure 1. Location of study area

2. Methodology

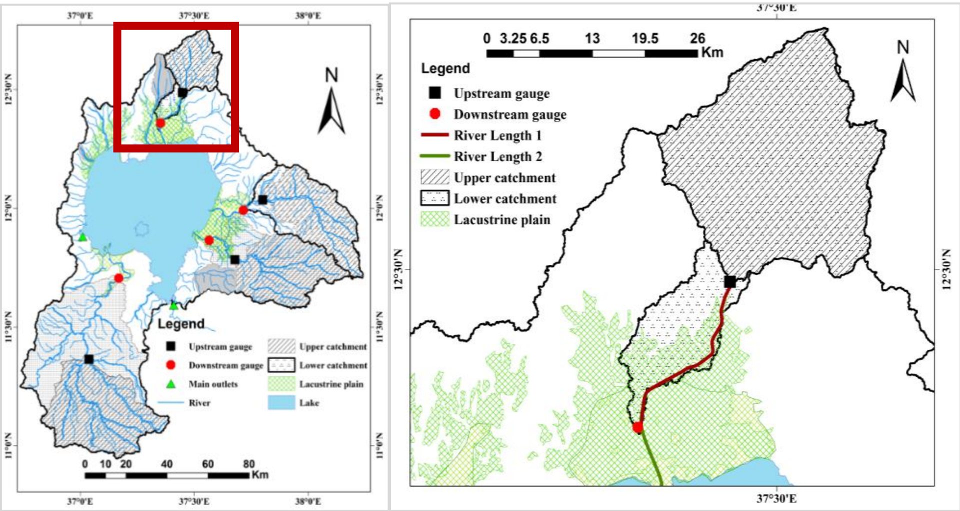
A total of 4635 data on discrete SSC with the corresponding river flow stage have been collected since June 2012, for 13 monitoring stations (Fig. 1; Table 1) by the project called 'Water and sediment budgets of Lake Tana for optimization of land management and water allocation' (WASE-TANA). The flow stage was collected every 10 to 20 minutes for the months of June to October and on daily basis for months of November to May, except the monitoring station at the Tana-Beles tunnel inlet. The river stage (m) was translated to discharge ($m^3 s^{-1}$) using the rating curves developed by Dessie et al. (2014).

Table 1. Monitoring stations and number of suspended sediment concentration (SSC) samples collected

No.	Station name	Area (km^2)	No. of SSC samples
1	Gelda	190	425
2	Upper Gumara (Wanzaye)	1227	386
3	Lower Gumara	1608	342
4	Upper Megech (Bridge)	514	409
5	Lower Megech (Robit)	652	338
6	Dirma	163	339
7	Lower Rib (Rib Bridge)	1394	485
8	Upper Rib (Abo-Bahir)	1166	394
9	Gibara	23	251
10	Lower Gilgel-Abay (Chimba)	3653	472
11	Upper Gilgel-Abay (Bikolo)	1656	490
12	Abay (Blue Nile) outlet		259
13	Tana-Beles tunnel inlet*		45

Note: * indicates gauge station where only SSC samples are taken, but discharge from EEPCo

To calculate sediment yield (SY) of the 11 gauged rivers, 5 rating curves within a year were developed in order to account for the seasonal effect (Zenebe et al., 2013). SY of ungauged catchments was also determined using an established regression model using catchment area and average annual catchment rainfall. Floodplain deposition rate was calculated from measurements taken at the upstream and downstream monitoring stations of Gilgel-Abay, Gumara, Rib and Megech Rivers (Fig. 2). The selected rivers are crossing large floodplains in their low-lying catchment areas.



$$\textbf{Load-1} = SY_{US} - SY_{DS}$$

$$D_{rate} = \frac{SY_{US} - SY_{DS}}{L_1}$$

$$\textbf{Load-2} = L_2 \times D_{rate}$$

Figure 2. Concept for determining floodplain deposition using upstream and downstream river gauge stations and river length

Load-1 and Load-2 were summed and gave total sediment load deposited on floodplains that are bordering that specific river.

Sediment leaving the lake through Abay (Blue Nile) River and Tana-Beles tunnel could be determined as the sum over the year of the product of daily discharge and daily SSC (constant for each month). In this case, we did not try to correlate SSC to Q given that (1) Q is not determined by a natural process but rather by decision of Ethiopian Electric and Power Corporation, and (2) SSC depends on the concentration in the lake, there is no high variability that can be related to discharges such as in river water.

The bed load fraction was estimated using an average measured range of 7% of the total load for for rivers that cross the floodplains (Adeogun et al., 2011) and 11.2% for the hilly catchments without floodplains (NBCBN, 2005). So far, the magnitude of the sediment delivered directly from the shores into the lake is unknown. However, the average erosion rate in LTB is 70 t ha^{-1} yr^{-1} (Kindye, 2013; NBCBN, 2005; Tilahun et al., 2014). Applying the Ethiopian Highlands Reclamation Study 10% estimated sediment delivery ratio to the water body, gives an average specific sediment yield (SSY) of 7 t ha^{-1} yr^{-1} from lake shores and other areas draining directly into the lake (FAO, 1986).

The sediment budget of Lake Tana Basin was then established as:

$$\Delta S_{LT} = SY_g + SY_u + SY_b + SY_s - D_f - SY_{AR} - SY_{TB}$$

where ΔS_{LT} is the net annual sediment deposition in Lake Tana, SY_g and SY_u are the annual suspended sediment load that are transported to the lake from the gauged and ungauged catchments, SY_b is the annual bed load transported to the lake, SY_s is the annual sediment load transported directly from the shores into the lake, D_f is the sediment deposited annually on floodplains bordering the main rivers, SY_{AR} and SY_{TB} are the sediment load exported from the lake through Abay river and Tana-Beles tunnel.

3. Sediment rating curve and SY from gauged rivers

From the developed sediment rating curves (Figure 3), it is clear that the curves developed for the five periods of the season perform generally much better than a rating curve based on all observations made during the entire measuring campaign: for a given river discharge, SSC values are lower towards the end of the rainy season than at the beginning of the rainy season (Fig. 3). The main reason is that the soil in cultivated lands is bare and loose due to frequent ploughing at the beginning of the rainy season and that there is increased ground cover by crops/vegetation, and decrease in sediment supply towards the end of the rainy season (Asselman, 2000) .

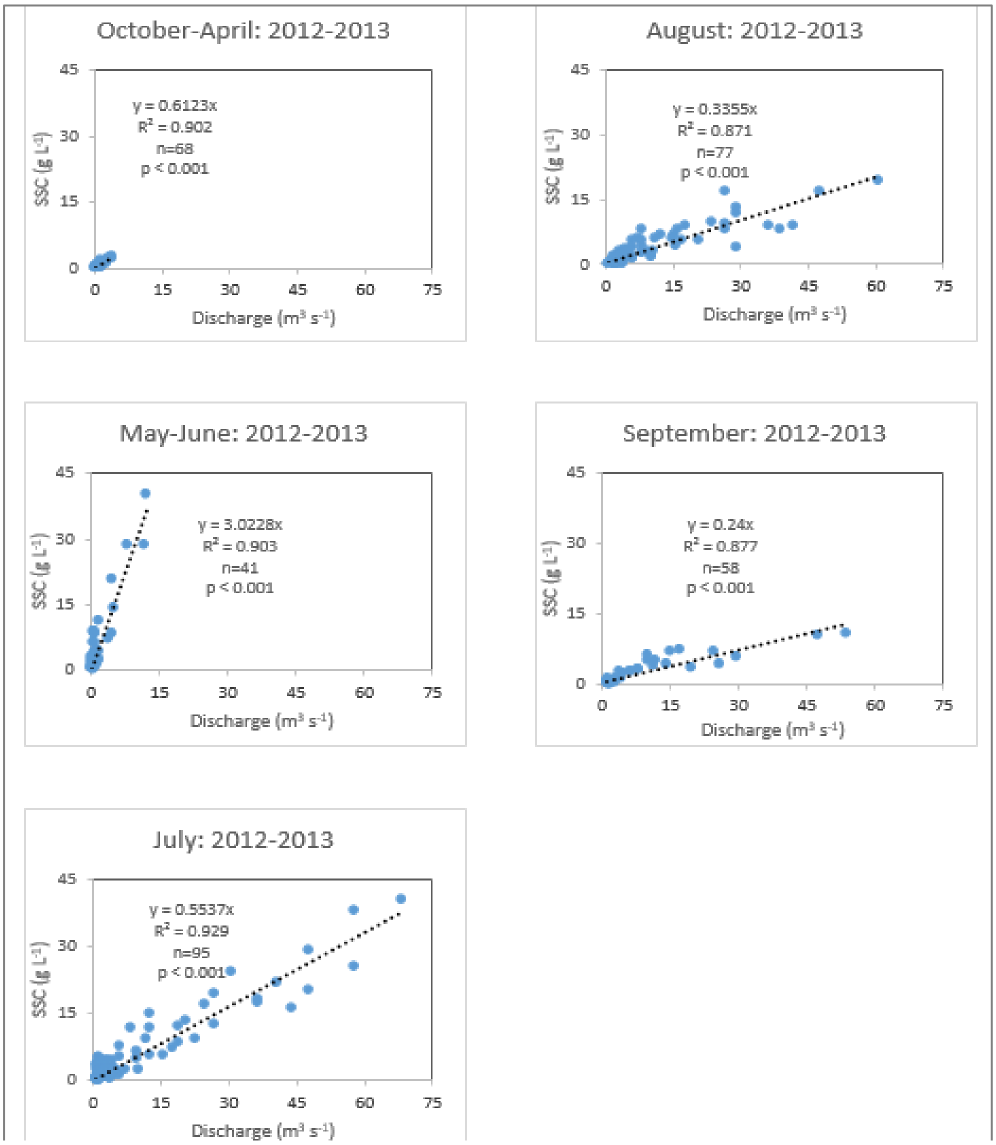


Figure 3. Sediment rating curves of Dirma monitoring station

After evaluating their performance, the rating curve equations were used to calculate the SY and SSY (Table 2). Besides having large catchment areas and higher rainfall, catchments in the south and east are more mountainous with steep slopes. Hence, most suspended sediment is originating from catchments in the South and East of Lake Tana. Regarding the relative order of importance of rivers in transporting suspended sediment load into Lake Tana, Gilgel-Abay (29%) delivers the highest, followed in decreasing order by rivers Gumara (21%), Megech (5%) and Rib (3.5%).

Table 2. Overview of average annual SY (2012-2013) and SSY for different gauged rivers draining into Lake Tana

Main River	**Gauge station**	**Area (km^2)**	**Average SY ($t\ yr^{-1}$)**	**SSY ($t\ km^{-2}\ yr^{-1}$)**
Dirma	Dirma station	163	28,509	175
Gelda	Gelda station	190	70,227	370
Gibara	Gibara station	23	4,733	206
Gilgel-Abay	Upper station (Bikolo)	1656	762,622	461
	Lower station (Chimba)	3653	753,739	206
Gumara	Upper station (Wanzaye)	1227	545,268	444
	Lower station	1608	274,591	171
Megech	Upper station (Megech Bridge)	514	119,325	232
	Lower station (Robit)	652	64,225	99
Rib	Upper station (Abo Bahir)	1166	92,876	80
	Lower station (Rib Bridge)	1394	71,075	51

4. SY from the ungauged rivers

Overall, catchment areas range from 12 to 3808 km^2, whereas the mean annual rainfall ranges from 872 to 1739 mm. After trial of various combinations of explanatory factors, it appeared that the product of catchment area and annual rainfall explained best the annual sediment yield (Fig. 4; Fig. 5).

The use of this equation to calculate SY based on catchment area (A) and annual rainfall (P) gives a total annual sediment yield of 996,968 tons yr^{-1} from all ungauged catchments.

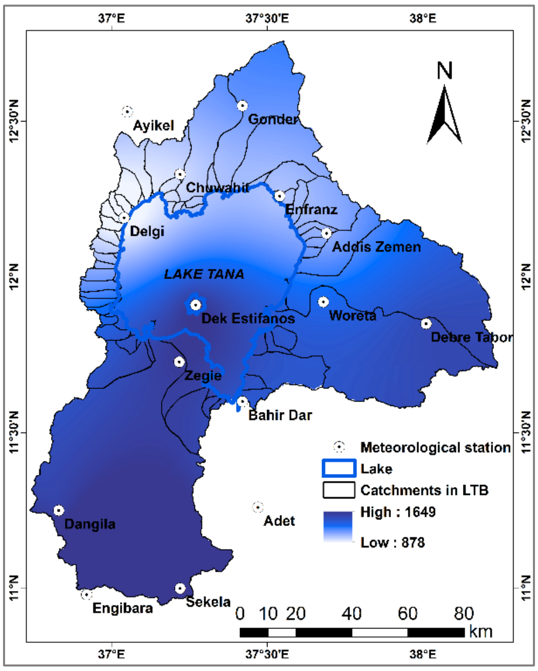


Figure 4. Average annual rainfall in LTB

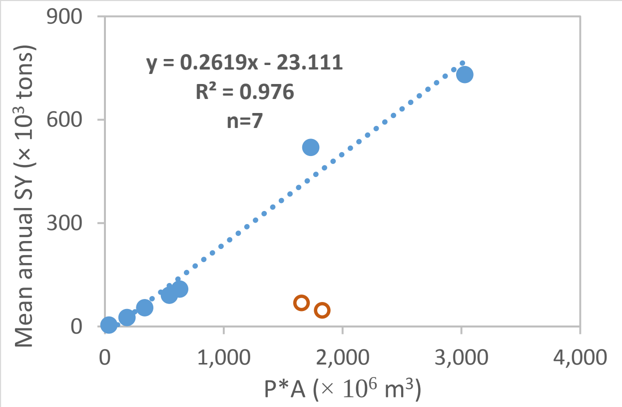


Figure 5. Relationship of mean annual SY of hilly catchments with the product of annual rainfall (P) and area (A). Rib data (open circles) were not taken into account

5. Sediment deposited in lacustrine plains

On average 482,364 tons yr^{-1} or 32% (ranging from 2% for Gilgel-Abay to 63% for Gumara) of sediment load from hilly catchments is deposited in the floodplains (Table 3). In terms of deposited mass, the lion share is taken by Gumara River followed by Megech and Rib rivers, while Gilgel-Abay contribution is the least. This seems logical as Gumara River has to cross an extensive floodplain bordering its meandering river in the downstream low-lying areas. In spite of mobilizing huge sediment by Gilgel-Abay River, floodplain deposition is minimum as its catchment has relatively smallest floodplain areas. As a result, Gilgel-Abay deposited its significant amount sediment at the lake shore that leads to visible delta development (Poppe et al., 2013).

Table 3. Sediment deposited on lacustrine plans and the net SY delivered to the lake in 2012-2013

River	Monitoring station		SY (t yr^{-1})		Floodplain deposition		Net SY into lake (t yr^{-1})
	Upper	Lower	Upper	Lower	(t yr^{-1})	% of upper station SY	
Gilgel-Abay	Bikolo	Chimba	762,622	753,739	12,831	2	749,791
Gumara	Wanzaye	Lower Gumara	545,268	274,591	342,106	63	203,163
Megech	Megech Bridge	Robit	119,325	64,225	73,322	61	46,003
Rib	Abo-Bahir	Rib Bridge	92,876	71,075	54,105	58	38,771
Total			1,520,091		482,364	32	1,141,197

6. Sediment exported out of Lake Tana

The mean annual sediment exported out of the lake was estimated to be 1,094,276 tons, of which Abay (Blue Nile) River and Tana-Beles tunnel shared 65% and 35% (Fig. 6). As the two outlets are positioned at different water depths, they get lake water with different SSC.

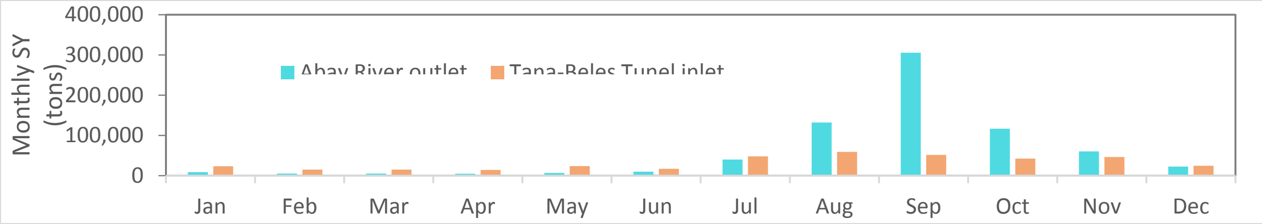


Figure 6. Monthly exported sediment load (tons) through Abay (Blue Nile) River and Tana-Beles tunnel

7. Annual sediment deposited in Lake Tana, its volume and trap efficiency of the lake

A net annual suspended sediment lake deposition of 1,043,888 tons yr^{-1} could be calculated with a trap efficiency of 49%. Dividing this mass by bulk density of 1.2 tons m^{-3} (SMEC, 2008) resulted in a total sediment deposition rate of 869,907 m^3 yr^{-1} in the lake, corresponding to an average deposition rate of 0.28 mm yr^{-1}. Incorporating the estimated bed load and SY from lake shores increased the total sediment entering the lake by 24% and the lake deposition by 50%. Moreover, the trap efficiency increased to 59% with a uniform sediment deposition rate of 0.42 mm yr^{-1}.

8. Sediment budget of LTB

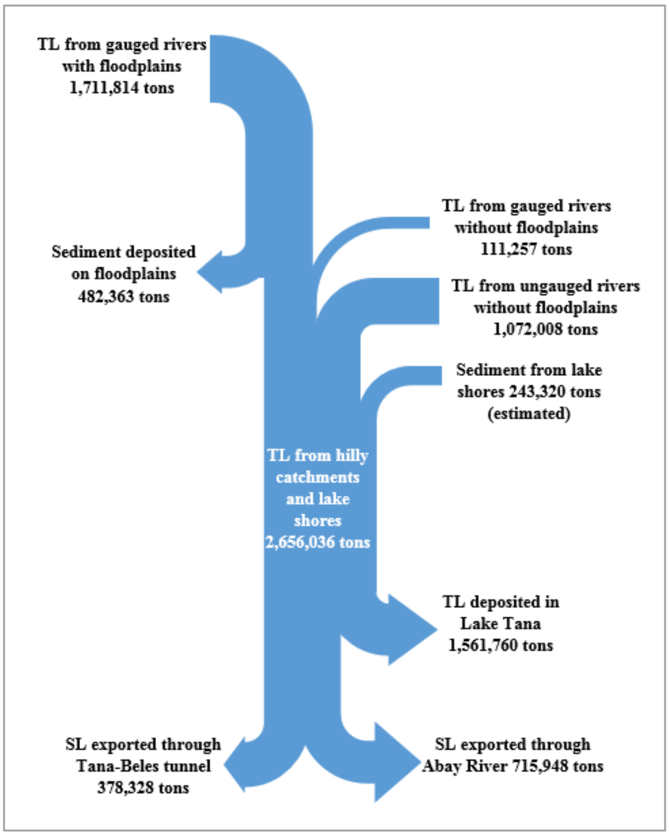


Figure 7. Average annual sediment budget in 2012-2013 for Lake Tana. All values are taken as average annual sediment load. Suspended load based on measurements; total load (TL) as suspended plus calculated bed load; SY of ungauged rivers, SY from shores and lake deposition were calculated

9. Major sediment deposition areas

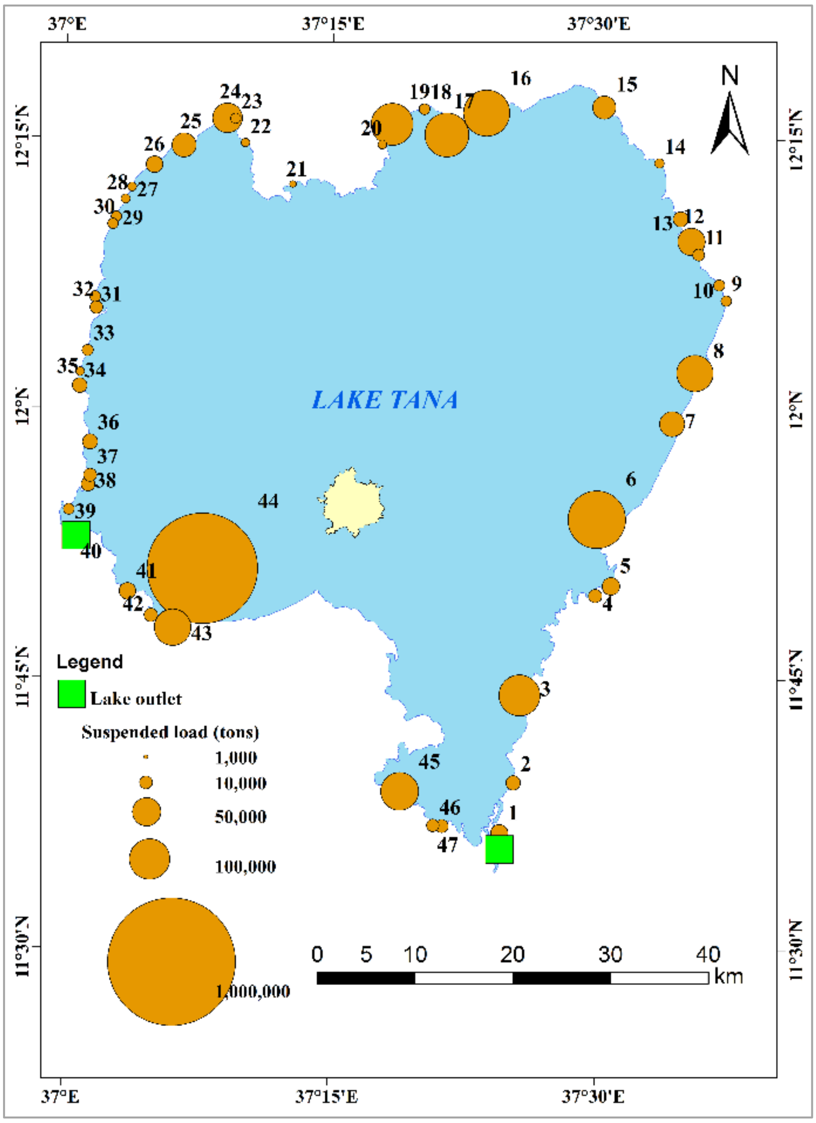


Figure 8. Major sediment depositional areas in Lake Tana

The highest sediment load from Gilgel-Abay River not only leads to visible delta development, it may also send sediment laden water to the Tana-Beles hydropower station of which the intake is located nearby.

10. Conclusion

The results obtained in this study are based on a large number of observations (about 4,327 sampled SSC and even much more river discharge, the largest set of observations in the area) with optimal spatial coverage and representativeness. Consequently, the estimated result in this study is assumed to be the most reliable so far. The trapping efficiency (T_e) of Lake Tana is estimated as 49%. In case bed load is also taken into account, T_e is even more, the lake is expected to fill up earlier, and the sediment budget is quite different.

References

Abate, M., Nyssen, J., Steenhuis, T. S., Moges, M. M., Tilahun, S. A., Enku, T., & Adgo, E. (2015). Morphological changes of Gumara River channel over 50 years, upper Blue Nile basin, Ethiopia. Journal of Hydrology, 525, 152–164. doi:10.1016/j.jhydrol.2015.03.044

Adeogun, B. K., Igboro, S. B., & Ibrahim, F. B. (2011). Estimate of bed load transport in Kubanni Watershed in Northern Nigeria using grain size distribution data. International Journal of Water Resources and Environmental Engineering, 3(5), 102–108.

Asselman, N. E. M. (2000). Fitting and interpretation of sediment rating curves. Journal of Hydrology, 234, 228–248. doi:10.1016/S0022-1694(00)00253-5

Dessie, M., Verhoest, N. E. C., Admasu, T., Pauwels, V. R. N., Poesen, J., Adgo, E., Deckers, J, Nyssen, J. (2014). Effects of the floodplain on river discharge into Lake Tana (Ethiopia). Journal of Hydrology, 519, 699–710. doi:10.1016/j.jhydrol.2014.08.007

FAO. (1986). Ethiopian Highlands Reclamation Study (EHRS): Final report. Food and Agriculture Organization of the United Nations, Rome, Italy.

Hanibal Lemma, Teshager Admasu, Mekete Dessie, Poesen, J., Enyew Adgo, and Nyssen, J., 2015. The sediment budget of Lake Tana (Ethiopia). Geomorphology, in prep.

Kindye, E. G. (2013). Soil erosion rate and sediment yield under various land use types: The case of Kezin watershed, Lake Tana Basin, Ethiopia. MSc.Thesis, Natural Resources Management Department, Bahir Dar University.

NBCBN. (2005). Watershed erosion and sediment transport. Nile Basin Capacity Building and Network. River morphology Research Cluster.

Nyssen, J., Poesen, J., Moeyersons, J., Deckers, J., Haile, M., & Lang, A. (2004). Human impact on the environment in the Ethiopian and Eritrean highlands—a state of the art. Earth-Science Reviews, 64(3-4), 273–320. doi:10.1016/S0012-8252(03)00078-3

Poppe, L., Frankl, A., Poesen, J., Admasu, T., Dessie, M., Adgo, E., Deckers, J., Nyssen, J. (2013). Geomorphology of the Lake Tana basin, Ethiopia. Journal of Maps, 9, 431–437. doi:10.1080/17445647.2013.801000

SMEC. (2008). Hydrological Study of the Tana-Beles Sub-Basins: Main Report. Ethiopia: Ministry of Water Resources, Addis Ababa.

Tilahun, S. A., Guzman, C. D., Zegeye, A. ., Ayana, E. K., Collick, A. M., Yitaferu, B., & Steenhuis, T. S. (2014). Spatial and temporal patterns of soil erosion in the semi-humid Ethiopian highlands: A case study of Debre Mawi watershed. In A. M. Meless, W. Abtew, & S. G. Setegn (Eds.), Nile River Basin: Ecohydrological challenges, climate change and cydropolitics (pp. 149–163). Springer International Publishing.

Zenebe, A., Vanmaercke, M., Poesen, J., Verstraeten, G., Haregeweyn, N., Haile, M., Amare, K., Deckers, J., Nyssen, J. (2013). Spatial and temporal variability of river flows in the degraded semi-arid tropical mountains of northern Ethiopia. Zeitschrift Für Geomorphologie, 57(2), 143–169. doi:10.1127/0372-8854/2012/0080

Species and structural composition of church forests in a fragmented landscape of Northern Ethiopia

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1. Introduction

Worldwide, forests have been fragmented into small patches, and forest structure and species composition have been influenced due to this fragmentation and habitat loss (Echeverria, 2006). An extreme case of fragmentation and isolation is presented by remnant dry Afromontane forests in the northern Ethiopian highlands. Deforestation in Ethiopian highlands often involves the conversion of landscapes with continuous forest to many small remnant forest patches around churches and inaccessible areas set in a matrix of non forest vegetation (Demel Teketay, 1996; Bingelli et al., 2003; Alemayehu et al., 2005; Aerts et al., 2006a). Ethiopian churches and monasteries have a long standing tradition of preserving and conserving their forests, including many native plants and animals (Alemayehu et al., 2005a,). This study assesses the species and structural composition of 28 church forests and investigates whether and how this composition varies with altitude, forest area and human influence. Specifically we address four questions: (1) what is the forest community structure and species composition of the church forests?; (2) How do altitude, forest area and human influence affect structure and species richness of these forests? (3) How do altitude difference and distance affect similarity in species composition among church forests?; and (4) Do altitude, forest area and human influence affect similarity in species composition between understorey and overstorey of church forests?

2. Methodology

The study was conducted in South Gondar Administrative Zone (SGAZ), Amhara National Regional State, Ethiopia (Fig. 1). Out of the 1404 church forests found in SGAZ, 28 forests with a total of 500.8 ha forest were selected for the present study (Table 1). They were located at altitudes ranging from 1816 to 3111 m a.s.l., and had areas varying between 1.6 and 100 ha. The churches in these forests were reportedly established between 368 and 1984 A.D.

Within each forest the vegetation was censused in 10 x 10 m plots located at 50 m distance to each other along parallel transects. The mean canopy openness, leaf litter depth, the number of clearly visible cattle trails and dead stumps ($\geq$ 5 cm diameter) were recorded for each plot.

All woody plants within the sample plots were identified and recorded. Diameter at breast height (1.3 m, dbh) of all living woody plants in the sample plots having $\geq$ 5 cm dbh were measured. Individuals with dbh < 5 cm diameter and > 1 cm diameter at 10 cm above ground were not measured but counted. Seedlings (here defined as woody plants with a diameter at 10 cm above ground of < 1 cm) were censused (identified and diameter measured at 10 cm) in a sub plot of 5 x 5 m that was marked on the right front quarter of the main 10 x 10 m plot. The heights of all woody plants were also measured

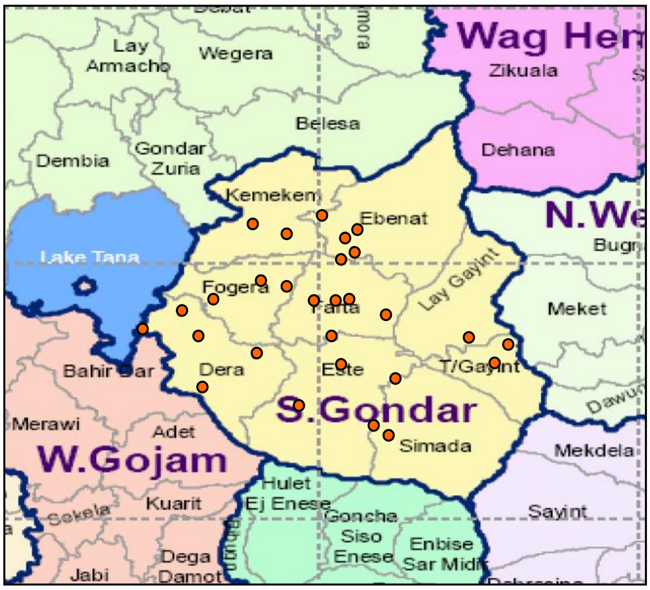

Figure 1. Location of church forests studied in the South Gondar Administrative Zone.

3. Results

A total of 168 woody species (100 tree species, 51 shrub and 17 climber) representing 69 families were recorded. Forests differed strongly in species number (15 to 78), basal area (4.8 to 111.5 m^2/ha), number of individuals ≥ 5 cm dbh (267 to 1553/ha), number of individuals >1 cm diameter (619 to 2421/ha) and number of seedlings (0 to 5263/ha).

Basal area decreased with wood harvest but was independent from altitude, forest area and cattle interference. Species dominance increased with altitude and cattle interference (Fig 2). The ratio understory to upperstory density decreased with cattle interference but was independent of altitude and forest area (Fig 3). The tree size class distributions of the 28 forests were grouped into four patterns of distribution (Fig. 4). The four groups were significantly different from each other in the number of dead stumps ($F_{3, 24}$=4.9, p=0.008) and cattle interference ($F_{3, 24}$=5.0, p=0.007) but not in their altitude ($F_{3, 24}$=1.1, p=0.36) or forest area ($F_{3, 24}$=1.2, p=0.31). Human interference thus is the most important factor determining the size class distribution of the forests.

All species richness measures and diversity indices decreased with altitude, but were independent of forest area, cattle interference and wood harvest (Fig 5). However, understorey species richness (seedlings) was not affected by altitude alone, but rather the interaction effect of altitude and cattle interference showed a significant effect. Both the observed and rarefied number of species in the understorey decreased with both altitude and cattle interference (Fig. 5C1-2). On the other hand, the ratio of understorey to overstorey species richness was not significantly related to any of the factors considered (altitude, forest area, cattle interference or wood harvest, Fig. 3 B1-4 ; r^2<0.02, p>0.05).

Similarity between forests decreased with altitude difference between forests, but geographical distance hardly explained variation (Fig 6).

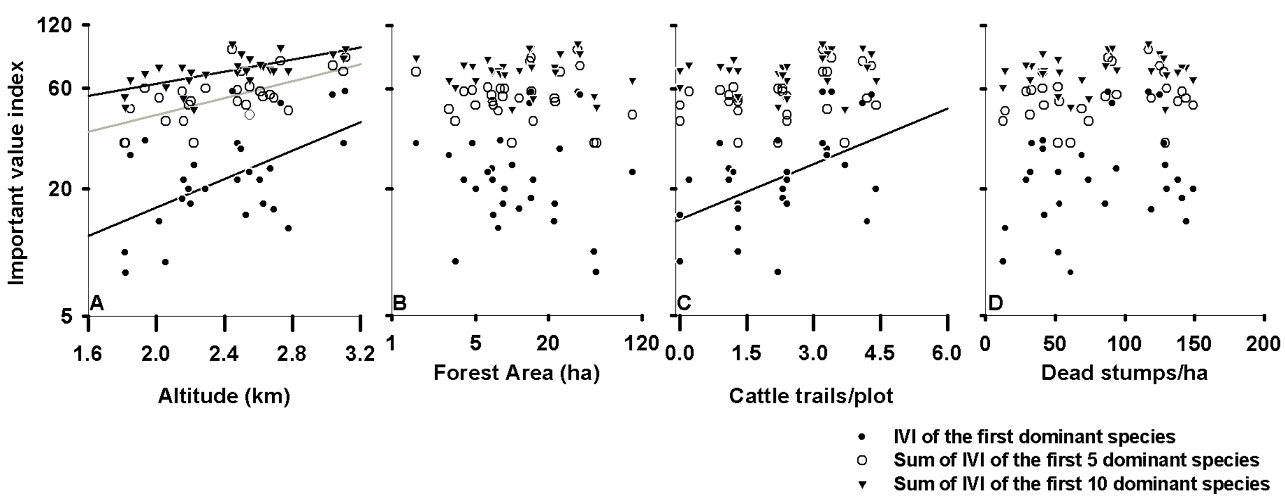

Figure 2. Species dominance in terms of important value index (IVI) as a function of altitude (A), forest area (B), cattle interference (C) and wood harvest (D). All values on y-axis and forest area are in log scale. Three levels of dominance are given, the IVI of the first dominant species (filled circles), the cumulative IVI of the first 5 (open circles) and that of the first 10 (triangles) most dominant species. The lines give significant linear regressions.

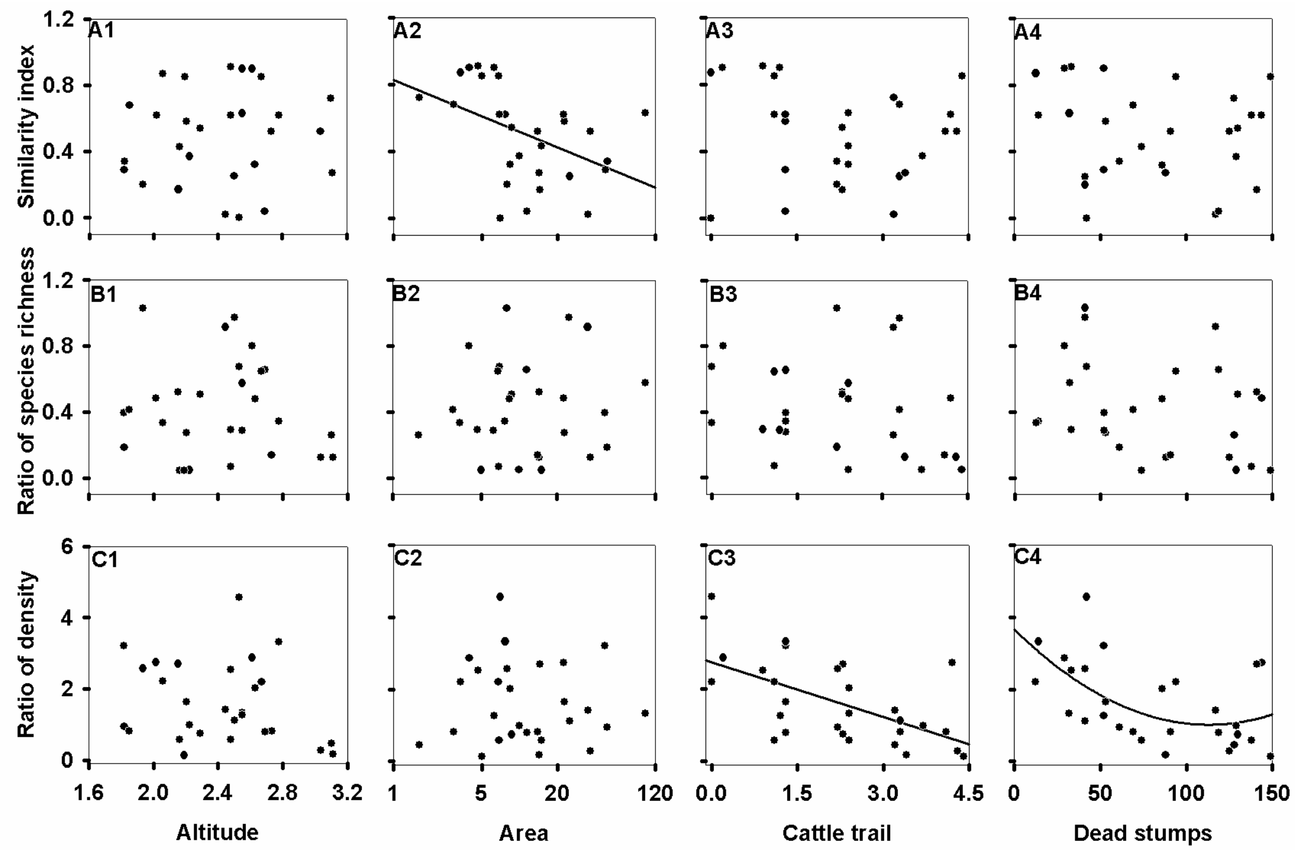

Figure 3. Species similarity (A1-4), ratio of understorey to overstorey rarefied species richness (B1-4) and ratio of understorey to overstorey density (C1-4) as a function of altitude, forest area, cattle interference and wood harvest. Forest area is given on a logarithmic scale.

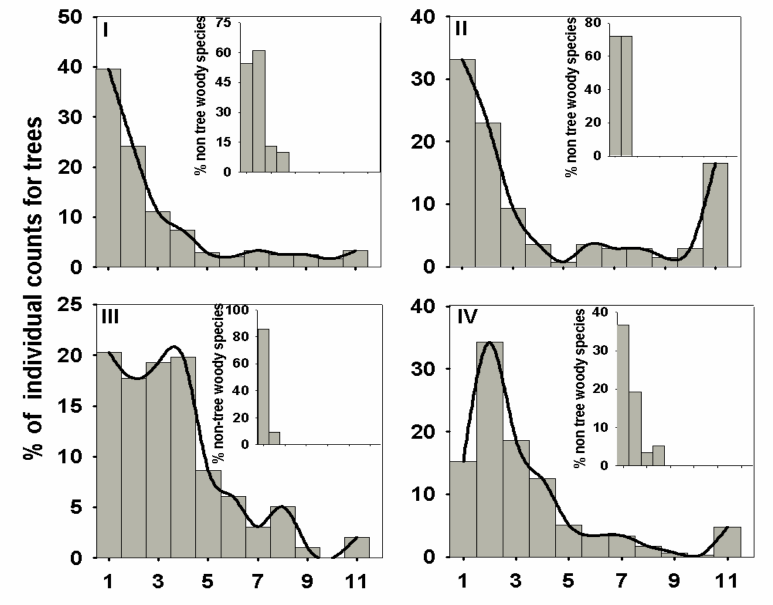

Figure 4. Size class distribution of trees (main figures) and contribution of non-tree woody plants in the first size class (inset figures) for the 28 forests, grouped into four major types. Diameter class for both main and inset figures 1: 0-5; 2: 5-10; 3: 10-15; 4: 15-20; 5 :20-25; 6: 25-30; 7: 30-35; 8: 35-40; 9: 40-45; 10: 45-50; 11:>50 cm dbh.

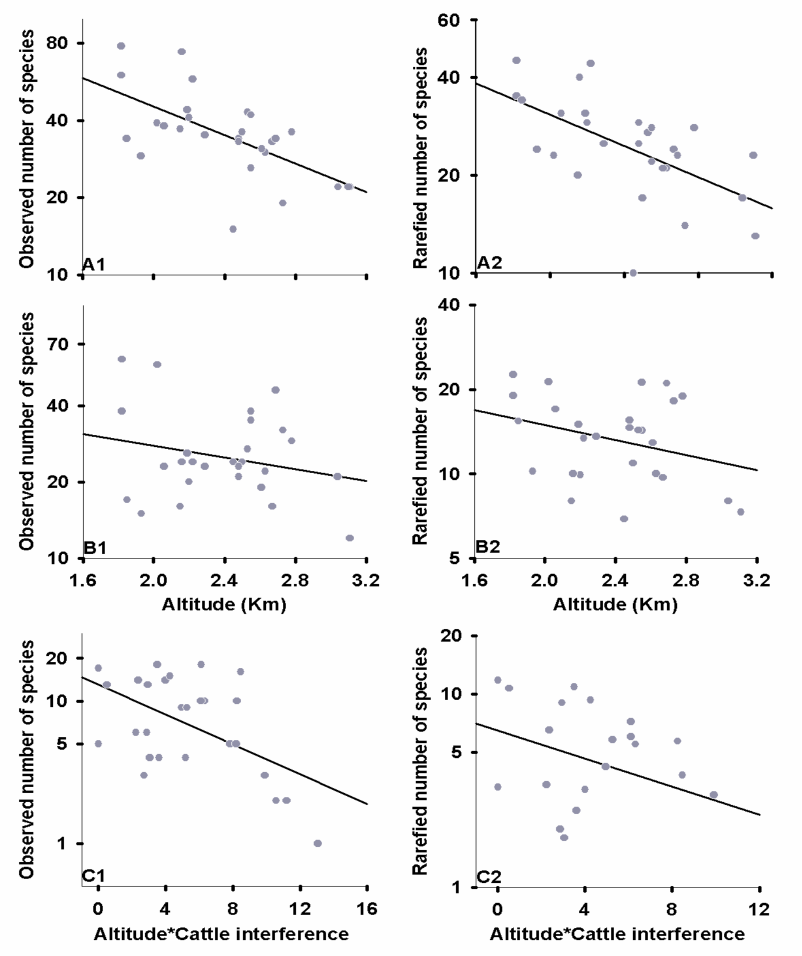

Figure 5. Observed and Cole-rarefied species numbers for 28 forests. Values for the entire forest (A1-2) and the overstorey only (B1-2) as a function of altitude. Values for the understorey (C1-2) as a function of interaction value between altitude and cattle interference. (Formulas and r^2 of the lines are presented in Table 4).

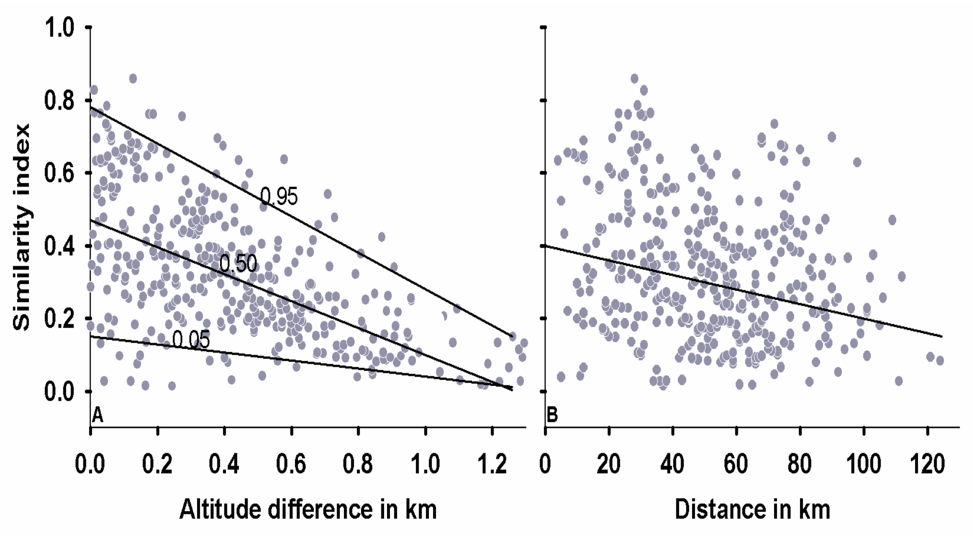

Figure 6. Similarity between forests as a function of (A) difference in altitude and (B) distance. The three lines in (A) show the 5th, 50th & 95th quantiles, the line in B shows the 50th quantile.

4. Conclusion

We conclude that altitude is the main factor determining species composition while human influence determines structural composition of these forests. Particularly, cattle's grazing strongly determines forest structure and species composition in the understory and is expected to have a strong longer-terms effect on whole forest structure and composition. Forest area has no significant effect on structural and species composition. This implies that although large size forests are a necessary element of successful conservation, small patches and appropriate matrix management could be useful complements.

Interconnecting these remnant forests by vegetation corridors following natural terrain or stream lines, creating buffer areas around them, excluding cattle interference, reducing intensity of wood harvest and developing more patches in the landscapes are possible landscape management activities. This will facilitate propagule and germplasm flow which may ultimately sustain these forests and help to restore the whole landscape.

5. References

Aerts, R., K. Van Overtveld, M. Haile, M. Hermy, J. Deckers and B. Muys, 2006a. Species composition and diversity of small Afromontane forest fragments in northern Ethiopia. Plant Ecology 187: 127-142.

Alemayehu Wassie, Demel Teketay and N. Powell, 2005a. Church forests in North Gondar Administrative Zone, northern Ethiopia. Forests, Trees and Livelihoods 15: 349-374.

Alemayehu Wassie, Demel Teketay and N. Powell, 2005b. Church forests provide clues to restoring ecosystems in the degraded highlands of Northern Ethiopia. Ecological Restoration 23: 2

Bingelli, P., Desalegn Desissa, J. Healey, M. Painton, J. Smith and Zewge Teklehaimanot, 2003. Conservation of Ethiopian Sacred Groves. European Tropical Forest Research Network. Newsletter 38: 37-38.

Demel Teketay, 1996. Seed ecology and regeneration in dry Afromontane forests of Ethiopia. Doctoral Thesis, Swedish University of Agricultural Sciences, Umea, Sweden.

Echeverria, C., D. Coomes, J. Salas, J.M. Rey-Benayas, A. Lara and A. Newton, 2006. Rapid deforestation and fragmentation of Chilean Temperate Forests. Biological Conservation 130: 481-494.

Fully-fledged papers related to the same topic

Alemayehu Wassie, F.J. Sterck, and F. Bongers. 2010. Species and structural composition of church forests in a fragmented landscape of Northern Ethiopia. Journal of Vegetation Science 21:938-948.

Alemayehu Wassie.2007. Ethiopian Church Forests: Opportunities and Challenges for Restoration. PhD Dissertatation, Wageningen University, The Netherlands.

Cropping Systems of the Uplands Surrounding Lake Tana

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Agroecology

Crop kinds and diversity are dictated by climate types. Due to high altitudinal variations in the country, climate variability in Ethiopia is very high. Thereby, the country possesses all kinds of climate and hence the country is suitable to all kinds of crops.

The uplands surrounding Lake Tana are found in the altitudinal ranges of 1750 m to 2000 m above sea level, but extend up to Semen, Guna and Choke mountains in the northeast, east and southeast of the lake with the altitude of >4600 m, >4100 m and >4000 m, respectively. Agro-climatically, hence, the uplands surrounding Lake Tana are grouped as intermediate highlands. Agro-ecologically, these areas fall in tepid moist highlands receiving rainfall annually about 1250mm largely in mono-modal pattern from May to October, while the peak occurs in July and August. This agro-climate and agro-ecology is suitable to many kinds of crops relatively with high growth and yield performances.

Here we consider the cropping system of Gedam Geregera farm village in which Wanzaye is located and which has approx. 3000 ha of rainfed cropland and around 600 ha of irrigated land.

Farming and cropping systems

As similar as that of most Ethiopian highlands, the farming system around Lake Tana is smallholder mixed farming both crops and livestock under the same management unit in less than one hectare of land holding size per household. In each community, indeed, there are pieces of communal grazing land, which are becoming very unproductive and subjected to serious land degradation due to over carrying capacity.

Fig. 1. Various types of livestock of a community kept in a communal grazing land

The land holdings are dominantly fragmented around the villages to minimize production risks such as hail and pests damages. Rainfed dry farming is so predominant, and crops production is largely carried out during the main rainy season starting in May. Recently, indeed, crops production with irrigation during dry season mainly for market sales has been expanded along rivers and streams. Land preparation is done traditionally with draught animals mainly oxen and other cultural practices are carried out manually.

Fig. 2. The common traditional land preparation method used around Lake Tana

Crops grown during the main cropping season with rainfall are so diverse and they are mainly produced for household consumption. Total areas of major crops, for instance, grown as sole in 2014/15 main cropping season in Gedam Geregera farm village, wherein Wanzaye is found, are presented in Fig. 3. Apart from these crops, there were some crops grown in the mixture of other crops, namely rape seed (*gomenzer*), safflower and sunflower.

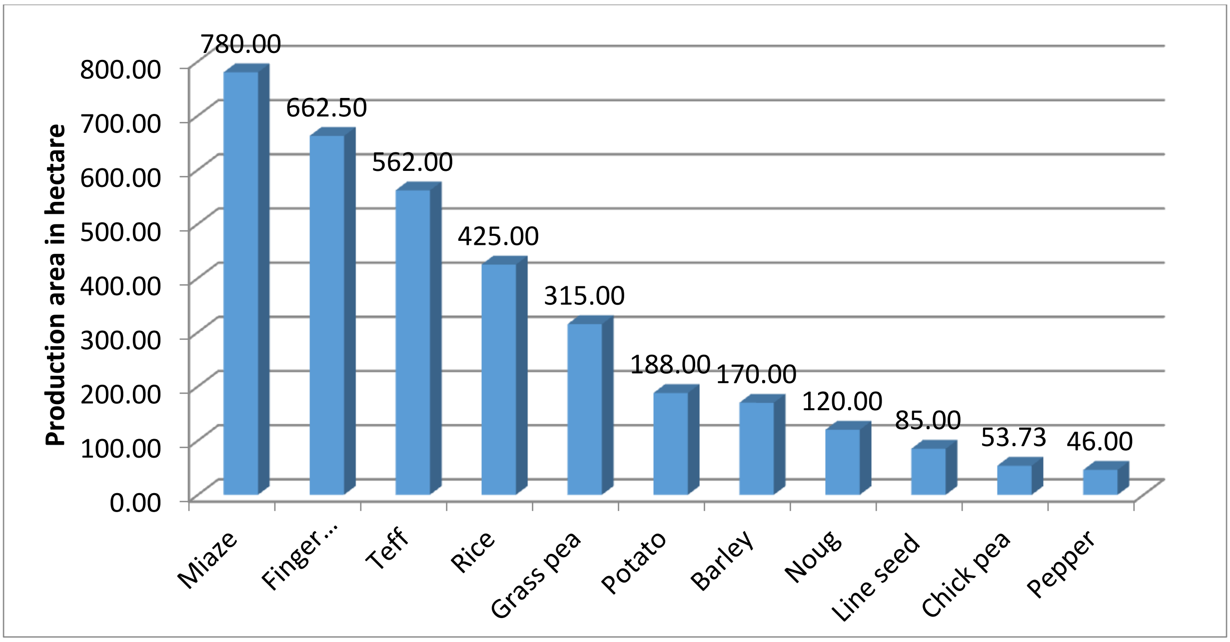

Fig. 3. Areas of main crops cultivated (ha) as sole cropping in the 2014/15 main rainfed cropping season in Gedam Geregera farm village

At the lower side of Gedam Geregera, there is a huge plain known as “Fogera Plain” which is largely flooded during the main rainy season. Earlier, except growing some water logging tolerant crops like teff and noug in very limited areas with very low productivity, the plain was left idle during the main rainy season. But, since 1985 a cold-tolerant rice variety known as locally “X-Gegina” has been introduced into the plain, expanded very widely and now become the major crop. Its productivity is more than five folds that of teff (Fig. 4). Unlike rice fields in other countries, farmers are able to maintain the soil structure of rice fields so as to use the fields for other crops in rotation without any difficulty as well as they are able to keep the fertility of rice fields through under sowing or rotation of chick pea or grass pea.

In this Fogera Plain, especially along rivers, crops production with irrigation during the dry season has recently been expanded widely. For instance, total areas of main crops cultivated with irrigation in 2014/15 cropping season in Gedam Geregera farm village are presented in Fig. 5.

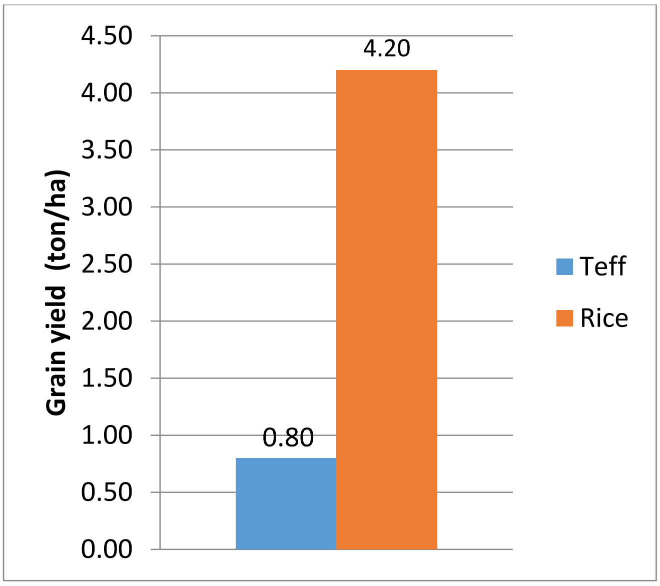

Fig. 4. Productivity of the indigenous crop teff and the newly introduced rice in Fogera Plain

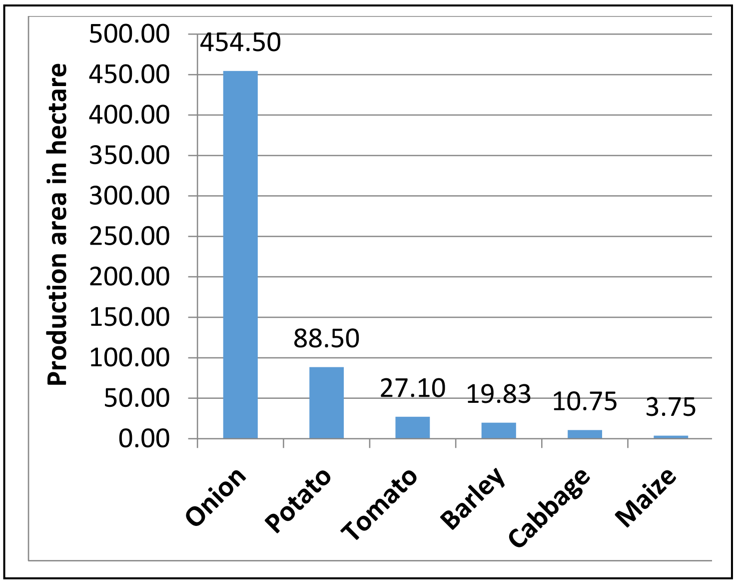

Fig. 5. Areas of crops grown for sale with irrigation in 2014/15 in Gedam Geregera farm village

Very recently, using the lake and its rivers/streams as sources of irrigation water, the drug plant khat (*Catha edulis* L.), whose young leaves with buds are chewed, has widely been expanding around Lake Tana. Besides, tropical fruit trees like mango, guava and avocado have recently been planted around Lake Tana and homesteads.

Major constraints of the cropping systems

Although there is a progressive increment in using soil fertilizers and improved seeds for selected crops, the use of improved farm inputs is still limited. Generally, the farming system is very exploitative and almost all crop residues are removed by free grazing and by man for animal feeds, house construction and/or firewood. Deforestation and vegetation removal is so high and crop fields remain barren and subjected to serious soil erosion. Even the solid wastes of domestic animals are collected, dried and used for personal fuel consumption and/or for market sale in the nearby cities/towns.

The traditional single-tine plowing implement “maresha” disturbs the soil always till the same depth of about 15 cm and creates a hardpan which limits further crops root penetration down as well as impedes water infiltration down and thereby increases surface runoff that aggravates soil erosion. Following the expansion of cities and towns around Lake Tana, plantation of eucalyptus trees used for constructions has been expanded aggressively even in crop fields. This eucalyptus plantation expansion has two impacts: first, it reduces crop production areas and secondly, it overexploits water resources severely as it is large water consumer.

Insect pests, mainly aphids, threaten chick pea and grass pea that are normally grown on residual moisture after the offset of the main rain. Similarly, these insect pests become a treat for most vegetables grown with irrigation. Damping-off disease has led to near-disappearance of pepper from the farmlands of the study area. Ball worm is also a serious insect pest for tomato and pepper.

Especially during the main cropping season, weeds infestation is another major bottleneck for most crop fields. Application of pesticides and herbicides to control these pests, on the one hand, is not affordable to farmers, and on the other hand, they are not healthy and environmentally friendly which kill beneficial organisms like bees as well as pollute water and the atmosphere.

Fig. 6. Removal of most of the straw and of the manure of freely roaming livestock leads to low soil nutrient contents. Tef straw (at left) is commonly incorporated in the earthen plaster used in traditional housebuilding, and cattle dung (right) is mixed with straw, dried and used as fuel.

Although production of vegetable crops during the dry season with irrigation is expanded well around Lake Tana, farmers do not benefit as they expected while the prices of vegetables during the peak harvest time are very low, 5-10% of that of the rainy season. On the other hand, farmers don't have facilities and means to store their fresh vegetable products.

High doses of nitrogen fertilizers are used for commercial crops grown with irrigation. These nitrogen fertilizers would be leached down and pollute the lake, rivers/streams and ground water. Since the income obtained from khat is attractive, growers apply pesticides and growth promoting hormones frequently to khat plants. On top of polluting the lake, rivers/streams and ground water, these pesticides and hormones applied to khat plants have resulted in human health breakdowns and exacerbate cancer disease occurrence which was not a serious problem earlier before expansion of khat production and consumption around Lake Tana.

Conclusions

The contrasts of the constraints of the cropping systems would be their respective solutions. Judicious utilization of improved farm inputs is necessary with due consideration of biodiversity, environment, soil, water and human health. Application of commercial inorganic fertilizers doesn't substitute the importance of organic fertilizers including crops residues, composts and farmyard manures. By any means, the use of green manures must be started and expanded, while composts and farmyard manures can't be used for wider areas. Most crop fields necessitate chisel plow to break the hardpan that is created by traditional plowing implement "maresha". There is a need to substitute eucalyptus with fast growing and environmentally friendly trees. Means of preserving vegetable products is badly needed to prolong the shelf life of vegetables so as to protect farmers from very low market prices of vegetables. Khat (*Catha edulis*) plantation and consumption must be banned legally as other heavy drugs, while it kills the productivity of the working forces especially youths.

Rainfall distribution over Lake Tana basin

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Introduction

The rainfall pattern in Ethiopia is dominantly controlled by the migrating inter-tropical convergence zone (ITCZ), making it highly seasonal (Hulme, 1996). Moreover, the spatial and temporal patterns of rainfall in Ethiopian highlands are affected by orographic and convective factors (Korecha and Barnston, 2006). This paper gives an assessment of rainfall distribution over Lake Tana basin.

Methodology

(1) Rainfall data of available stations within and around the basin

The National Meteorological Agency of Ethiopia (NMA) is the major source of meteorological data in the country. There are more than thirty meteorological observation stations in the Lake Tana basin (Fig.1). The stations at Bahir Dar, Adet, Dangila, Debretabor, Gondar and Aykel are the principal meteorological stations, meaning several climatological variables such as rainfall, maximum and minimum temperatures, sunshine hour, relative humidity, wind speed at 2 m and 10 m heights and pitch evaporation are measured. The other stations measure only a few variables, e.g. only minimum and maximum air temperatures of the day and total rainfall amount in 24 hours or only total daily rainfall. Few of the stations like Bahir Dar and Gondar are equipped with floating-type recording gauges for rainfall measurements at shorter time scales, while most of the stations use manual rain gauges for rainfall recording.

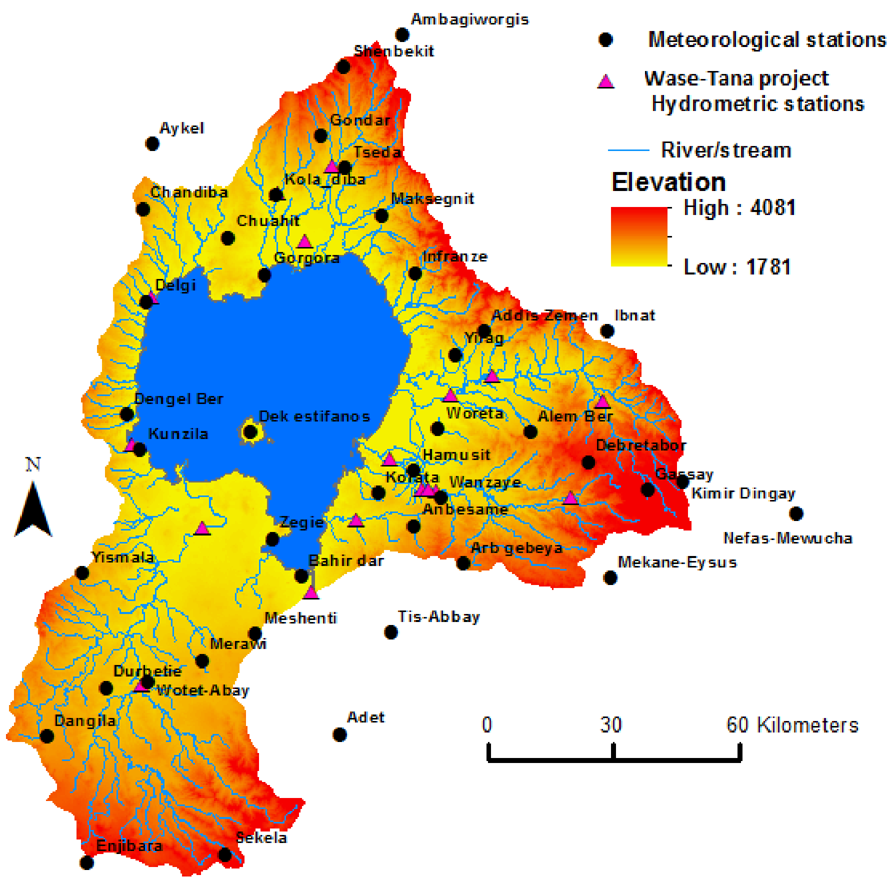

Figure 1. Meteorological and hydrometric stations within and nearby the Lake Tana basin (Hydrometric stations shown here were established by the Wase-Tana Project)

(2) Wase-Tana Project rainfall measuring stations

The Wase-Tana Project has installed two e+ RAIN loggers and manually recorded rain gauges (Fig. 2) at two nearby watersheds in the Gumara catchment since end of August, 2013. The automatic rainfall loggers operate on the tipping bucket principle and they are connected to a digital data logger.

(3) Delaunay triangulation method of interpolation

The rainfall distribution map (Fig. 4) was obtained by building triangular irregular networks (TIN) and the method of Delaunay triangulation method of interpolation. The triangulate procedure constructs a Delaunay triangulation of a planar set of points. Delaunay triangulations are very useful for the interpolation, analysis, and visual display of irregularly-gridded data.

Figure 2. Typical manually recording rain gauge and e+ RAIN logger installation in Wanzaye area

Results and discussion

1. **Rainfall distribution in the basin**

The recent two years (2012 and 2013) rainfall data of available stations within and around the basin show that the rainfall distribution is highly variable in the basin (Fig. 4). The mean annual rainfall of the Lake Tana basin was estimated as 1345 mm. Generally, the upper southern part of the Lake Tana basin (upper part of Gilgel Abay catchment) receives high amount of rainfall (can reach 2400 mm in a year). On the contrary, the northern portion in the vicinity of the lake gets the minimum amount of rainfall (as low as 910 mm/year). Like other parts of Ethiopia, rainfall is highly seasonal in the basin and more than 70% of the annual rainfall occurs in the rainy season (*Kiremt*).

In Ethiopia, higher elevations receive more rainfall than low arid areas. The 2012 annual rainfall amounts and corresponding elevation of the 32 stations in the Lake Tana basin were investigated for any relationship between them. However, the correlation of annual rainfall with topography for the basin was poor, as shown by the scatter plot (Fig. 3).

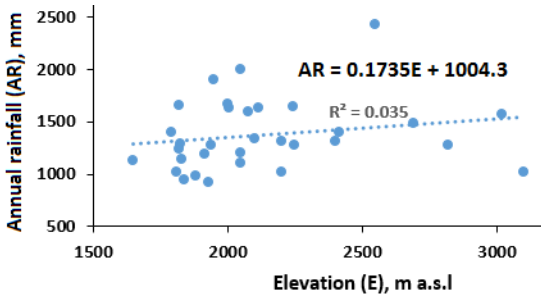

Figure 3. Plot of the 2012 annual rainfall and elevation of the 32 rainfall stations in and around the Lake Tana basin

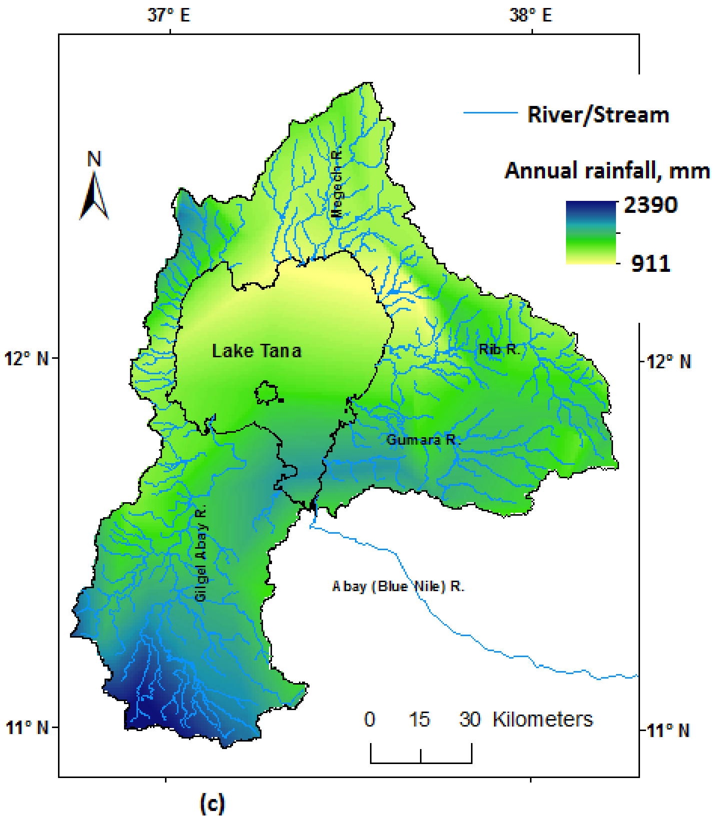

Figure 4. Mean annual rainfall over Lake Tana basin (based on 2012 and 2013 years data), derived from the point input rainfall data of 33 stations in the basin

2. Rainfall intensities

Based on the e+ RAIN logger data from August 30, 2013 to June 23, 2015 at Gedam site in Wanzaye area, the mean rainfall intensity was 4 mm/hr. As it can be seen from Fig. 5, rainfall intensities as high as 32 mm/hr have also been recorded.

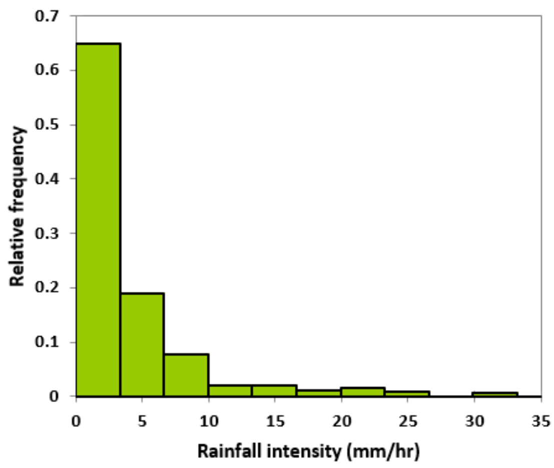

Figure 5. Histogram of rainfall intensity at Gedam Site in Wanzaye area

Conclusion

Like most parts of Ethiopia, the rainfall distribution in the Lake Tana basin is characterized by its spatial and temporal variability. The correlation of annual rainfall with topography for the basin was poor.

References

Hulme, M., 1996. Climate change within the period of meteorological records. In Adams, W.M., Goudie, A.S., Orme, A.R. (Eds.). The Physical Geography of Africa, pp. 88-102. Oxford: Oxford University Press.

Korecha, D., Barnston, A.G., 2006. Predictability of June-September rainfall in Ethiopia. Monthly Weather Review 135: 628-650.

Effects of land drainage ("*feses*") and physical soil and water conservation on gully and rill erosion in Lake Tana basin

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1. Hydrogeomorphic impacts of land drainage

The establishment of drainage ditches aims at draining the excess of water from the farmland, particularly in areas where soils are saturated in the rainy season. The use of drainage ditches has an impact on the farmland itself and on the downstream area. Although drainage has a wide range of benefits for the farmer's land, the establishment of drainage ditches is increasingly recognized as a major factor of off-site environmental impact, as it increases sediment load, peak runoff rate and thus increasing flooding problems downstream as well as a possible sources of conflict between neighboring farmers. On-site problems such as the development of the drainage ditches into (ephemeral) gullies are less documented, although they may be important. The environmental impacts of land surface drainage cannot be simply and clearly stated (Figure 1) and researchers are still divided about the balance of their positive and negative effects.

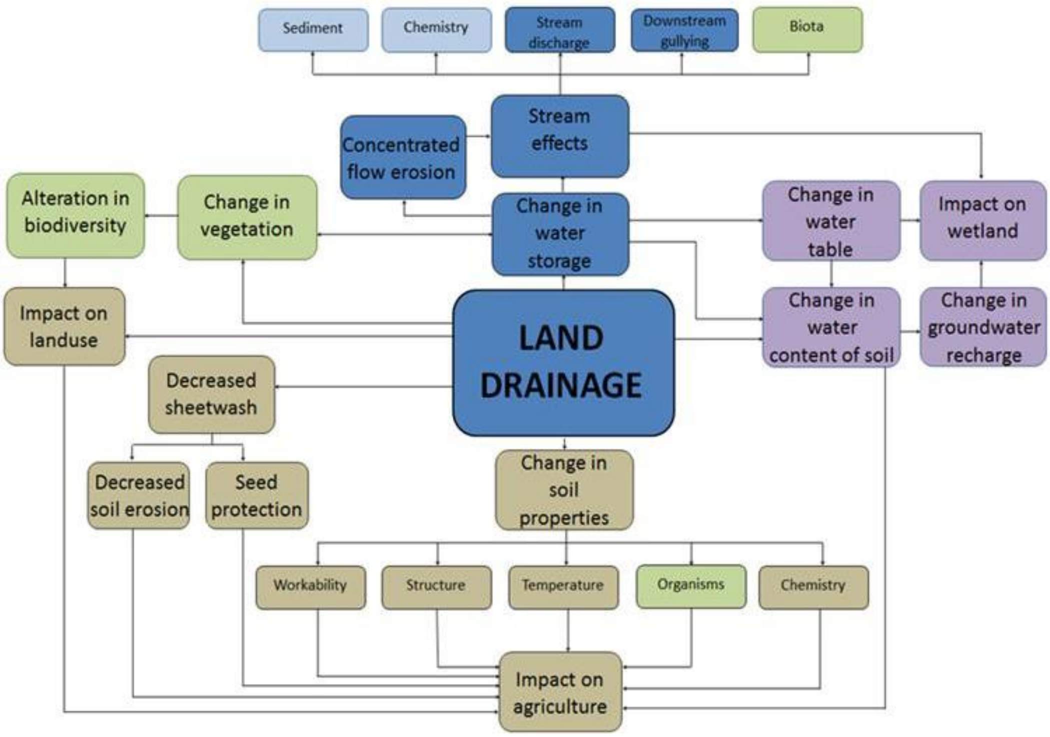

Figure 1. Environmental changes induced by drainage ditch construction: in brown color changes linked to agriculture, in green to vegetation and biodiversity, in purple to groundwater, and in blue to surface water. Changes addressed in this study are in dark blue (modified from Spaling & Smit, 1995).

2. Land surface drainage (*feses*): measuring their on-site and off-site effects

A case study area was chosen around Wanzaye (Figure 2), North Ethiopia, for its particular condition where three types of land management practices are used side by side on cropland: (i) the catchment-wide use of stone bunds on the contour, (ii) the use of slightly sloping drainage ditches (*feses*) prepared by ox-plough, and (iii) the combined use of stone bunds and *feses* (Figure 3). *Feses* in the study area are found to be constructed with an average top width of 27 cm (±9 cm; n = 41), and a drainage density ranging from 53 to 510 m ha^{-1} (n=19). Based on intensive measurements in 10 catchments around Wanzaye during the rainy season of 2013, a correlation table for stone bund density; *feses* density; fraction of cultivated barley, millet and tef; surface stoniness; soil depth; bulk density; catchment slope gradient; angle between established *feses* and the contour; *feses* gradient; and total rill volume per area has been established (Table 1).

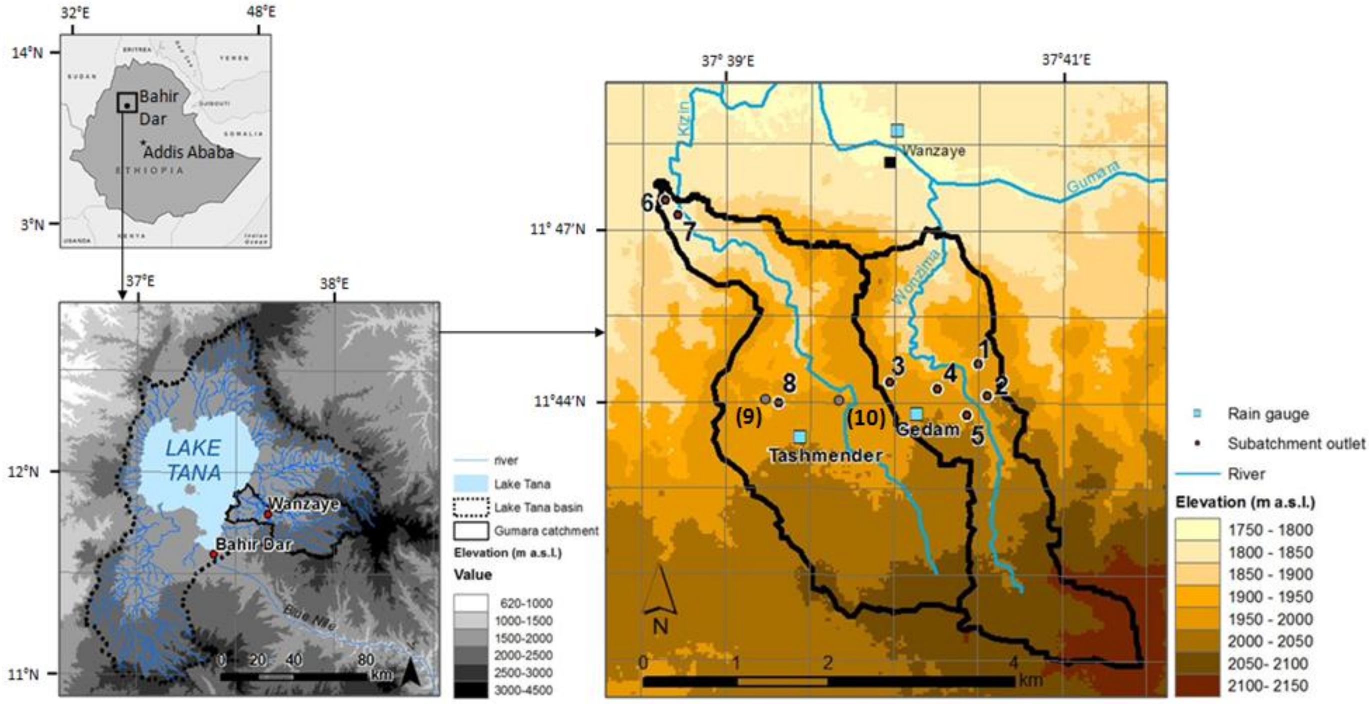

Figure 2. Location of the ten subcatchments and rain gauges. Two outlier catchments (in brackets) are marked by a grey dot.

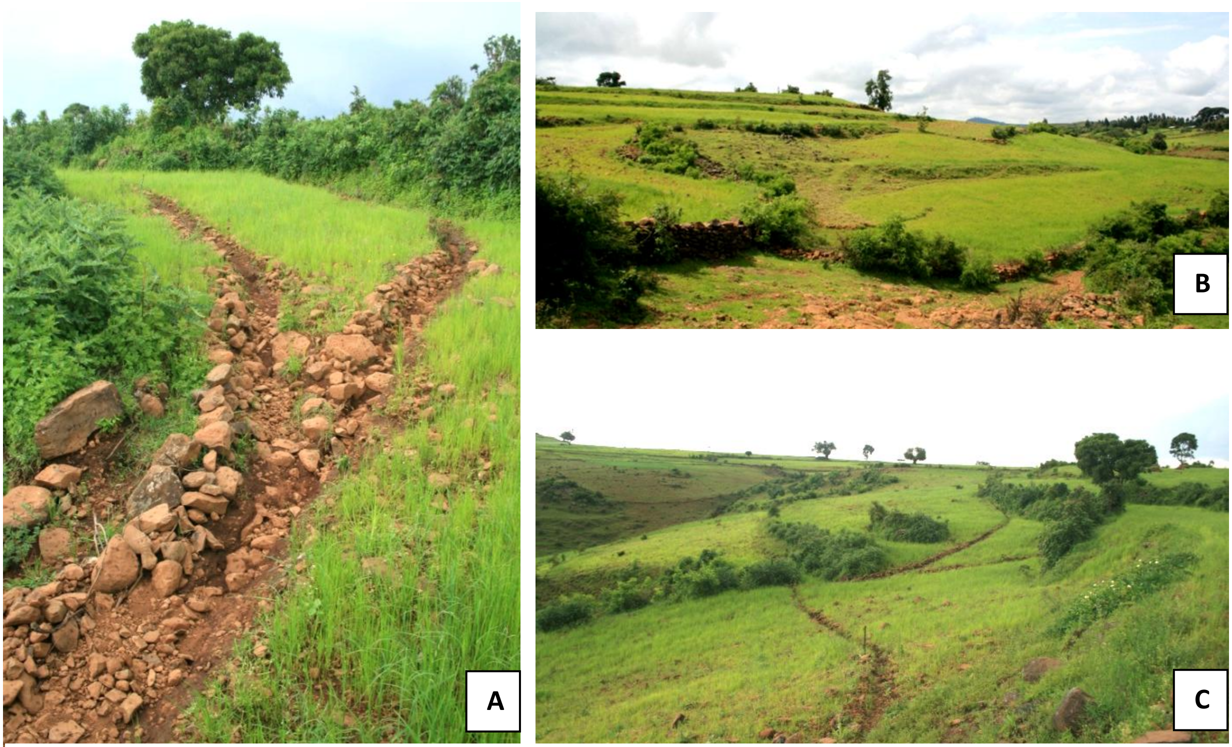

Figure 3. A, C: Use of drainage ditches in catchment 1. B: The exclusive use of stone bunds in catchment 2 (numbers of catchments referring to Figure 2).

3. Runoff response and on-site erosion

Stone bunds are a good soil and water conservation tool, making the area more resistant against on-site erosion, and allow that *feses* can be established at a greater angle with the contour line. The use of *feses* cause higher rill volumes, although *feses* are perceived as the best way to avoid soil erosion when no stone bunds are present. The mean volume of rill erosion per ha for the ten study catchments during the rainy season of 2013 was 3.73±4.20 m^3 ha^{-1} and the mean corresponding soil loss was 5.72±6.30 ton ha^{-1}. Catchments 1-8 (Figure 2) have been used for runoff analyses (Figure 4). To calculate runoff discharge at the catchment outlet, two main measurements are performed: routine flow depth measurements and rating curve establishment. A data collector for each catchment has been trained to conduct routine flow depth measurements, i.e., recording for every daytime rainfall event runoff depth at the outlet channel with an interval of five minutes. Routine flow depths were converted to continuous runoff discharge series by a rating curve and the use of the Manning formula.

Table 1. Correlation (R) matrix between: stone bund density (SBD); feses density (FD); fraction of cultivated barley, millet and tef; surface stoniness (stone); soil depth (s_depth); bulk density (BD); catchment slope gradient (c_gradient); angle between established feses and the contour (f_contour); feses gradient (f_gradient); and total rill volume per area (TRA). Significant correlations for α = 0.05 are marked by an asterisk. All correlations are based on ten observations.

	SBD	FD	barley	millet	tef	stone	s_depth	BD	c_gradient	f_contour	f_gradient
TRA	-.50	.59	.66*	-.59	.06	.26	-.46	-.25	.54	-.53	-.27
SBD		-.72*	-.46	-.05	.37	.21	-.05	.15	-.17	.75*	.28
FD			.53	-.25	-.26	.15	-.40	-.13	.37	-.67*	-.04
barley				-.35	-.46	.31	-.29	-.27	.65*	-.17	-.13
millet					-.64*	-.26	.32	-.39	-.66*	-.05	-.42
tef						-.17	.08	.64*	.01	.17	.35
stone							-.79*	-.50	.68*	.03	.34
s_depth								.52	-.64*	.10	-.30
BD									-.19	.51	.30
c_gradient										-.12	.55
f_contour											.30

*Significant at α = 0.05

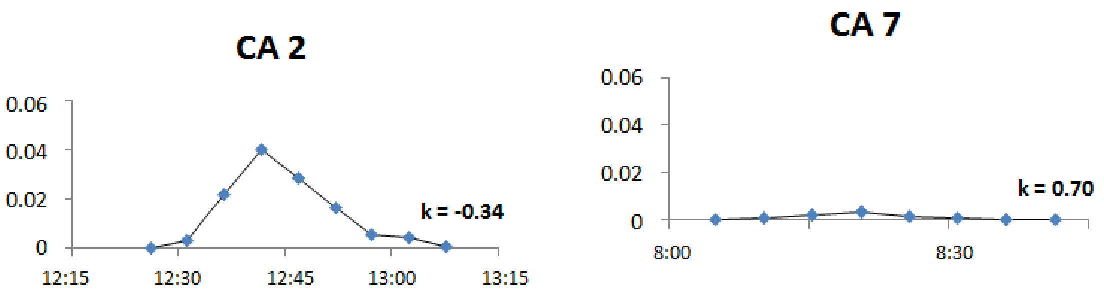

Figure 4. Hydrographs for runoff events measured at the outlets of CA 2 and CA 7 on August 7 around Wanzaye (Ethiopia). Values for the kurtosis (k) of the hydrograph is shown.

The use of *feses* induces higher event-based runoff coefficients (RC). Event-based runoff coefficients over all study areas ranged from 5% to 39%. Also, a combination of low stone bund density and high *feses* density results in a higher RC, whereas catchments with a high stone bund density and low *feses* density have a lower RC. To understand the impact of *feses* and stone bunds on the erosion processes, a relation for hydrograph peakedness has been sought (Table 2). There is lower hydrograph peakedness for a higher stone bund density and a higher hydrograph peakedness for a higher *feses* density.

Table 2. Correlation (R) matrix for: stone bund (SBD) density, feses density (FD), kurtosis, velocity of rise time (VRT), Qp over base time, and the normalized peak discharge ($Q_p A^{-1}$). Significant correlations for α = 0.05 are marked by an asterisk. All correlations are based on seven observations.

	SBD	**FD**	**kurtosis**
Q_p A^{-1}	-0,47	0,26	,76*
SBD		-0,61	-0,67
FD			0,52

4. Threshold coefficients for different land managements (off-site effect)

The impact of different land management practices on gully head development in cropland is studied in 75 catchments around Wanzaye, based on a standardized procedure for topographical threshold analysis: $s > kA^{-b}$ (Eq. 1), where *s* represents the slope gradient of the soil surface, *A* the drainage area at the gully head, b an exponent and k a coefficient reflecting the resistance of the land to gully head development. The lowest k-values (0.078–0.090) are found for catchments treated with *feses*, the highest k-values (0.198–0.205) are observed for stone bund catchments, and medium k-values (0.092–0.099) are found for mixed catchments (Figure 5). This finding implies that catchments with the exclusive use of drainage ditches are the most vulnerable to gully head development compared with mixed catchments and stone bund catchments. However, on-site sheet and rill erosion rates are reduced by *feses* as they lower the gradient of the overland flow lines (Figure 6). Three trends in cropland management around Wanzaye and the wider region are observed: (i) *feses* are exclusively made on rather steep slopes where small drainage areas lead to the rapid development of gully heads; (ii) stone bunds are constructed on both steeper and gentle sloping cropland; and (iii) larger and gently sloping catchments seem to be most suitable for the combined use of drainage ditches and stone bunds.

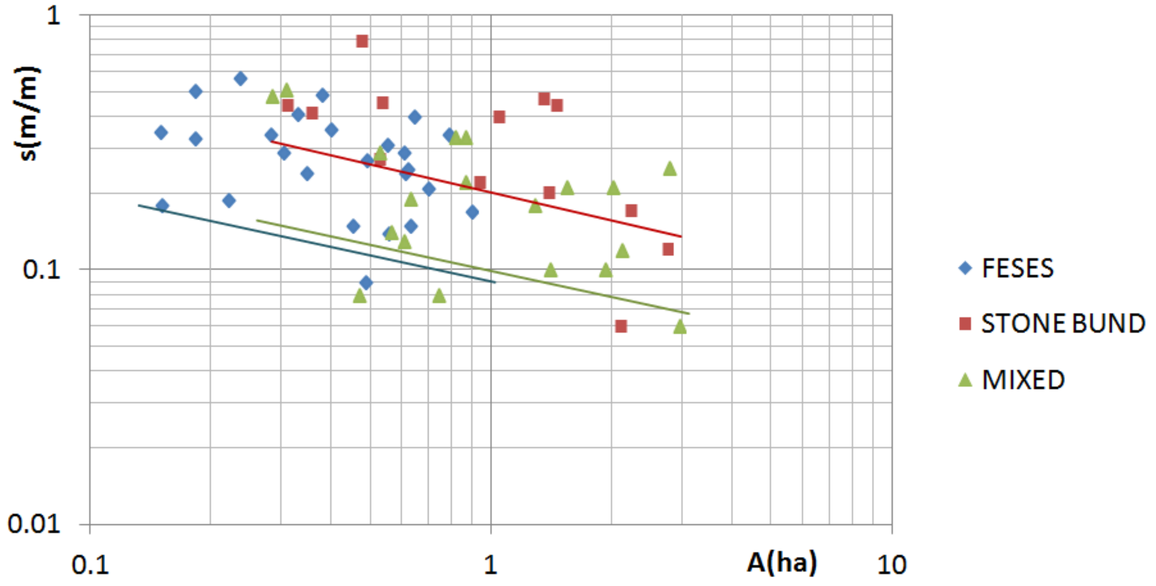

Fig. 5. Topographic threshold lines based on slope gradient s and drainage area A for gully head development under three cropland management practices: i.e.; stone bunds (squares), drainage ditches or feses (diamonds) and their mixture (triangles). Exponent b of Eq. (1) is set constant at 0.38.

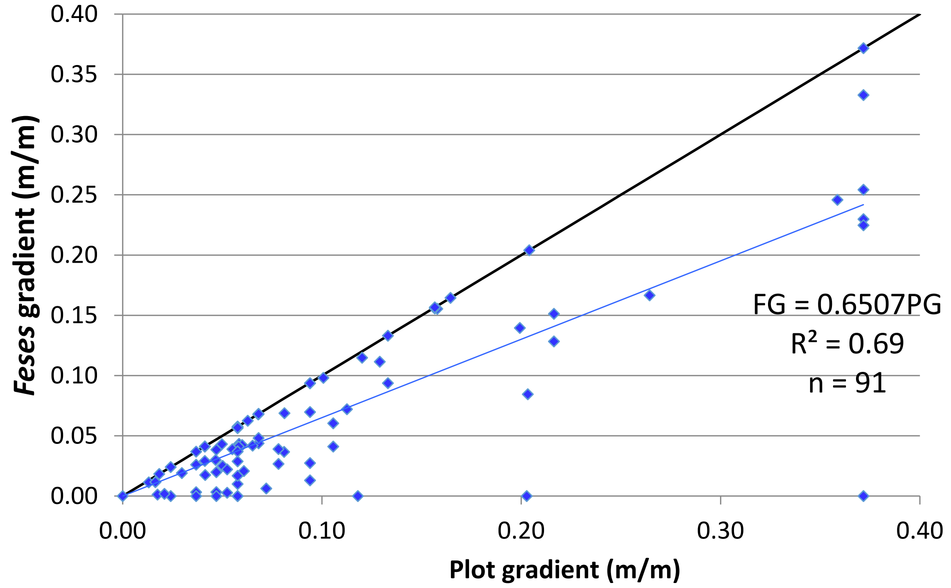

Fig. 6. Relation between plot gradient (PG) and feses' gradient (FG) for 91 feses in the study area (August 2013). 1:1 line is also shown.

5. Conclusions

We found that the establishment of *feses* is the result of a difficult balance that the farmers make between the *feses*' erosive characteristics and its soil protecting characteristics. Stone bunds are a good soil and water conservation tool, which makes the area tolerable for *feses* established at a greater angle with the contour.

We have illustrated the practical use of topographic thresholds for gully head development to study the effect of various cropland management practices on vulnerability to gullying. Values for the coefficient k in the topographical threshold equation can help soil conservationists to identify which management practices reduce vulnerability to gully erosion. *Feses* catchments are found to be most vulnerable to gully head development compared to the stone bund and mixed catchments. Yet, on-site sheet and rill erosion are reduced by the use of *feses* as they reduce the runoff gradient. The use of *feses*, however, induces a range of other effects on the productivity of cropland, which needs further research.

Feses cause greater rill volumes than stone bunds, although *feses* are perceived as the best way to avoid soil erosion when no stone bunds are present.Peak discharge decreases when stone bund density increases, whereas the contrary is found for *feses* density.

References

Monsieurs, E., Dessie, M., Adgo, E., Poesen, J., Deckers, J., Verhoest, N., Nyssen, J. 2015. Seasonal surface drainage of sloping farmland and its hydrogeomorphic impacts. Land Degrad. Dev. (26) 35-44. DOI: 10.1002/ldr.2286.

Monsieurs, E., Poesen, J., Dessie, M., Adgo, E., Verhoest, N., Deckers, J., Nyssen, J. 2015. Effects of drainage ditches and stone bunds on topographical thresholds for gully head development in North Ethiopia. Geomorphology.234, 193-203.

Monsieurs, E., Dessie, M., Verhoest, N., Poesen, J., Adgo, E., Deckers, J., Nyssen, J. To what extent does the drainage of hilly lands in humid Ethiopia affect runoff response and on-site erosion? In process.

Torri, D., Poesen, J., 2014. A review of topographic threshold conditions for gully head development in different environments

Effects of irrigation on groundwater behavior

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Introduction

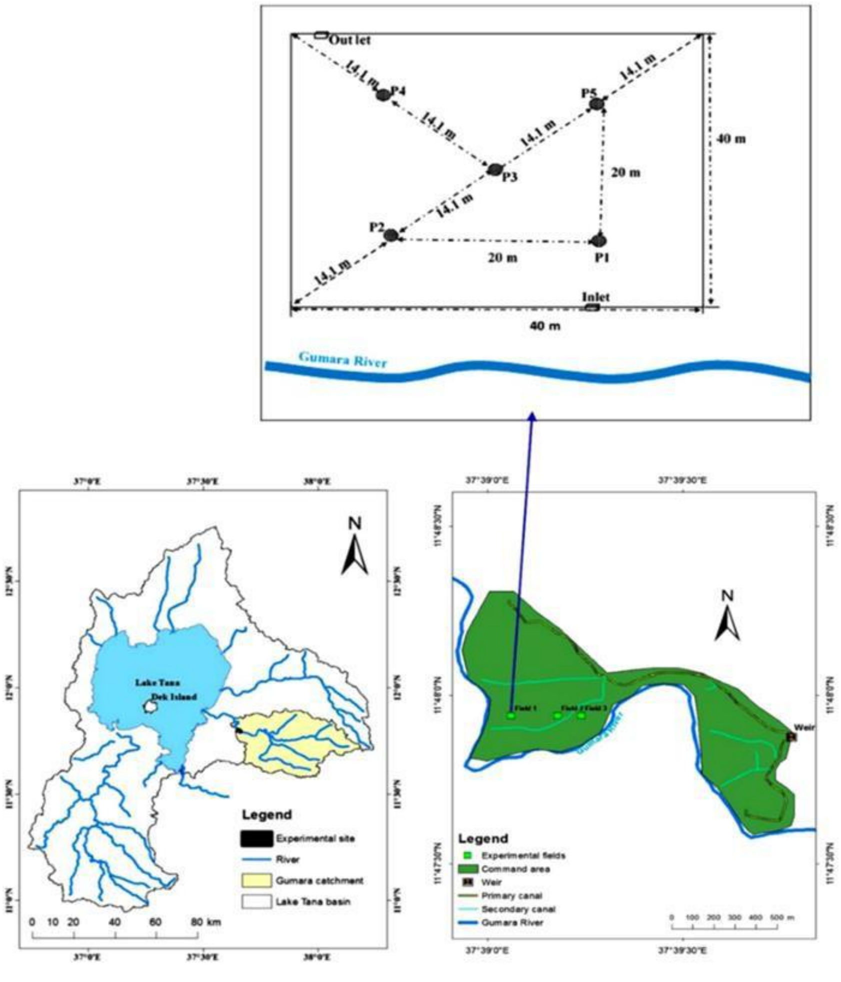

Fig 1. Location map of the study area (Source: modified from MoWR) and experimental field

Irrigation affects the hydrological processes by influencing mainly infiltration and evapotranspiration, which in turn affect the surface water - groundwater interactions. Infiltrated irrigation water percolates to the deeper soil layers and replenishes groundwater. If the source of irrigation water is not from groundwater pumping, deep percolation rises the groundwater level of a given area. On the other hand, the crop roots tap water from the capillary fringe when the plant available water from the top soil declines. At high temperature conditions, surface evaporation is high and thus the evapotranspiration rises. Direct evapotranspiration of groundwater also occurs in areas with shallow water tables (Healy, 2010) .This taping of the water table causes the water table to fall and hence these hydrological processes (deep percolation and evapotranspiration) cause the groundwater to fluctuate. Field experimentation and measurements were used to study the shallow groundwater response to irrigation. Three experimental fields (each approx. 40 m x 40 m) were selected to consider soil and groundwater gradient variations and the crop grown was onion.

Methodology

The following major activities were conducted during field extermination:-

1. Piezometer installation (Sundaram et al., 2009) and groundwater level measurement for recharge determination and to analyze the behaviour of the groundwater following irrigation. Recharge was determined using water table fluctuation method (WTFM) (Healy, 2010; Healy & Cook, 2002).

$$Re = S_y \, x \Delta h \qquad (1)$$

Where, Re is recharge (mm), $S_y$is the soil specific yield (-), Δh is the change in water table height (mm). The S_y was determined based on Johnson (1967) textural triangle and alternatively based on porosity specific retention relationships. Recharge highly depends on the value of S_y.

2. Field water - application was measured by designing and constructing a triangular thin plate wooden V-notch weir according to Shen (1981) and Greve (1932) to estimate the effect of irrigation amount and to quantify the ratio of recharge to irrigation amount. Irrigation application efficiency was also determined.

$$Ea = \frac{Dr}{Df} x100 \qquad (2)$$

Where, *Ea* is field-application efficiency (%), D_r is depth of water added to the root zone and D_f is depth of water applied to the field (mm).

Fig.2. Piezometer measurement

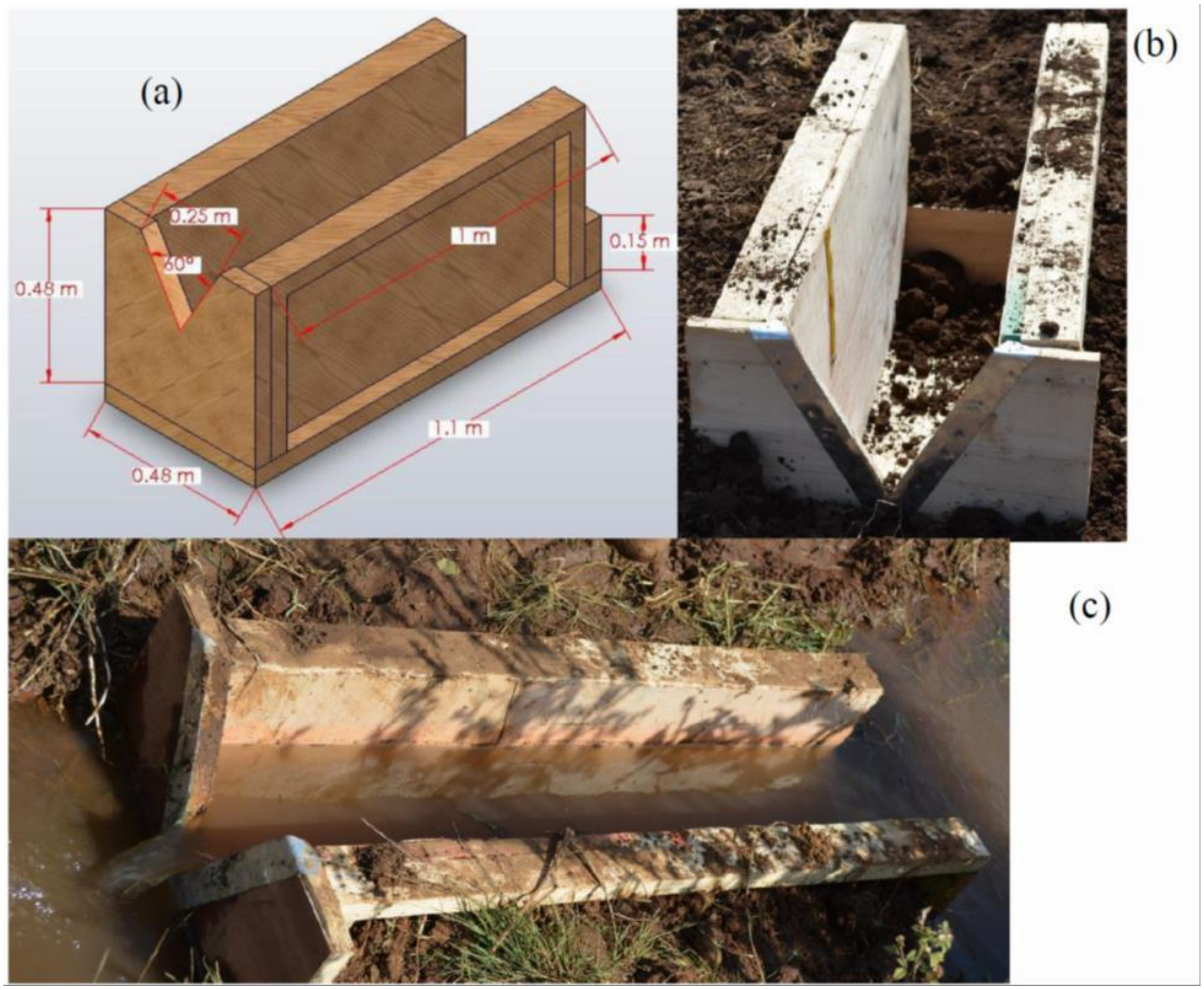

Fig.3. V-notch, thin-plate weir for farm water measurement (a) design, (b) installed and (c) measuring water flow through the V-notch

3. To examine the contribution of groundwater lateral flow to the recharge estimation, groundwater flow direction was determined by developing water table contour map by Inverse Distance Weighting (IDW) interpolation method using Arc GIS 10.1. The ground water flow velocity was determined using Darcy's law.

$$v = -k_s \frac{\Delta h}{\Delta l} \qquad (3)$$

Where, v is velocity of flow (m day^{-1}), Δh is the head gradient in the direction of groundwater flow (-) and Δl is the saturated hydraulic conductivity (m day^{-1}).

4. Analysis of meteorology data in relation to recharge and calculation of ET_o according to Allen et al.(1998) was also done.

Results and discussion

Water Level Response and Groundwater Recharge

The highest water level rise (0.56 m) was observed in field 3 on 9 Dec, 2014 and 15 March,2015. The second highest water level rise (0.46 m) was observed on 10 Apr, 2015 in field 2.

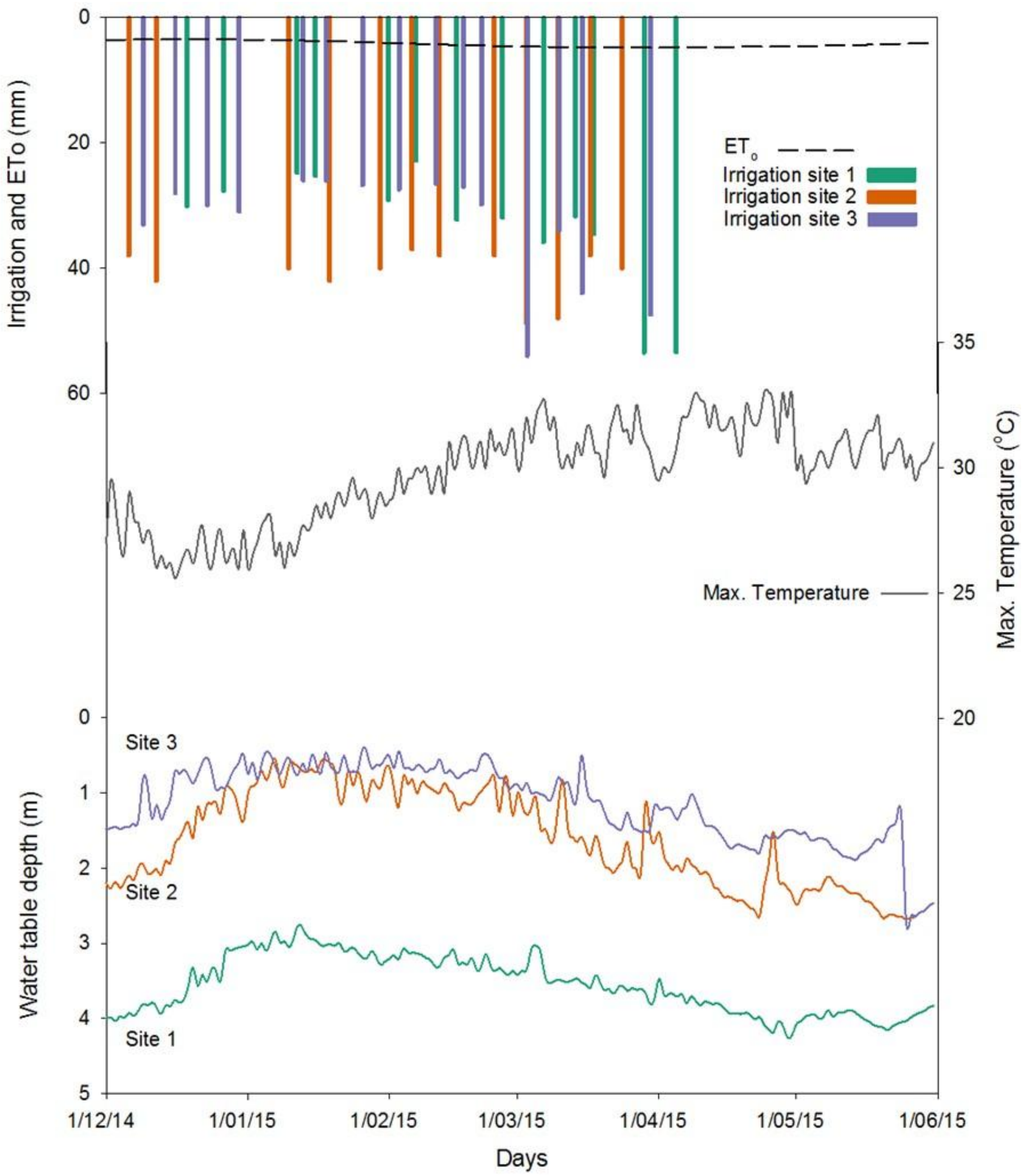

Fig. 4. Water table response, irrigation amount, temperature and reference crop evapotranspiration

The seasonal groundwater recharge for field 1, field 2 and field 3, using the specific values based on Johnson (1967) was 54 mm, 55 mm and 65 mm for irrigation applications of 432 mm, 490 mm and 467 mm respectively. Since recharge is highly dependent on the value of the specific yield used for determination, this recharge estimation could increase by 20 to 70 % if we were applying the value of the specific yield according to porosity and specific retention. Generally, higher groundwater recharge was observed in fields 3 than field 1 and 2. This is because the soil is shallow (2 m) in this filed than field 1 (4 m) and field 2 (3 m) so that most of the infiltrated water might reach the water table faster than deeper soils.

Table 1. The specific yield, saturated hydraulic conductivities and groundwater velocities of the experimental fields

	Field 1	Field 2	Field 3
based on Johnson 1967	0.027	0.015	0.017
	0.031	0.039	0.062
	0.875	0.626	0.71
Av. groundwater gradient (-)	0.014		
	From Field 3 to Field 2		From field 2 to field 1
Groundwater velocity (m day^{-1})	0.009		0.01
Real velocity of flow (m day^{-1})	0.018		0.022

Field irrigation application efficiency

The field application efficiency varies from 20 % to 80% and the average values (%) for fields 1,2 and 3 are 51 (±0.17), 46 (±0.12) and 48 (±0.17) respectively. Losses from field occur as deep percolation below the root zone and runoff (Walker, 2003). The applied irrigation water is either deep percolated to the groundwater or stored in the root zone for plants use because there was no any run off observed throughout the season. Since the ratio of water stored in the root zone to applied water (referred to as field application efficiency) is low, this implies that the amount of deep percolation is higher.

Groundwater lateral flow velocity and direction

The groundwater flows from field 3 to field 1 through field 2 (Fig. 5). The velocity of groundwater flow is very low (0.02 m day^{-1}) due to the low groundwater gradient and hydraulic conductivity (Table 1). According to this velocity, a water molecule needs more than 1.5 years to travel as groundwater from one field to the next. This shows the contribution of lateral groundwater flow to our estimation of irrigation event based recharge is negligible.

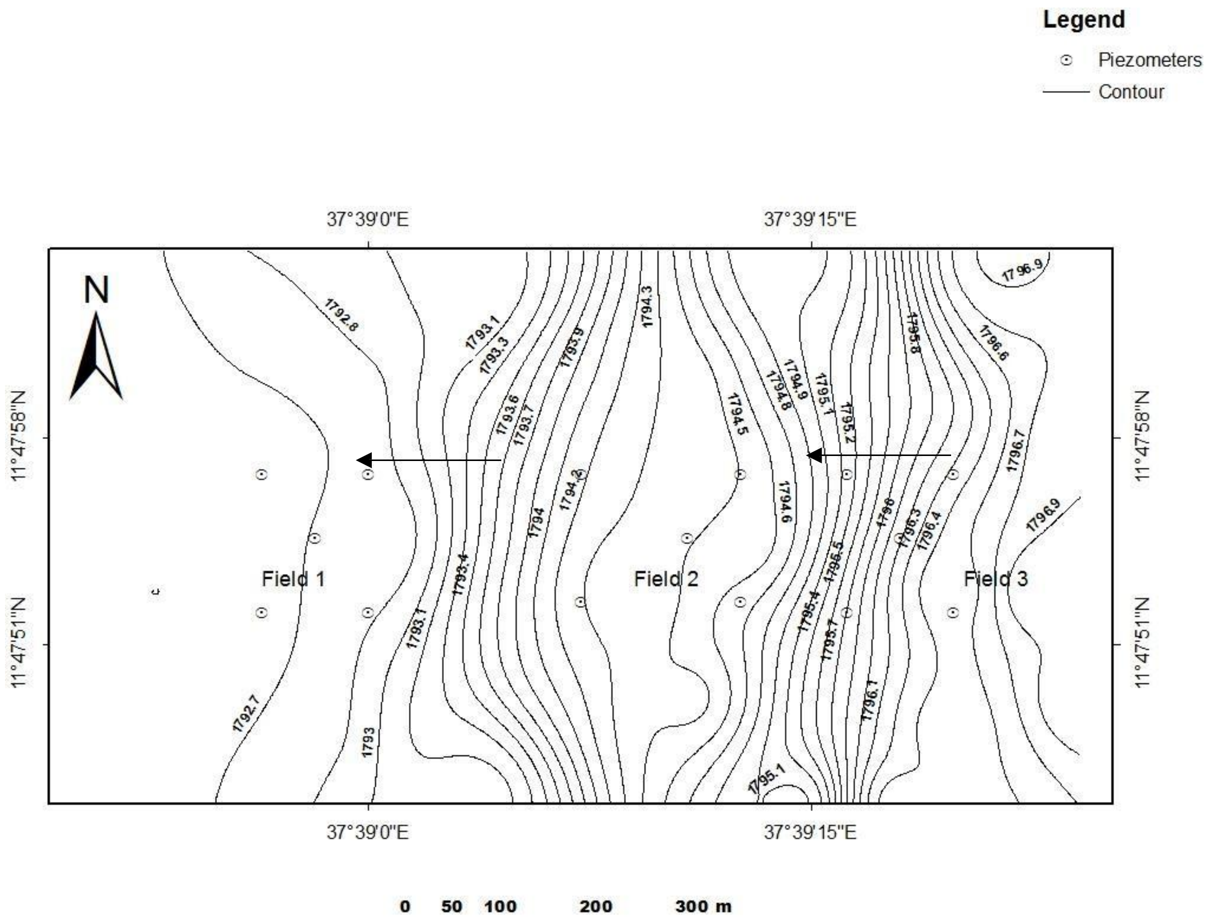

Fig 5. Average water table contour map of the experimental site showing groundwater flow direction

CONCLUSIONS

From this experimental study it has been seen that irrigation can be a significant source of groundwater. Generally, we have observed that the groundwater response from deep percolation of irrigated water was influenced by irrigation amount, soil depth, and seasonal climate variations and crop growth stages. We have also observed that, the amount of recharge estimation using WTFM highly depends on the specific yield value. This research result reveals that the contribution of groundwater lateral flow from the adjacent irrigated fields is negligible for recharge estimation regarding water table response for individual irrigation event. The field water application efficiency suggests that there is much room for improvement of efficiency. The study evidences that in the study area the hydrological regime is strongly affected by irrigation.

References

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). *Crop Evapotranspiration. Guidelines for Computing Crop Water Requirements, FAO Irrigation and Drainage Paper 56, .* Retrieved from Rome:

Greve, F. W. (1932). *Flow of Water Through Circular, Parabolic, and Triangular Vertical Notch-weirs*: Purdue university.

Healy, R. W. (2010). *Estimating groundwater recharge*: Cambridge University Press.
Healy, R. W., & Cook, P. G. (2002). Using groundwater levels to estimate recharge. *Hydrogeology Journal, 10*(1), 91-109.

Johnson, A. I. (1967). *Specific yield: compilation of specific yields for various materials*: US Government Printing Office.

Shen, J. (1981). *Discharge characteristics of triangular-notch thin-plate weirs*: US Geological Survey.

Sundaram, B., Feitz, A. J., de Caritat, P., Plazinska, A., Brodie, R. S., Coram, J., . . . Australia, G. (2009). *Groundwater sampling and analysis: A field guide*: Geoscience Australia.

Walker, W. R. (2003). *Surface irrigation simulation, evaluation and design*. Retrieved from

Human impacts on the hydrogeomorphology of Gumara River, Upper Blue Nile basin, Ethiopia

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1. Introduction

The processes of erosion, transport and deposition of sediments has modified the landscape of the upper Blue Nile basin, Ethiopia (Conway, 1997) indicates that alluvial and lacustrine plains may get huge sediment depositions. As a result of sediment deposition in the alluvial plain, the flood carrying capacity of the stream channel is reducing in recent times. This might be due to changes of river morphology (geometry) or as a result of land use and land cover changes (Poppe et al., 2013). Alluvial rivers change their shapes in reaction to humans influence on the natural system. Since long time, the human-induced factors have disturbed the alluvial river channels of the upper Blue Nile. This paper highlights the results of the recent study by Abate et al. (2015) on planform change along a 38-km stretch and the vertical adjustment of the Gumara River which drains towards Lake Tana and then to the Blue Nile. Over a 50 years period, agriculture developed rapidly in the catchment and flooding of the alluvial plain has become more frequent in recent times.

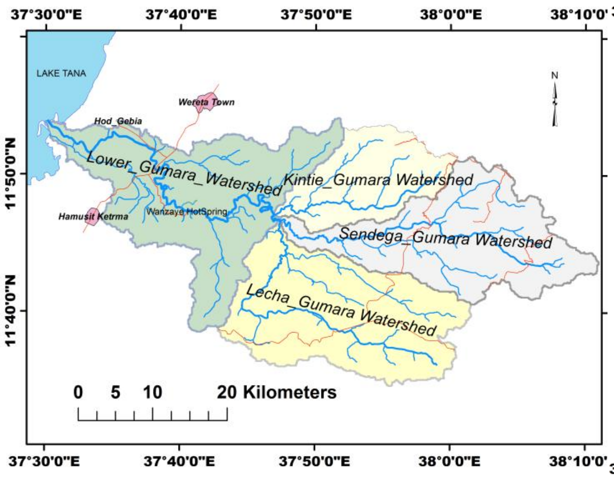

Fig. 1: The Gumara catchment and its sub catchments (modified after Abate et al., 2015).

Fig. 2: The study reach (Kizin to Lake Tana) of Gumara River and the excursion location (modified after Abate et al., 2015).

2. Materials and Methods

2.1 Description of the study area

The study area is the Gumara River with a total catchment area of about 1496 km^2. The studied reach starts at the confluence of Kizin and Gumara Rivers, at the edge of the hills bordering the lacustrine plain, and ends at Lake Tana (Fig. 2). The whole reach is of the meandering type.

2.2 Preparation of data

Aerial photographs (1957, 1980 and 1984), SPOT image of 2006, Google Earth and field observations were the data which have been used for the understanding and analysis of the planform changes of the study reach of Gumara river.

3. Results

3.1 Planform change

The results indicated that the lower reach of Gumara has undergone major planform changes (Fig. 3 and 4).

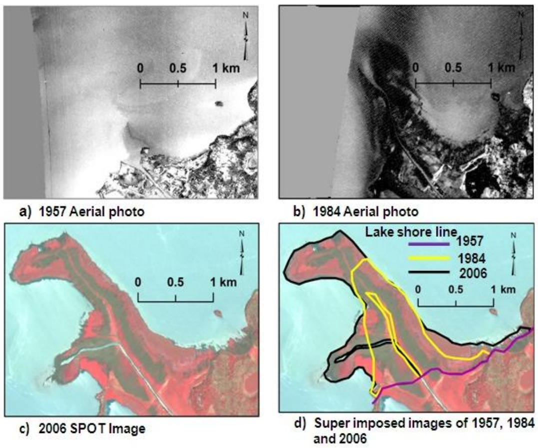

Figure 3. The Gumara River outlet at Lake Tana for the three periods (a, b and c). At the mouth of the river (d), a 1.12 km² delta has been created over 27 years (1957-1984) and an additional 1 km² area has been added in the 22 years spanning 1984-2006 (after Abate et al. (2015)*).*

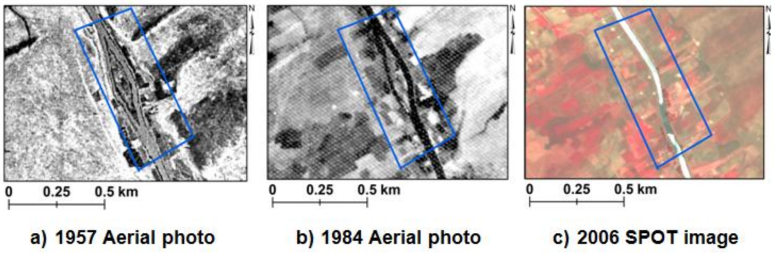

Figure 4. Example of in stream sediment deposition. A 1.74 ha island was observed on the 1957 aerial photograph (a), and after 27 years its area increased by 0.43 ha (b). The extent of the island expanded further and in recent years it became part of the left floodplain (c) (after Abate et al. (2015)*).*

At Gumara bridge, the deepest riverbed aggraded in the order of 2.91m for the period 1963-2009 (Fig. 5) and the banks undergone erosion and deposition (Table 1). As it is shown on Table 1, the channel cross sectional area at the bridge is reduced in its size for the reported period indicates that the flood carrying capacity of the channel is decreasing over time.

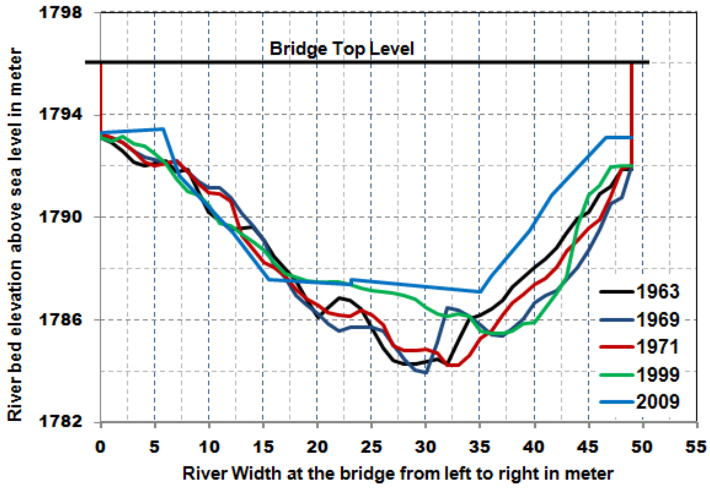

Figure 5. Changes to Gumara River cross-section at the Gumara bridge (source: MoWIE) (after Abate et al. (2015)).

3.3 Aggradation of natural levee induced by river bank overtopping

Although it is very difficult to quantify the depth of deposition in the floodplain, some structures, for instance automatic water level recorder (Fig. 6) which is installed in the river bank showed that the natural levee of the river is aggraded by about 1.4m.

Figure 6. Automatic water level recorders installed by USBR in 1959, and photographed in June 2012 along the alluvial Gumara River (a; at 11.838408°N, 37.637086°E) and the bedrock Abay River 4 km downstream from Chara-Chara weir at the outlet from Lake Tana (b; at 11.567543°N, 37.403952°E). Δz indicates the depth of sediment that was accumulated in Gumara's natural levee over the intermittent 53 years, i.e. 140 cm (after Abate et al. (2015)).

4. Discussion

The position or geometry of streams may suddenly change due to human pressure on the catchment. (Heede, 1980; Surian, 1999; Urban and Rhoads, 2003; Surian and Cisotto, 2007). The notable development that occurred in the planform of Gumara River is the delta (Fig.3) creation at the mouth of the river within 50 years and the eliminated mid channel bar or island (Fig.4) in the channel located at a distance of about 8 km from Lake Tana indicating that the effects of the upper catchment erosion and the sediment input into the stream is increased and this is most probably related to human induced land-use changes in the catchment. Direct anthropogenic impacts; irrigation activities (Fig. 7), building of dykes along the river banks and artificial rising of Lake Tana level have contributed to the huge deposition (Fig. 8) in the river bed. Since there is no buffer area between the irrigation areas and the river banks, there is high hydraulic gradient and seepage is observed along the river banks which makes them to collapse into the river channel. Upstream of the Gumara Bridge, water pumping is intensively done, more than 6.52 km^2 area is irrigated in the study reach since 2006 (Fig.7); to the extent that the whole base flow is exhausted before it arrives at Gumara Bridge (Fig.9). This study showed that changes to the riverbed level are substantial and its implication that the flood carrying capacity of the Gumara river channel has diminished.

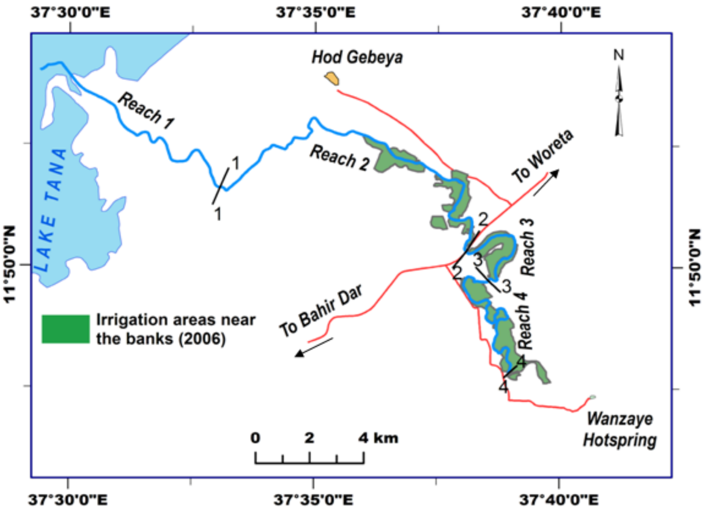

Figure 7. An Example of pump irrigation activities along the Gumara River banks (after Abate et al. (2015)).

Figure 8. Thickness of deposits in the river bed in the sand mining area (after Abate et al. (2015)).

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Figure 9 Gumara River at the Gumara Bridge location showing that there is no base flow.(Photo by Mengiste A. March 2015)

5. Conclusions

The changes in Gumara River channel are attributed to human induced factors (Fig.10). The overall analysis shows that the changes in the channel characteristics in the alluvial plain are linked to human-induced modifications in the upper catchment, in the river corridor, and on lake levels. The planform changes are very slow but the vertical morphological changing process is very active: in-channel deposition (2.91 m), development of natural levees and streambank erosion. The anthropogenic activities along the banks of the river have facilitated bed deposition. The raise of the river bed level results in more frequent high floods and sediment deposition. This will further increase the river bed level and this further reduces the flood carrying capacity of the channel.

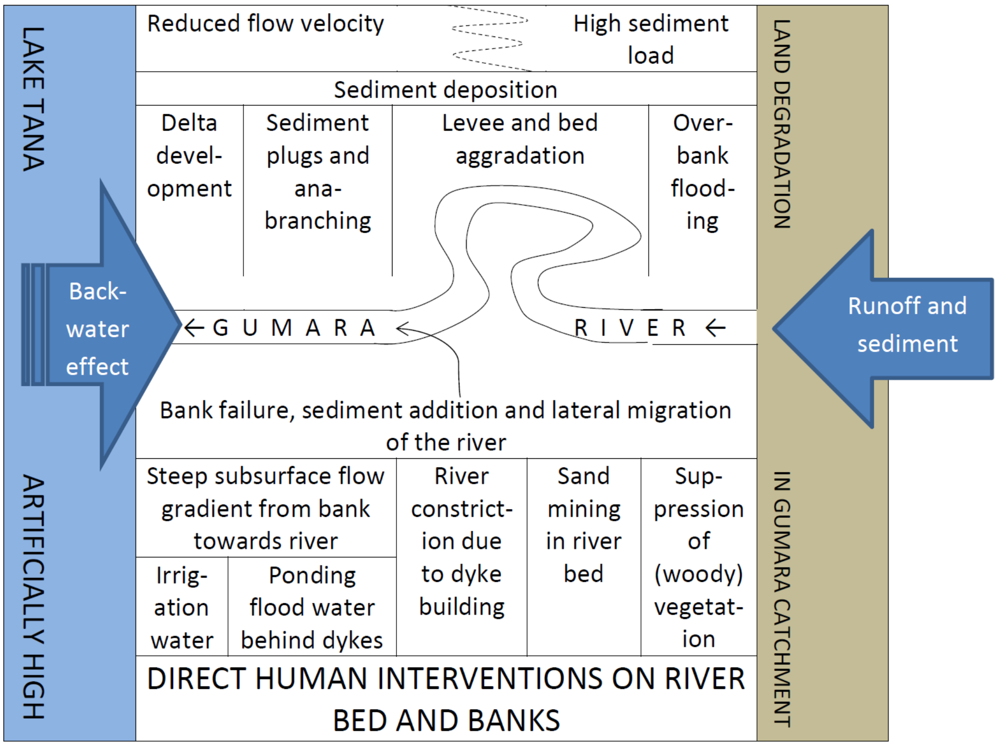

Figure 10. Conceptual model of hydrogeomorphic dynamics of Gumara River in the Lake Tana lacustrine plain. Major human impacts that influence the system are written in block letters at the lower, left and right sides of the diagram. Sequence of processes is both from top and bottom of the diagram towards the middle (after Abate et al. (2015)).

References

Abate M, Nyssen J, Steenhuis T, Mehari M, Admassu S, Enku T, Adgo E. 2015. Morphological changes of Gumara River channel over 50 years, Upper Blue Nile basin, Ethiopia. Journal of Hydrology.

Conway D. 1997. A water balance model of the Upper Blue Nile in Ethiopia. Hydrological Sciences Journal 42: 265-286.

Heede BH. 1980. Stream dynamics: an overview for land managers. US Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report.p 26.

Poppe L, Frankl A, Poesen J, Admasu T, Dessie M, Adgo E, Deckers J, Nyssen J. 2013. Geomorphology of the Lake Tana basin, Ethiopia. Journal of Maps 9:431-437.

Surian N. 1999. Channel changes due to river regulation: the case of the Piave River, Italy. Earth Surface Processes and Landforms 24:1135-1151.

Surian N, Cisotto A. 2007. Channel adjustments, bedload transport and sediment sources in a gravel-bed river, Brenta River, Italy. Earth Surface Processes and Landforms 32:1641-1656.

Urban MA, Rhoads BL. 2003. Catastrophic human-induced change in stream-channel planform and geometry in an agricultural watershed, Illinois, USA. Annals of the Association of American Geographers 93:783-796.

Fogera Plain: Rice cultivation and North-Korean hybrids

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Setting the scene

The Fogera plain is a vast area along the southern fringe of Lake Tana. As it is located at some meters above the present average lake level it can be considered as the first alluvial terrace of the lake. The soils are Vertisols, composed heavy swell-shrink clays of alluvial origin. As these soils are water-logged during the rainy season, they remained idle during the rainy season. During the dry season specialized crops such as chick peas, sorghum and safflower were grown, however their yields remained rather low.

Past efforts to make the Fogera plains more productive

In a move towards self-reliance, the Government of Ethiopia has been making efforts to make the Vertisols of the Fogera Plain more productive. After the Great Famine of the mid-1980s, Korean and Ethiopian experts explored how they could turn the problem of surface flooding of the Vertisols into an opportunity of growing a waterlogging-resistant high-yielding crop. They came up with rice and in 1986 the first experiments with Korean rice varieties were established on farmers' field near Woreta. Right from the onset of the experiment, the vegetative growth of the rice was superb; hence expectations were high for harvesting a bumper crop. Unfortunately, things started changing when the plantlets started flowering. Pollination was rather poor and henceforth yield levels were disappointingly low. What was the problem: were the varieties not adapted to the cool temperatures of the Ethiopian highlands or was surface flooding excessive?

Two big steps were undertaken to tackle the problem:

(1) The Woreta Institute of Agricultural Research was established and new rice varieties from the International Rice Research Institute (IRRI - The Philippines) were flown in for field testing. (2) The Agriculture Development Department (ADD) of the Ministry of Agriculture undertook in collaboration with the International Livestock Centre for Africa a concerted effort to improve the surface drainage of Vertisols. Trials were set up to shape the soil surface into beds and furrows by the so-called 'Broadbed and Furrow Maker (BBM)', which was especially designed for the purpose. ADD established a 2.5 ha applied research site near Woreta where the new management techniques (BBM, new varieties, alternative crops, crop rotation, time of planting) could be tested systematically. The result of this land surface shaping on Vertisols was spectacular. Not only rice was performing better, the drained land could also be planted with more exigent crops such as maize and faba beans

Present situation: interview of Ato Bayuh Belay, Director of the Fogera Rice Research Institute

- *How many ha are cultivated with rice in Fogera plain?*

40,000 ha in three districts (Fogera, Libokemkem and Dera districts) in South Gondar.

- *What is the average harvest of rice?*

On average 3 t / ha.

- *Which are the varieties that are currently grown on farmers' field?*

As lowland rice there are X-Jigna and Ediget; as upland rice there is Nerica 4

- *With which varieties are you currently experimenting?*

The following are five recently released varieties

Variety	Ecology	Year of release	Yield (Q/ha)
Adet/WAB-450/	Upland	2014	24 - 42
Nerica-12	Upland	2013	30 - 48
Hibbire	Lowland	2013	40 - 44
Hiddassie	Upland	2012	30 - 42
Ediget	Lowland	2011	32 - 50

- *Which is the origin of these varieties?*

X-Jigna is from Korea; the remaining are from AfricaRice and IRRI

- *What is the management technique that you recommend to farmers for rice growing?*

We recommend weeding, fertilizer application, bunding and leveling, row planting and transplanting

- *Can you give a short overview of the other activities of your institute?*

The Fogera National Rice Research and Training Institute was established in August 2013 under the Ethiopian Institute of Agricultural Research. It was established to serve nationally as center of excellence for rice research and training. The Japanese government supported more than 10 million dollar for the establishment of this center. Different buildings for administrative office, research and laboratory, training centers are under construction.

Regarding the research activities, there are several activities in the following components: breeding, agronomy, plant pathology, extension, socioeconomics, and seed multiplication.

Conclusion

Rice production in the Fogera plains has very rapidly evolved from early testing with mixed success in the beginning to a massive and rewarding enterprise for the farmers in the area and beyond. This is a nice example illustrating that a good research idea along with some relatively small financial means can make all the difference for sustainable livelihood of farmer communities in Ethiopia.

References

Deckers J. 1989. Soil fertility assessment of Ethiopian Vertisols on the basis of extension trials series of the Ministry of Agriculture. In: Jutzi, S., Haque, I, McIntire, J., and Stares, J. (eds). Proceedings of a conference held at ILCA, International Livestock Centre for Africa, Addis Ababa, Ethiopia, 31 August to 4 September 1987, 431 pp.

Jutzi, S., Anderson, F., and Abiye Astatke (1987). Low-cost modifications of the traditional Ethiopian tine plough for land shaping and surface drainage of heavy clay soil: Preliminary results from the on-farm verification trial. ILCA Bulletin 27, 28-31

Poppe, L., Frankl, A., Poesen, J., Teshager Admasu, Mekete Dessie, Enyew Adgo, Deckers, J., Nyssen, J., 2013. Geomorphology of the Lake Tana basin, Ethiopia. Journal of Maps, 9(3), 431-437.

Tilahun, G., Kahsay, B., Hoekstra, D., Alemu, B., 2012. Rice value chain development in Fogera woreda based on the IPMS experience. Nairobi, Kenya: ILRI

The water balance of Lake Tana

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Introduction

Lakes are very important components of the earth's hydrological cycle, providing a variety of services for humans and ecosystem functioning. For a sustainable use of lakes, a substantial body of knowledge on their water balance is vital. We present here a daily water balance analysis for Lake Tana, the largest lake in Ethiopia and the source of the Blue Nile.

A review of the previous water balance studies of the lake reveals that most of these studies ignored the extensive floodplain of the Lake Tana basin and its impacts on the water balance of the lake. Significant contribution in this perspective is attributed to Kebede et al. (2011). Floodplains are specific ecosystems, oscillating between terrestrial and aquatic phases (Junk, 1996), having different topography, soils and vegetation patterns. The water balance studies of the lake should address the floodplain hydrology properly and its impacts on the water budgets of the lake. This study analyses the water balance of the lake and the impacts of the extensive floodplain on its water balance.

Methodology

Water balance components of the lake (Fig.1) are quantified simulating two scenarios. Scenario 1 attempts to analyze the water balance of the lake omitting the floodplain. This scenario hypothetically removes the floodplain and its buffering effect from the lake system and estimates the water balance of the lake. Scenario 2 deals with the real field situation (the lake basin and the lake-floodplain system) and the effects of the floodplain are included. in the analysis. Based on a comparison of the results of both scenarios, the impacts of the floodplain on the water balance of the lake will be evaluated.

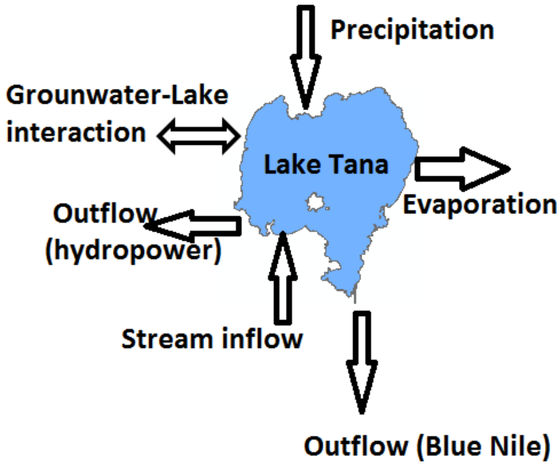

Figure 1. Main components of the water balance terms of Lake Tana

The lake level fluctuations are governed by an Input-Storage-Output process, which can be described by the following water balance model (all terms in $Mm^3\ day^{-1}$):

$$\frac{\Delta S}{\Delta t} = P_{lake} - E_{lake} + Q_{gauged} + Q_{ungauged} - Q_{out} + \varepsilon$$

where $\frac{\Delta S}{\Delta t}$ denotes the change in storage over time, P_{lake} is lake areal rainfall, E_{lake} is the rate of lake evaporation, Q_{gauged} is gauged river inflow, $Q_{ungauged}$ is ungauged river inflow, Q_{out} is the outflow at the Blue Nile River and at the tunnel to the hydropower station, and ε represents the uncertainties in the water balance arising from errors in the data and other terms, such as net groundwater flux or minor abstractions, which usually cannot be accounted for directly.

(1) Estimation of rainfall and evaporation on the lake

Daily measurements from six precipitation stations, located at the lake shore (Bahir Dar, Gorgora, Dengel Ber, and Zegie), at the island of the lake (Dek Estifanos) and close to the lake (Maksegnit), were used to calculate areal rainfall on the lake by the Thiessen Polygon method.

For estimating the lake water evaporation depth, daily maximum and minimum air temperature data from the above 6 stations is used, whilst wind speed, relative air humidity and sunshine hours are collected from Bahir Dar meteorological station. The daily evaporation depth was estimated by the Penman-combination method (Maidment, 1993), which is widely applied as a standard method in water resources engineering.

(2) **Runoff from gauged and ungauged catchments**

The daily runoff flowing into the lake from the gauged catchments (Fig. 2) has been derived for the period 2012 and 2013 using measured water levels of the rivers. The runoff from the ungauged parts of the catchments (Fig. 2) was estimated using a conceptual hydrological model and a runoff coefficient approach.

The conceptual hydrological model of Dessie et al. (2014) was used for ungauged catchment rivers that drain to the lake with no or minimal influence of the floodplain on their way to the lake. The runoff estimation of the ungauged floodplain and the hillslope catchments (Fig. 2) that are affected by the floodplain as the rivers flow across the floodplain are made using the runoff coefficient approach. The runoff coefficients (Table 1) were determined based on discharge measurements from three discharge monitoring stations in the floodplain.

Table 1. Characteristics of the ungauged catchments (including the floodplain), the runoff which are influenced by the floodplain on the way to the lake, and the runoff coefficients used to estimate their corresponding runoff depths.

Location	catchment area (km^2)	Runoff coefficients for stations in the floodplain		Average runoff coefficient
		year 2012	year 2013	
Gumara catchment	81.7	0.65	0.53	0.59
Rib Catchment	950.1	0.22	0.2	0.21
North of Lake Tana basin (including Megech, Dirma and adjacent catchments)	1170.3	0.37	0.11	0.24
Gilgel Abay and Adjacent catchments	336.5	0.61	0.5	0.56

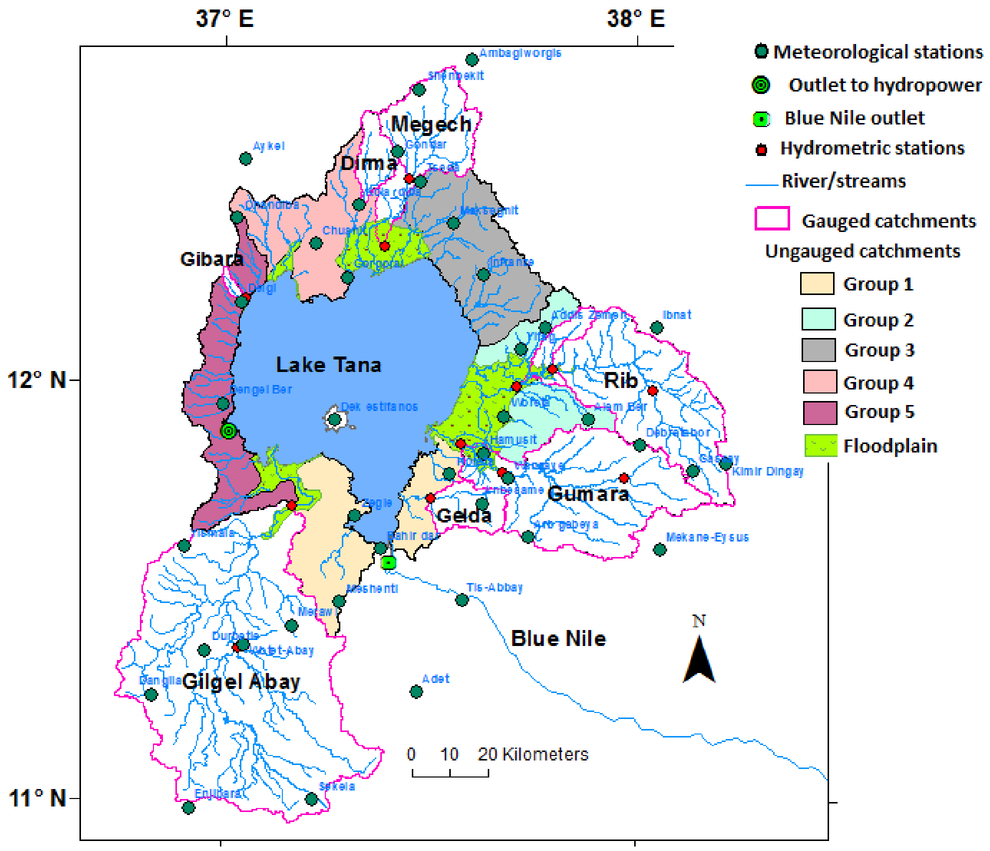

Figure 2. Gauged and ungauged catchments in the Lake Tana basin. Runoff from the groups of ungauged catchments was predicted based on calibrated model parameters of observed runoff data from Gelda for Group 1, from Rib for Group 2, from Megech for Group 3, from Dirma for Group 4, and from Gibara for Group 5.

(3) Outflow, lake levels and water level-area-volume relationships

Daily observation records of discharges are available on both outlets (at Chara Chara weir near the city of Bahir Dar, and a tunnel hydropower outlet for Tana Beles hydropower (from Ministry of Water, Irrigation & Energy and Tana Beles Hydroelectric Power Plant, Ethiopia) and are directly used in the present water balance and lake level simulation studies. We obtained daily lake water level data at Bahir Dar and Kunzila stations (Tana Beles Hydropower outlet) for the years 2012 and 2013.

Results and discussion

(1) River inflows

The analysis of river inflows for the years 2012 and 2013 revealed that Lake Tana received an average yearly runoff of 5.61×10^9 m^3 from gauged and 1.22×10^9 m^3 from ungauged catchments, disregarding the water abstraction by irrigation in the ungauged catchments. More importantly, 0.42×10^9 m^3 of water does not reach the lake. Most of the abstraction (about 50% of the total) takes place by the floodplain (via runoff transmission losses) following the downstream reaches of the Rib River. Floodplains at some reaches of the Gumara River and the southern shore of the lake are exceptions and there is runoff contribution from these floodplains as indicated by the presence of many springs in these areas. Further analysis of the river inflows to the lake shows that 58% of the inflow to the lake is generated from the southern part of the catchment (Table 2), which covers about 38% of the total catchment area of the lake.

Table 2. Runoff inflows to Lake Tana for different sub-catchments

Lake Tana catchment divisions	Major Rivers	Catchment area (km^2)	Average annual rainfall (mm)	Inflow to the lake (mm)	Inflow to the lake ($x10^6$ m^3)	Inflow to the lake from the total (%)
Southern catchment	Gilgel Abay	4507	1660	880	3961.08	58
Eastern catchment	Gelda, Gumara and Rib	4182	1470	490	2044.76	30
Northern catchment	Garno, Arno, Gabi Kura, Megech, Dirma	2651	1140	260	689.24	10
Western catchment	more than 20 smaller streams	660	1035	210	136.41	2

(2) The water balance terms

The results of the annual input and output water fluxes of the lake for both scenarios are indicated in Table 3.

Table 3. Average annual water balance terms of Lake Tana (years 2012 and 2013).

Water balance terms	Scenario 1		Scenario 2	
	mm	10^6 m^3	mm	10^6 m^3
Lake areal rainfall	1330	4129.0	1330	4129.0
Gauged river inflow	1819	5645.5	1807	5608.2
Ungauged river inflow	530	1645.3	394	1223.3
Lake evaporation	-1789	-5547.3	-1789	-5547.3
Outflow from the lake	-1618	-5022.9	-1618	-5022.9
Water abstraction by irrigation	-35	-108	-42	-134
Closure term	238	741.6	82	256.3

(3) Lake level simulations

The results of lake level simulations (Fig. 3) indicate a good match with the observed lake levels for both scenarios, although larger deviations are observed for scenario 1 during the end of the simulation period. The lake level simulations resulted in R^2 values of 0.94 and 0.95 for Scenario 1 and Scenario 2 respectively, which is very similar irrespective of the differences in the closure terms of the water balance terms.

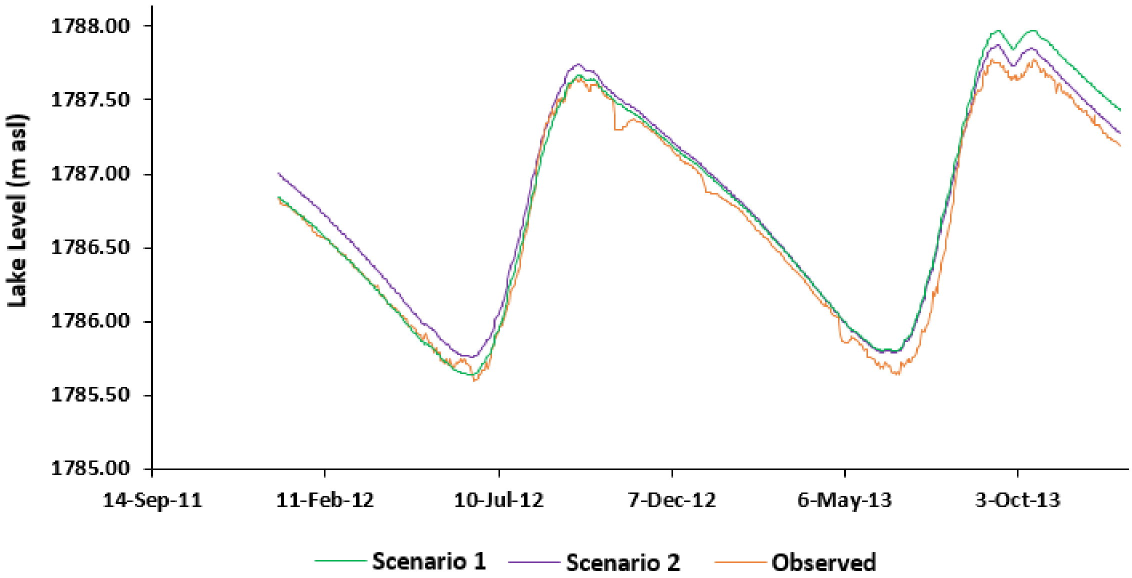

Figure 3. Observed and simulated lake levels for the two Scenarios. Scenario 1 simulates the lake level of Lake Tana omitting the floodplain and its effects. Scenario 2 simulates the real field situation (i.e. the lake basin and the lake-floodplain interactions).

Conclusions

The Lake Tana water balance analysis presented here describes the different water balance components of the lake and provides a meaningful assessment of the components. It demonstrates the importance and the influence of the extensive floodplain on the water balance of the lake. More importantly, 0.42×10^9 m^3 of water does not reach the lake.

References

Dessie, M., Verhoest, N.E.C., Pauwels, V.R.N., Poesen, J., Adgo, E., Deckers, J., Nyssen, J., 2014. Analyzing runoff processes through conceptual hydrological modelling in the Upper Blue Nile basin, Ethiopia. Hydrol. Earth Syst. Sci., 18, 5149-5167, doi: 10.5194/hess-18-5149-2014.

Junk, W. L., 1996. Ecology of floodplains - a challenge for tropical limnology, in Schiemer, F., Boland, E. J. (Eds.), Perspectives in Tropical Limnology. SBP Academic Publishing, Amsterdam, pp. 255-265.

Kebede, S., Admasu, G., Travi, Y., 2011. Estimating ungauged catchment flows from Lake Tana floodplains, Ethiopia: an isotope hydrological approach. Isotopes in Environmental and Health Studies, 47:1, 71-86. doi:10.1080/10256016.2011.556724.

Maidment, D.R. 1993. Handbook of Hydrology. McGraw-Hill: New York.

Experimental plots for soil loss assessment

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Introduction

Accelerated soil erosion is causing significant challenges to the Ethiopian Highlands´ smallholder farmers that support 85% of the total population. Such huge amount of soil loss is imposing negative on-site effects such as losses of soil fertility and moisture and thus land productivity and also off-site effects such as flooding, siltation and pollution of reservoirs (Tamene and Vlek, 2008). The upper Blue Nile basin which covers a drainage area of about 199,800 km^2 (BCEOM, 1998) is also suffering from such problems.

To reduce the vulnerability to soil erosion and climate variability, the Ethiopian government assisted by multi-donors (World Bank, Finland government, FAO, EU, GIZ, WFP and others) launched a Sustainable Land Management (SLM) program since 2008. The first phase is completed and since this year SLM Phase II program has been launched (Danyo, 2014).

The program aims at reducing land degradation in agricultural landscapes, improve the agricultural productivity of smallholder farmers and restoration of ecosystem functions and diversity in agricultural landscapes.

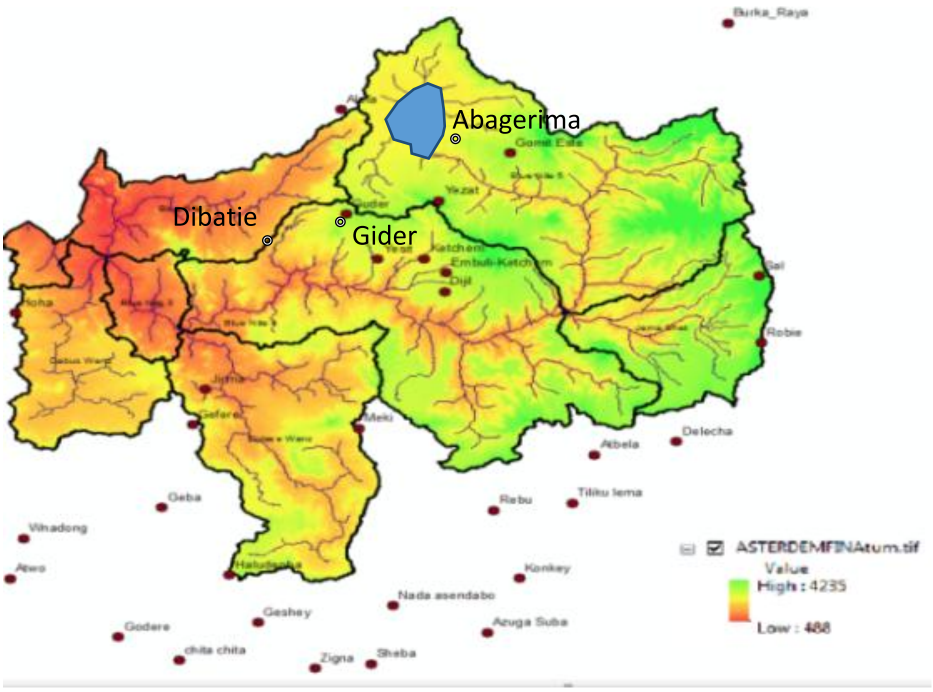

Figure 1: Location map of Upper Blue Nile basin, SLMP sites (in red) and KAKENHI watersheds (in white)

Bahir Dar University in collaboration with the Arid Land Research Center of Tottori University of Japan, initiated a five-year (2013-2018) research project titled, "Land Management to Mitigate Soil Erosion in the upper Blue Nile River basin". The project is funded by Grants-in-Aid for Scientific Research (KAKENHI) from Japan Society for the Promotion of Science (JSPS), Ministry of Education, Culture, Sports, Science and Technology (MEXT). The main aim of this research project is to analyze impacts of SLM on sediment and runoff budget, soil fertility improvements, crop yield and biomass production in the upper Blue Nile basin. To monitor impacts of SLM interventions, three sites; Gider, Aba Gerima and Dibatie were identified representing highlands (*Dega*), midlands (*Woyna Dega*) and lowlands (*Kolla*) (Figure 1).

Aba Gerima Watershed

Aba Gerima watershed is located 15 km away from Bahir Dar town in northeastern direction. The watershed has an area of 900 ha. Like in other areas of Lake Tana basin, farmers' livelihood in the watershed is based on mixed farming system of livestock rearing and crop production. Finger millet, maize and teff are among the dominant cereal crops in the area. Since some 15 years, farmers in the area produce khat as cash crop and sell in towns like Zenzelma (small town near Bahir Dar). During the dry season, it is common to see farmers pumping water from their hand dug wells and streams to their khat fields. Cattle, sheep, goat and equines are also kept by most farmers.

SLM project activities have been implemented started from 2012 and now (2015) a total of 760 ha land is covered with different SWC structures including soil and stone bunds, fanja juu, cut-off drain, waterways and exclosures (Figure 2).

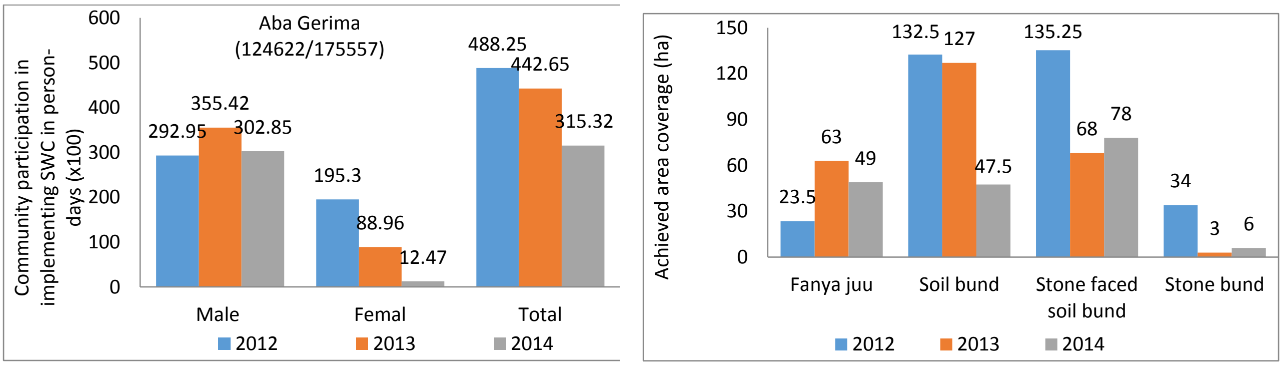

Figure 2: Number of households in SWC activities (left) and area coverage of the four major SWC structures (right)

Sesbania, pigeon pea and Napier grass are used to stabilize most of the constructed physical structures. This land rehabilitation activity is done through mass mobilization of farm households. As indicated in Figure 2, more than 300,000 individuals have been participated over the last three years in land rehabilitation activities (WLRC, unpublished). The Water and Land Resource Center (WLRC), a Swiss-funded center, is providing financial and technical support to the watershed management activities while the district Office of Agriculture is the major coordinator of the work. Beehives with bee colonies have been also been introduced in the exclosed areas and given to landless youths. Two shallow hand-dug wells that are constructed by the support of WLRC improve the availability of potable water for the local commmunities. Free grazing is completely banned in the watershed and farmers use a cut-and-carry system.

To evaluate the effects of SLM on sediment and runoff, KAKENHI project identified twin micro watersheds; Kecha (treated) and Laguna (control or untreated) (Figure 3). Kecha micro watershed with an area of 384 ha is part of the larger Aba Gerima watershed.

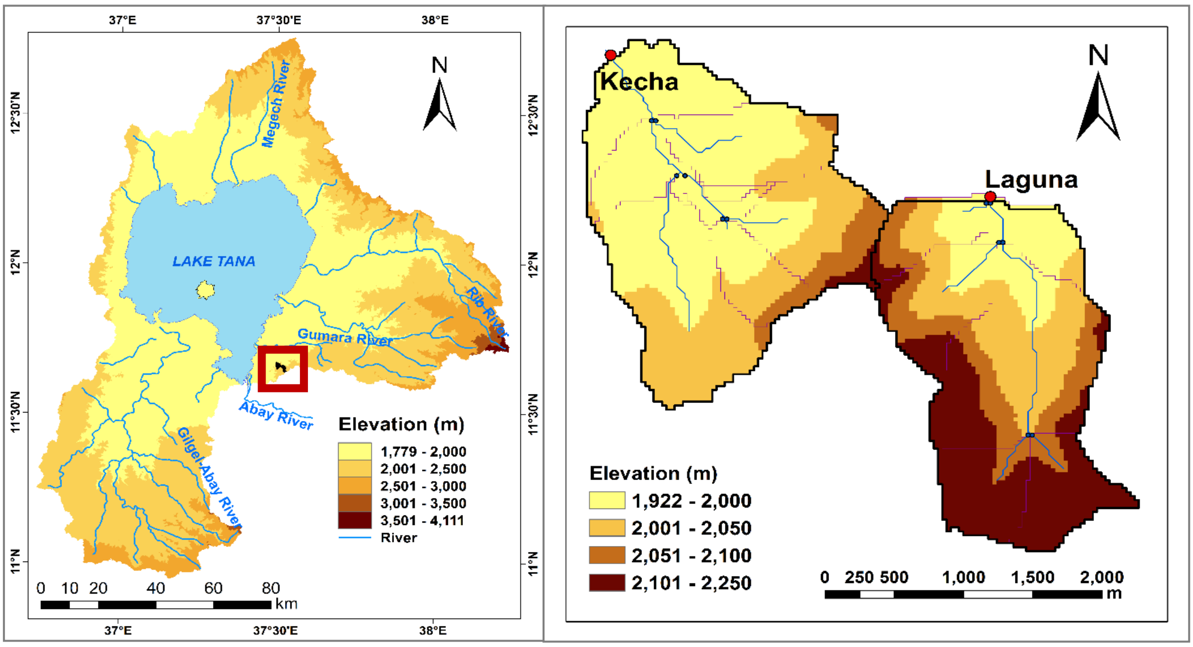

Figure 3: Twin experimental sites, Kecha (left) and Laguna (right)

The Laguna (control) micro watershed has an area of 335 ha and is located east of the treated Kecha watershed. Both micro watersheds have comparable area; biophysical and socioeconomic characteristics except an extended steep bushland in Laguna micro watershed. Cultivated land, bushland and grazing land are the major land use types in both watersheds.

Experimental setup

Both twin watersheds are gauged for discharge and sediment measurements and data are collected since the 2015 rainy season. Moreover, bounded runoff plots representing the main land use and slope classes have been established to evaluate the runoff and sediment contributions of each land use type (cultivated, grazing and bushland) as well as to test the effectiveness of individual soil and water conservation measures. Frequently practiced SWC structures are being evaluated in the experiment, i.e. four treatments (control, soil bund, fanja juu, soil bund stabilized by biological materials) on cultivated land and only two treatments (control and trench) on degraded bush land and grazing land.

Since cultivated lands are found both in steep slopes and gentle slopes, two runoff plot sites are established at slopes of 15% and 7%, while runoff sites for bushland and grazing land are at slopes of 25% and 5%, respectively.

Each plot had a 30 m * 6 m runoff catchment area and about 10 m^3 runoff harvesting trench at its lower side which is lined with 0.4 mm thick geo-membrane plastic sheet (Figure 4). This runoff collector has a capacity to store the maximum possible runoff to be generated from the plot and this depends on the rainfall, land use and soil and other related characteristics. A runoff plot is bounded by corrugated iron which is partly inserted to the soil (13 cm) and the other part remained above the ground (20 cm) to control flood coming from up slopes (Figure 4). Within treatment plots, respective SWC structures are constructed as per the regional recommended guidelines.

Figure 4: Experimental runoff plots of sloping cultivated land (left) and grazing land (right)

In cultivated land, the farmers sow their preferred crop types every year. However, land preparation is done manually without *maresha* plow. Time and frequency of land preparation, sowing, weeding, and harvesting dates are continuously recorded. Other variables such as soil moisture (piezometer), surface cover (vegetation or stone), yield and yield components of the test crop are also monitored regularly. Detailed topographic mapping is done for the whole plot areas and the river cross sections where gauging sites are positioned.

Data recording procedures

Discharge and sediment are being collected from the twin watersheds and runoff plots. From river gauging stations, discharge is measured continuously using diver and also manually using staff gauge three times a day (morning, noon and evening) and during peak discharge events. Sediment samples are also collected two times in a day (morning and evening) and during peak runoff events. They are collected manually during low river flow by entering to the stream and dipping down a plastic bottle in an integrated depth sampling procedure. During high floods, on the other hand, a suspension cable is used to take sediment samples which is spanned between two pillars at both sides of the river.

Daily runoff depth collected in the collector trench is measured within 24 hours every morning (ca. 8:00 am) and then drained out immediately to make space for the next runoff event. Each runoff collection trench was calibrated by adding a known volume of water to know runoff amount more accurately at different depth of the collection trench. Runoff collected in the trenches is then calculated by measuring depth of the water in the trench at different points.

Direct rainfall that falls into the trenches was deducted to know the actual volume of runoff generated at each plot, however the amount of water added directly from rainfall to trenches was found to be negligible. For this purpose, data collected from rain gauges (tipping bucket and manual) installed in the watershed is used.

For sediment yield analysis, the harvested runoff was disturbed vigorously with floor brush and a uniform 1 liters sample was taken. Sediment filtering was conducted using Whatman no. 42 filter paper at Bahir Dar University “Highway” laboratory. All the filtered materials were oven dried at a

105 °C for 24 hours. Those oven-dried samples were used to measure sediment yield after weighing by sensitive balance and converted to equivalent dry mass expressed in ton/ha/yr for each runoff plot.

Moreover, different types of data are being collected both at plot (topography surveying, soil parameters like texture, bulk density, organic matter etc; stoniness, land cover) and watershed level such as soils (texture, soil depth, stoniness, infiltration, geology, land use/cover, gully erosion)

Monthly and seasonal runoff and sediment losses (preliminary results from Guder site)

Preliminary results from Guder watershed showed that maximum runoff values for all runoff plots under cultivated land were observed in August (Figure 5a). Likewise, the associated soil loss rates were highest in this month for treated plots (Figure 5b). However, for the control plot, soil loss rate was significantly larger in July and getting smaller through August and September. The result also showed clear effects of SWC structures on runoff reduction which is between 45 and 50% lower than the control plots. The reduction in sediment is highest at the beginning of the rainy season (only a quarter of the control). Soil losses decrease towards the end of the rainy season. Zegeye *et al.* (2010) also indicated a decreasing trend in soil loss with the progression of the rainy months for crop lands in Debre Mewi watershed of Lake Tana basin.

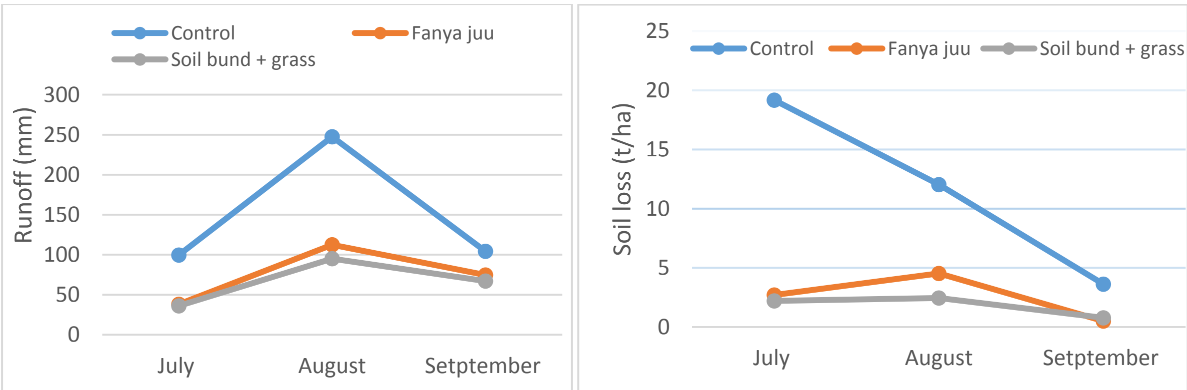

Figure 5: Monthly runoff (left) and soil loss (right) on different treatments under cultivated land

At the beginning of the summer rains, the fields have undergone at least two tillage operations and are bare and vulnerable to splash and runoff erosion. Nyssen *et al.* (2009) also explained that soil loss by water erosion even in the northern Ethiopia, occurs mainly at the beginning of the main summer rainy season in cultivated lands.

The cumulative runoff depth, obtained from 82 events over the rainy season, was greatest from the control plot (422 mm) as compared to treated plots (Table 1).

Table 4: Seasonal soil loss and runoff for different treatments under cultivated land

Treatments	Seasonal runoff (mm)	Relative runoff (%)	Seasonal soil loss (t/ha)	Relative soil loss (%)
Control	421.9	100	34.9	100
Fanyajuu	215.9	51.2	7.7	22.0
Soil bund + grass	191.9	45.5	5.4	15.5

On annual basis, treatments reduce runoff depth by 45 to 51% as compared to the control. The corresponding highest total soil loss was also found on the control plot (35 t/ha) while the smallest magnitude of seasonal soil loss rates was found in the plot treated with soil bunds stabilized by grass (Table 1).

References

Danyo, S. 2014. *Ethiopia - Sustainable Land Management Project-II : P133133 - Implementation Status Results Report : Sequence 02*. Washington, D.C. : World Bank Group.

Nyssen J, Clymans W, Poesen J, Vandecasteele I, Haregeweyn N, Naudts J, Moeyersons J, Haile M, Deckers J, 2009. How soil conservation affects the catchment sediment budget: a comprehensive study in the north Ethiopian highlands. *Earth Surf Proc Land* 34:1216–1233. doi:10.1002/esp.1805

Tamene, L. and Vlek, P.L.G. 2008. Soil Erosion Studies in Northern Ethiopia. In: A.K Braimoh and P.L.G. Vlek (eds.) Land Use and Soil Resources, Springer

Zegeye, A.D., Steenhuis, T.S., Blake, R.W., Kidnau, S., Collick, A.S., & Dadgari, F. (2010). Assessment of soil erosion processes and farmer perception of land conservation in Debre Mewi watershed near Lake Tana, Ethiopia. *Ecohydrology & Hydrobiology, 10*(2), 297-306.

The Anglo-Egyptian plans for Lake Tana water management in the 1920s

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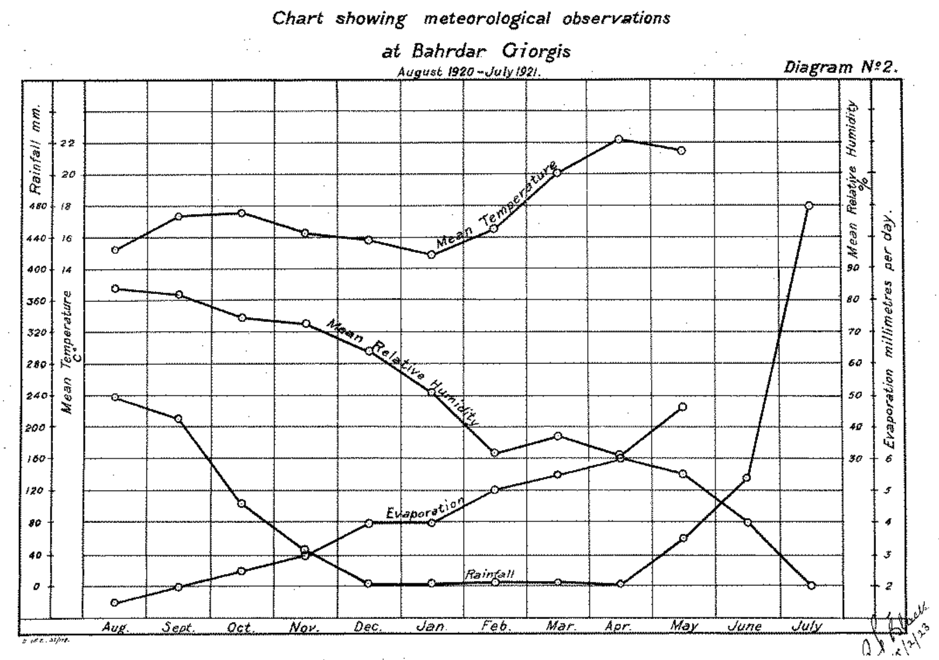
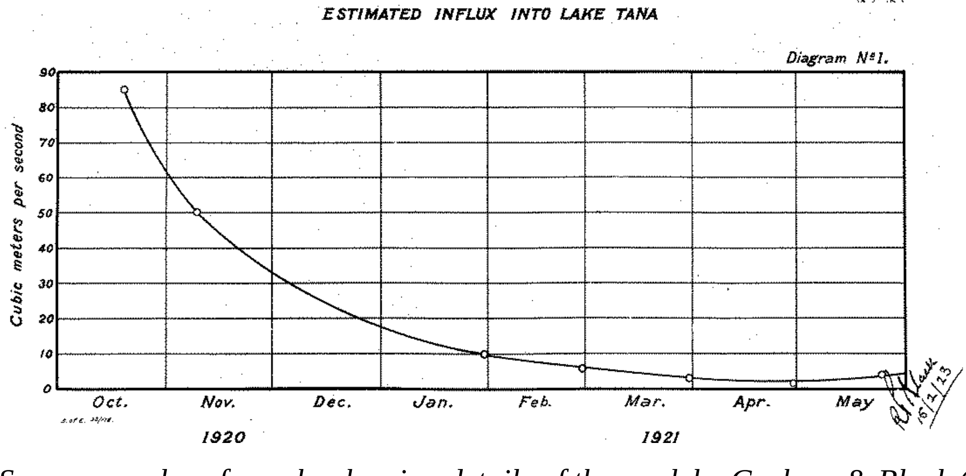
In the 1920s, the British had taken up the plan to construct a dam at the Chara-chara outlet of Lake Tana, as part of the overall normalization or control of Nile waters (Tvedt, 2004), similarly to the Owen Falls dam that was eventually built on the Lake Victoria outlet in 1954 (Rubin & Warren, 2014). The aim was to have a more regular flow, allowing to irrigate more land in Egypt and Sudan (Tvedt, 2004). Diplomatically, it was a complex issue, in which, besides the British and Ethiopian government, also Italy was involved, as well as intrigants. There were also disagreements among the British and Egyptians about the extent to which the Blue Nile needed to be controlled (Tvedt, 2004).

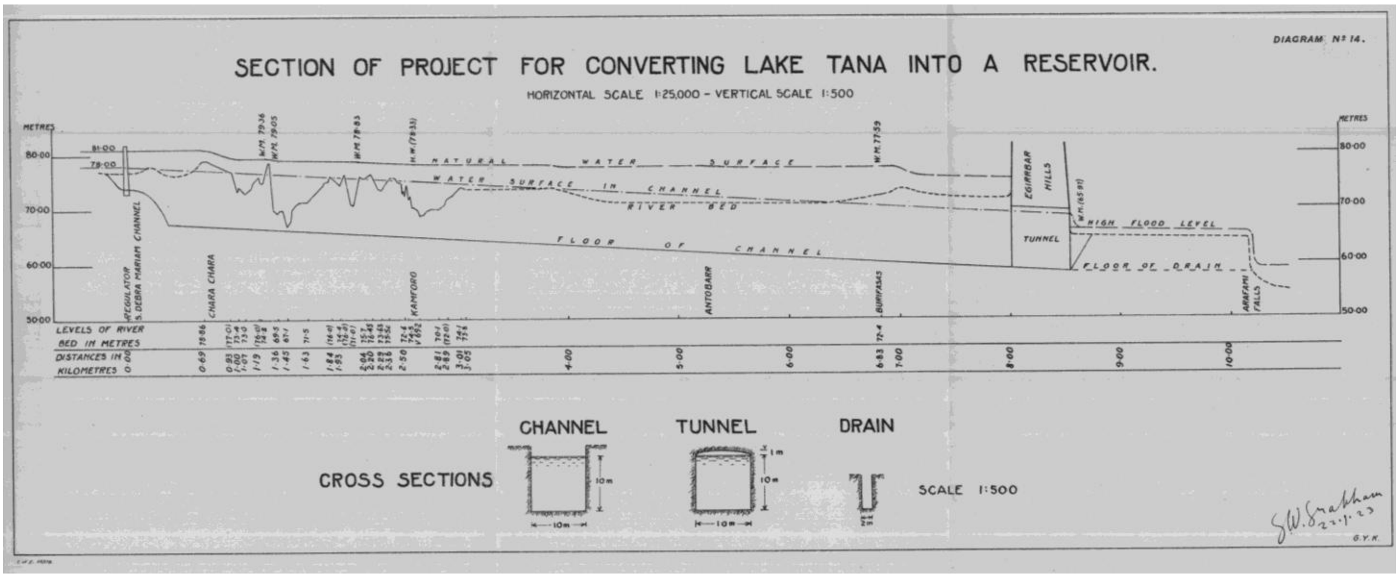
In the framework of these plans to dam Tana lake outlet, a first detailed hydrological study was carried out by Grabham and Black; their mission was in 1920-1921, but the report was only published in 1925 as it was a very sensitive matter. The book (Grabham & Black, 1925) provides a unique dataset that has been exploited by historians but rarely by hydrologists.





Some examples of graphs showing details of the work by Graham & Black (1925)

Volumes of available water had been calculated; challenges were not only political, but also technical, such as how the dam should be constructed, and further how the channel the water efficiently downstream towards the British territories. The upper part, between Chara-chara outlet and Tis Issat (Blue Nile falls), where the river runs and meanders across Quaternary lava flows was planned to be rectified, including the digging of a tunnel to cut off the Egirbarr meander (Grabham & Black, 1925).



Design cross-section along Blue Nile from Chara-chara to Arafami Falls (Grabham & Black, 1925)

The Bezawit viewpoint gives a view on this river segment, and historical photographs and maps (Grabham & Black, 1925) pertaining to the area will be contrasted with the current situation.

"The Blue Nile channel leading from the outlets of Lake Tana", as seen in 1920 (Grabham and Black, 1925) from Bezawit viewpoint.

Acknowledgment: Mr. R. Neil Munro is thankfully acknowledged for having provided the historical materials

References

Grabham, G. W., & Black, R. P. (1925). Report of the Mission to Lake Tana, 1920–21. Min. of Public Works, Egypt.

Rubin, N., & Warren, W. M. (2014). Dams in Africa: An Inter-Disciplinary Study of Man-Made Lakes in Africa. Routledge.

Talling, J. F. (2009). Physical and chemical water characteristics. In *The Nile* (pp. 367-394). Springer Netherlands.

Tvedt, T. (2004). The River Nile in the age of the British: political ecology and the quest for economic power. IB Tauris.

Role of alluvial plains in buffering floods and sediment

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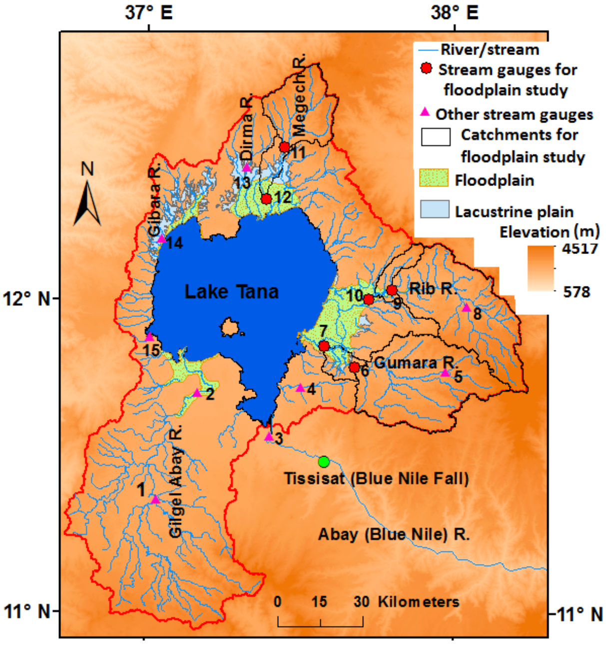
Introduction

Lake Tana, in the northwestern highlands of Ethiopia, is associated with an extensive floodplain adjacent to the lake and its lowland tributaries. The floodplain is the hydrological connector between the lake and the upper catchments, and affects the water balance and sediment flux of the lake. This study provides the role of alluvial plains in the Lake Tana basin in buffering floods and sediment.

Methodology

Water level measurements and sediment sampling were made at the foot of the hillslopes, at the interface of the floodplain (upstream stations), and within the floodplain (downstream stations). The upstream and downstream measurement stations for Gumara, Rib and Megech Rivers were mainly used to study the floodplain and river interactions (Fig. 1). The upstream stations are located at the transition from foot hills to the floodplain, whereas the downstream stations are located within the floodplain. The location of the upstream stations is chosen in such a way that no overbank flow prevails near these stations during any flow condition and the measurements capture all the upstream flows during peak discharge.

The water levels (flow depths) measured were used to obtain discharges from the relationship between stages and discharge (rating curve). Rating curves were prepared for each of the upstream and downstream stations. Details of the procedures are indicated in Dessie et al., 2014.



Details of numbers shown in the figure

Number	Name of stream gauge	Name of catchment
1	Picolo	Gilgel Abay
2	Chimba	Gilgel Abay
3	Bahir Dar	Tana
4	Gelda	Gelda
5	Gumara	Gumara
6	Wanzaye	Gumara
7	Lower Gumara	Gumara
8	Rib near dam	Rib
9	Rib at Abobahir	Rib
10	Rib at bridge	Rib
11	Megech at bridge	Megech
12	Lower Megech	Megech
13	Dirma	Dirma
14	Gibara	Gibara
15	Kunzila	Tana Beles outlet

Figure 1. Stream gauges, the floodplain (lacustrine plain) and the rest catchments in Lake Tana basin; topographic data from SRTM DEM

Results and discussion

1. Monthly runoff for the upper and lower stations and for the incremental area (difference of the two)

At the beginning of the rainy season (early June), the incremental areas of Gumara and Megech (containing large floodplain areas) do not contribute runoff in June and July, rather abstraction of runoff from the upland flow is observed (Fig. 2). Excessive runoff contribution in August to the downstream stations was observed. At the beginning of the rainy season, the floodplain is recharged with groundwater, supplied by the higher elevated areas. The floodplain is also recharged by infiltration of rainfall and by the rivers that release water to the floodplains as overbank flows. Proceeding to the main rainfall of July and August, these recharging components are still active and contribute to the floodplain aquifer's saturation.

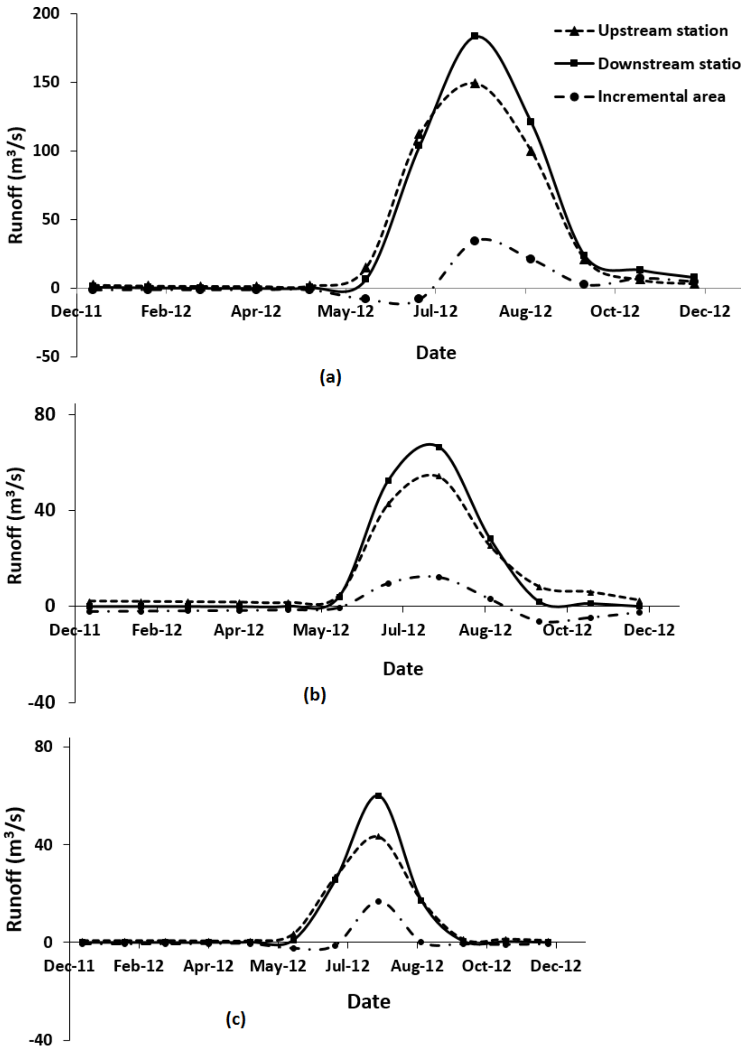


Figure 2. Temporal variability of runoff volumes at the upstream and downstream stations of Gumara (a), Rib (b) and Megech (c) rivers.

2. The floodplain as regulator of floods

The analysis of weekly peak floods (Q_p) for the months of June to October (Fig. 3) indicates that magnitude and variability of peak flow discharges in the floodplains (downstream stations) are on average 71 m^3/s (or 30%) smaller than the corresponding peak flow discharges at the upstream stations. Obviously, the peak discharges and the shapes of the flood hydrographs change as flood waves move downstream in the stream channels due to the routing process. However, it is less likely that the channel routing effect, for a reach distance of less than 15 km, can result in such a very pronounced reduction in flood magnitudes at the downstream station. The more likely explanation is that the actual peak discharges experienced in the rivers are very much affected by the flood storage within the floodplain. Therefore, the peak discharges of rivers in the floodplain of Lake Tana basin are buffered by the floodplain.

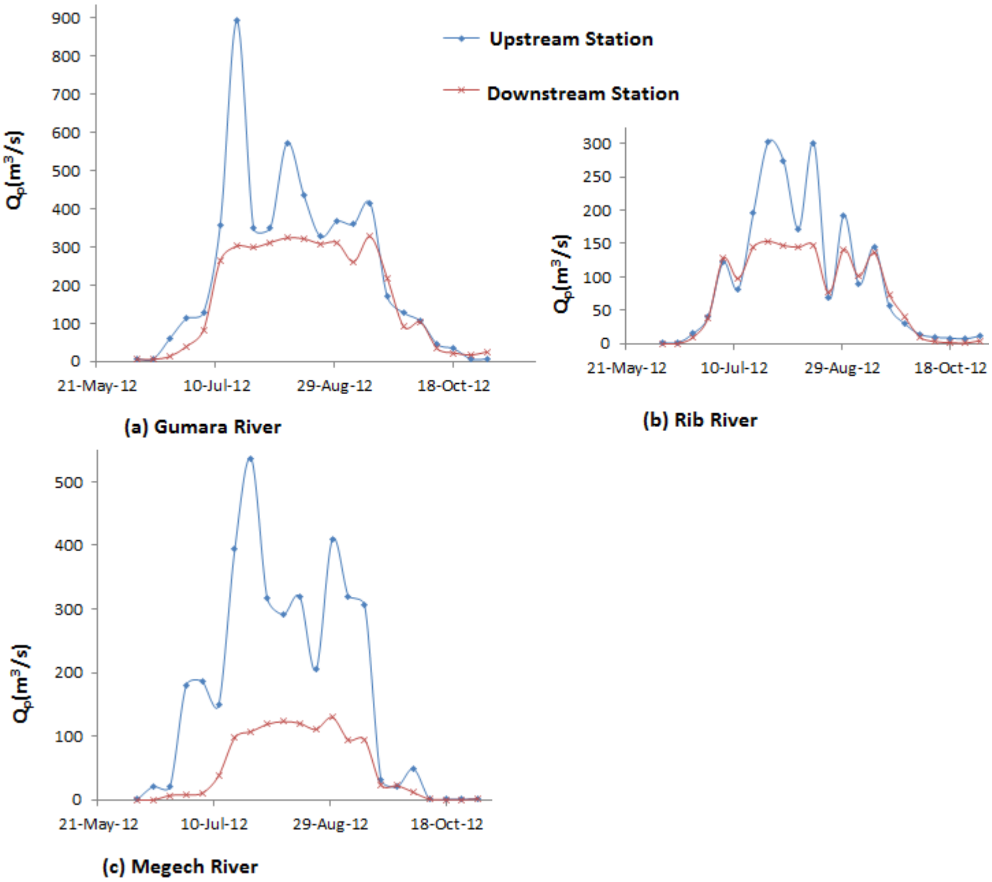


Figure 3. Weekly peak flow discharges (Q_p) at upstream and downstream stations for Gumara (a), Rib (b) and Megech (c) rivers.

Conclusion

The extensive floodplain in the Lake Tana basin has its impacts on the river discharges to the lake and on the sediment flux of the lake. In June and July, abstraction of runoff from the upland flow is observed. The magnitude and variability of peak flow discharges in the floodplains (downstream stations) are on average 71 m^3/s (or 30%) smaller than the corresponding peak flow discharges at the upstream stations.

Reference

Dessie, M., Verhoest, N.E.C., Admasu, T., Pauwels, V., Poesen, J., Adgo, E., Deckers, J., Nyssen, J., 2014. Effects of the floodplain on river discharge into Lake Tana (Ethiopia). Journal of Hydrology, 519: 699-710. DOI: 10.1016/j.jhydrol.2014.08.007.

Quantifying sediment accumulation in Chimba wetland near Lake Tana, Ethiopia

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Introduction

Wetlands are among the most productive ecosystems on the earth. They are often described as "the kidneys of the landscape", because of the functions they perform in the hydrological and chemical cycles, and as "biological supermarkets" because of the rich biodiversity they support (OECD, 1996). According to Dugan (1990), wetlands provide various resources and products such as food, fresh water, fuel, biochemical products, genetic materials, ornamental species etc. They also play key role in environmental regulation such as carbon sink, hydrologic regulations (groundwater recharge and discharge, stream flow, erosion control, flood attenuation water quality regulation through filtering and detoxification of pollutants).

Figure 1. Sediment deposited by from Gilgel Abay River at Chimba wetland (July 2014)

Methodology

Determining rate of sediment accumulation of wetlands

To quantify the amount of sediment accumulated in the wetlands, two methods have been used.

1. Flood sampling

Flood samples were taken in two places of Chimba wetland at main inlet and outlet points using one liter plastic bottles, weekly at fixed times, starting from July first till the end of August, 2014. Each sampling was composed of three replicates. The samples were thoroughly mixed or bulked. Then from each bucket one bulk sample of usually one liter was taken. A total of 20 samples (10 samples from inlet point and 10 samples from outlet point) were taken. While taking the flood samples, the depth of water stored in the study wetland was recorded. Finally the samples were taken to Bahir Dar University sediment analysis laboratory for filtration and separation of sediments. In the laboratory the samples were filtered by using Whatman 40 filter papers and then the filtered sediments were put in to the oven to dry for 24 hours at 105^0C. Then using the sensitive balance, the weight of each sample was measured.

2. Measurement of sediment deposition

To measured sediment deposition, cans were put in the wetland along three transect lines (Fig. 2). The first transect line lies near at main entrance point, the second around the middle of wetland and the third transect line lies near the outlet point, all across the flow direction. In each transect line 3 cans were put. A total of 9 cans were installed in the wetland starting over July and August, 2014. The cans were firmly contacted with the ground and small stones were put in the bottom of the cans. For ease management, supervision and safety, a rope was attached to each can and the tip of the rope was tied with plastic material to float on the water surface. GPS readings were taken on each transect line before the sample cans were arranged on the selected transect lines. The sediment accumulated in the entire wetland using can method was calculated as:

Sediment accumulated in Chimba wetland: $S= A_w*S_c / A_c$ (1)

Where, S= sediment accumulated in entire wetland, A_w = area of wetland (7,593,300 m^2), S_c = sediment accumulated in the can (kg), A_c = Area of the can (m^2)

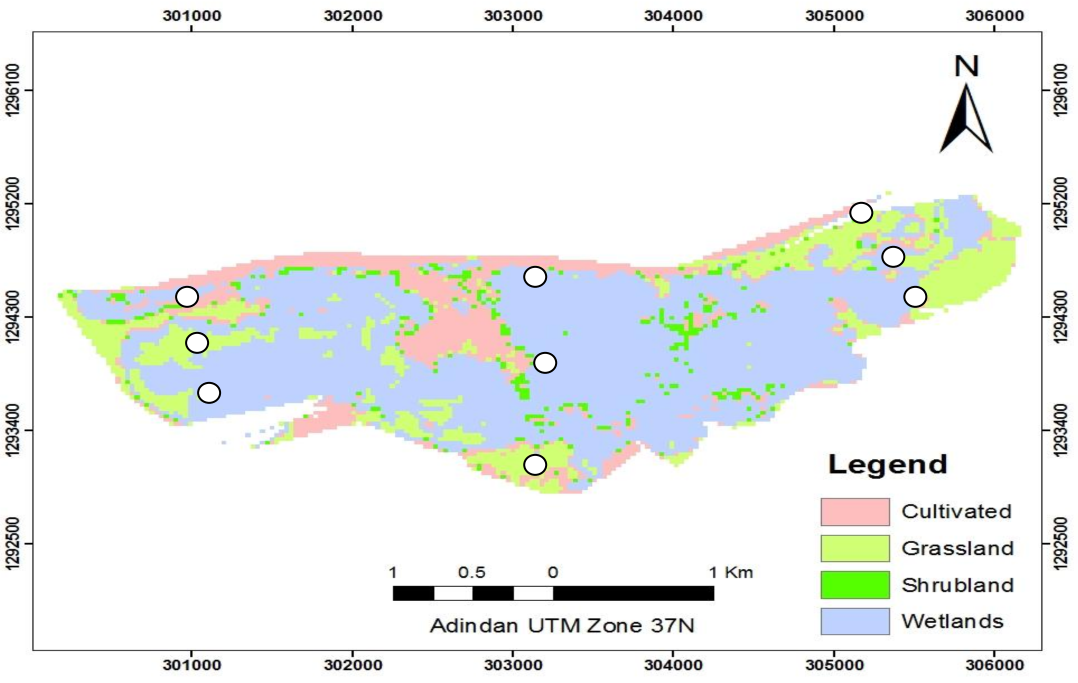

Figure 2. Transect lines showing locations of the cans in the wetland

Results and discussion

Sediment deposited in the study site as indicated in figure 3 from flood samples is varying in different periods. The mean percentage of sediment accumulation in Chimba in the month of July & August was 73.4% and 65% with a seasonal average of 69.2%. The result shows a linear trend of decreasing. In Chimba wetland the maximum sediment accumulation rate was recorded 6.058 g/liter in the month of August in the first week of sampling date, and the minimum accumulation was recorded 1.222 g/liter in the month of July at the last date of sampling. Variations in sediment accumulation within the sampling dates may be due to rain fall amount and its intensity to generate high amount of runoff carrying high sediment load and vice versa. The maximum inlet and outlet result for Chimba wetland was 7.215 g/liter & 3.575 g/liter in (22/11/06 & 27/12/06) respectively.

Sediment accumulated in the cans on selected three transects lines was found different for each transect. High and low amount of sediment 941 g/can and 145 g/can was accumulated in T1 and T3 respectively. Transect line one (T_1) is situated near the inlet points of the wetland across the flow direction and accounts for **941** g/transect (**56%**) of the total sediment accumulation by can method. Sediment accumulated in the second transect line (T2) is **275** g/transect and accounts for **26%** of the total sediment accumulated from all transects. The third transect line is situated near to the outlet side arranged in the same way as T_1 & T_2. Sediment accumulated in the third (T3) transect line is **145** g/3cans and accounts for **18%** of the total sediment accumulated in the whole transects lines**.** It is clearly seen that sediment accumulation is high in the first transect (T_1) and then decreases linearly up to the third transect (T_3) line. The trend shows that sediment at vicinity of the entrance points are maximum (due to heavy texture) and gradually decreases through distance (SPAC,2008) in the wetland and finally a flood carrying less amount of sediment leaves the wetland and continues its way to Lake Tana.

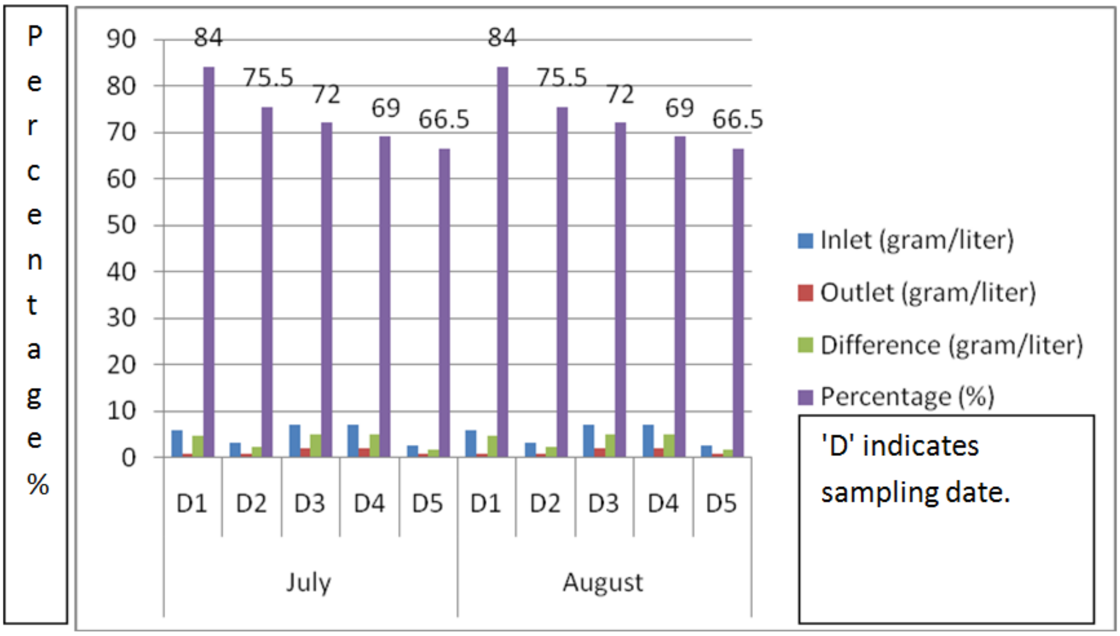

Figure 3. Sediment accumulation rate in flood samples from inlet and outlet points.

Sediment accumulation in the wetland area shows variation (figure 4). According to the can method, the total sediment accumulated in the entire wetland is calculated and the result was 140 ton per season.

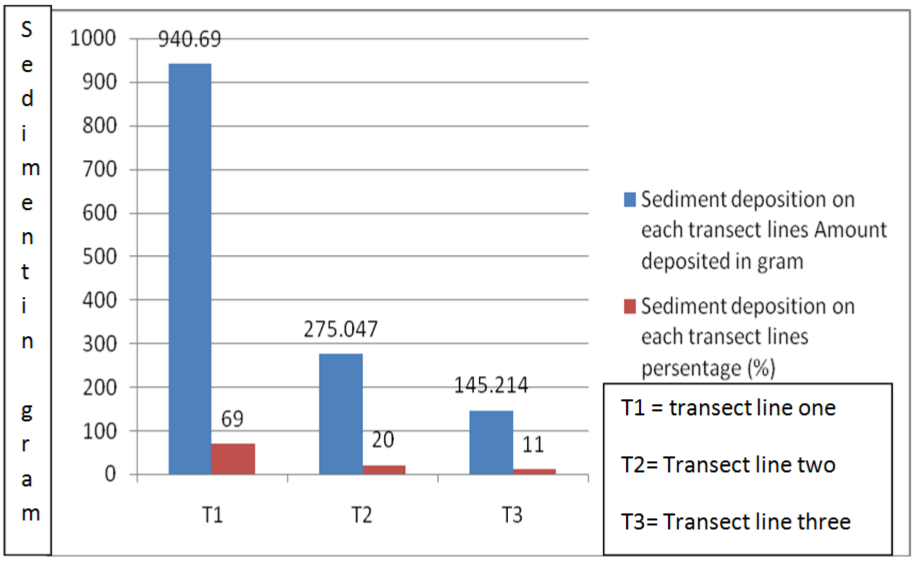

Figure 4. Sediment accumulation in gram unit on each transect lines (T1, T2 and T3)

Conclusion

Wetlands play a great role in maintaining the ecological and economical role in the watershed if they are well protected and managed. It can be concluded from this research that Chimba wetland contributes significant control in protecting Lake Tana and surrounding water bodies from sediment load that may carry excess nutrients like phosphates and nitrates that would cause eutrophication (formation of algal blooms on the surface of water) which is dangerous for existence of aquatic organisms (fish species in particular) and the sustainability of the Lake Tana ecosystem in general.

References

Dejen, J. Vijverberg, L. A. J. Nagelkerke, and F. A. Sibbing, 2004. Temporal and spatial distribution of micro-crustacean zooplankton in relation to turbidity and other environmental factors in a large tropical lake (L. Tana, Ethiopia), Hydro-biology vol. 513, pp. 39–49, 2004

Dugan, P.J. (1990) Wetland Conservation*:* a Review of Current Issues and Action. IUCN, Gland, Switzerland

Ethiopia Network on Food Security (2001) Monthly report, 7 February2001. http://www.fews.net/centers/ Files/Ethiopia 200101en.pdf

Organization of Economic Cooperation and Development (OECD) (1996). Guidelines for aid agencies for improved conservation and sustainable use of tropical and sub-tropical wetlands, guidelines on aid and development No. 9, OECD, 69 pp

SPAC (Soil & Plant Analysis Council). 2008. Handbook on reference methods for soil analysis. Georgia Univ. Stn., Athens. GA

Effects of scattered *Croton macrostachyus* trees on soil physicochemical properties and grain yield of maize in different parts of Ethiopia: A Review

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1. Introduction

Scattered trees grown in farmlands characterize a large part of the Ethiopian agricultural landscape and it is the most dominant agroforestry practice in the semi-arid and sub-humid zones of the country (Kindeya, 2004). For example, the growing of *Ficus albida, Cordia africana and Croton macrostachyus* on farmlands is commonly practiced in most parts of the Ethiopian agricultural landscape. In the Lake Tana basin, particularly in the southern part, pollard crotons are a key element in the landscape. This paper reviews research undertaken to investigate the effect of *Croton macrostachyus* (Amharic: *bisana*; common name: broad-leaved croton) on selected physico-chemical properties of soil and crop yield of maize (*Zea mays*).

2. Methodology

Tree density count was carried out for mature trees. Distribution and spatial arrangement of trees were assessed visually. For soil chemical properties determination, three adjacent *Croton* trees having approximately the same size and age, and growing side by side were selected. Soil samples were taken at four radial transects of different distances away from the tree base and at different soil depths, and composited for each distance and depth.

3. Tree density, distribution, and spatial arrangement

The density of trees varied from farm to farm within a site and between sites. Tree density per farm ranged from 8 to 16 trees per hectare with an average value of between 11 and 14 trees per hectare (Table 1). The distribution of trees within each farm was variable, with a few tree patches covering smaller areas and other trees scattered within the farm.

Table 1. Height, diameter, and crown cover of sampled trees and number of trees per farm of Croton macrostachyus at Adet and Bure, 1997

Tree No.	Height (m)		Diameter (m)		Crown cover (m^2)		Density (ha^1)	
	Adet	Bure	Adet	Bure	Adet	Bure	Adet	Bure
1	12	12	1.7	1	32	28.3	10	16
2	14	12	1.8	0.65	34	38.5	8	14
3	12	10	1.6	0.6	30	32	14	14

4. Soil Physical and chemical properties

4.1 Soil moisture and bulk density

The soil moisture content under the canopy of *Croton macrostachyus* is always higher (15.9%) than outside the canopy (13.6%) at Wondo Genet (Jiregna Gindaba, 1997) and 24.09% under the canopy and 20.89% in the open field at Umbulo Wacho watershed (Belay Manjur *et al*., 2014).

The soil bulk density under *Croton macrostachyus* significantly ($P<0.05$) increased from 0.92 g/cm^3 at the base of the tree to 1.05 g/cm^3 in the open cultivated field (Belay Manjur *et al.*, 2014) and from 0.79 g/cm^3 under the canopy to 0.86 g/cm^3 outside the canopy (Jiregna Gindaba, 1997). This decline in bulk density under tree canopy might be due to high accumulation of organic matter than the open land. Similar to these studies, lower bulk densities were observed under isolated *M. ferruginea (*Tadesse Hailu *et al., 2000*) and *Croton macrostachyus*, *Ficus albida* and *Cordia africana* (Abebe Nigussie, 2006) elsewhere in Ethiopia.

Table 2. The effect of C. macrostachyus trees, on soil chemical properties along canopy radius (standard deviations between brackets).

Location	Distance from tree base	OC %	TN %	C/N	Av. P (Ppm)	CEC	K	Ca	Mg
						(Meq/100 g soil)			
SNNR-Umbulo Wacho (Belay Manjur *et al.*, 2014)	1.5	2.03 (0.21)	0.41 (0.03)	4.93 (0.70)	11.33 (0.6)	53.09 (5.99)	1.33 (0.32)	42.05 (1.83)	13.22 (2.29)
	3.5	1.49 (0.32)	0.31 (0.04)	4.94 (1.69)	10.03 (0.4)	52.66 (4.58)	1.13 (0.3)	39.04 (1.7)	11.21 (2.10)
	25	1.38 (0.29)	0.23 (0.03)	6.11 (1.85)	8.73 (0.47)	38.10 (3.11)	0.79 (0.16)	29.38 (0.79)	8.7 (0.66)
Amhara-Adet (Yeshanew Ashagrie *et al.*, 1999)	0.5	2.36 (0.23)	0.26 (0.02)	9.08 (1.61)	4.23 (0.32)	28.6 (4.1)	2.74 (0.34)	12 (0.63)	2.02 (0.23)
	1.5	2.27 (0.13)	0.24 (0.04)	8.41 (0.32)	3.58 (0.13)	27.4 (2.05)	2.06 (0.17)	12 (1.9)	2.75 (0.18)
	3	2.21 (0.21)	0.22 (0.01)	10 (0.31)	3.05 (0.24)	27.27 (0.41)	1.73 (0.22)	11 (0.65)	2.58 (0.14)
	8	2.04 (0.05)	0.20 (0.03)	10 (0.29)	3.41 (0.22)	26.2 (0.35)	0.72 (0.12)	10 (0.75)	2.25 (0.15)
SNNR-Wondo Genet (Giregna Gindaba, 1997)	1	6.58 (0.35)	0.56 (0.04)	11.75 (0.25)	3.29 (0.39)	30 (2.05)	2.53 (0.19)	25 (2.5)	2.56 (0.16)
	3	6.13 (0.1)	0.53 (0.01)	12.5 (0.29)	1.39 (0.11)	27 (0.34)	2.4 (0.11)	19 (0.85)	1.74 (0.04)
	5	5.29 (0.05)	0.42 (0.01)	12.5 (0.29)	1.39 (0.11)	24 (0.58)	1.56 (0.20)	18 (0.94)	1.45 (0.26)
	30	4.53 (0.52)	0.34 (0.08)	14 (1.63)	7.44 (1.33)	22 (0.42)	1.14 (0.03)	15 (1.98)	1.87 (0.15)

4.2 Soil organic carbon, Total nitrogen and Available phosphorus

Organic matter has an important influence on soil physical and chemical characteristics, soil fertility status, plant nutrition and biological activity in the soil (Brady and Weil, 2002). In all the studies, values of OC, TN, Av. P were higher under the canopies of the scattered *Croton macrostachyus* trees than in the open field and all showed a decreasing trend with increasing distance from the base of the tree towards the open field *(*Table 2*)*. This variation in OC, TN, Av. P with distance away from the tree canopy was quite logical as the higher contents of organic carbon under the tree canopies were due to the leaf litter fall and decomposition of dead roots from the tree. This is a positive indication that agroforestry systems have the potential to maintain soil organic matter and nutrients.

These findings are in agreement with previous studies in different sites of Ethiopia, by Abebe Nigussie (2006) for *Cordia africana, Ficus albida* and *Croton macrostachyus*; Zebene Asfaw and Agren (2007) for *Millettia* f*erruginea* and *Cordia africana,* Tadesse *et al. (*2000) for *Millettia* f*erruginea and* Abebe Yadessa *et al.* (2001) for *Croton macrostachyus* and *Cordia africana.* All reported significantly higher OC, TN and Av. P under tree crowns as compared to the open cultivated land. Kindu Mekonnen *et al.* (2009) also reported that the content of OC, TN, Av. P showed a decreasing pattern with soil depths and with increasing radius from the closest to the midst and distant positions under *Hagenia abyssinica*, *Senecio gigas*, *Chamaecytisus palmensis* and *Dombeya torrida* tree canopies. Soil OC, TN and Av. P on the surface soil under the canopy of *Croton macrostachyus* were higher than outside (data not shown). Regarding soil depth, Jiregna Gindaba *et al*. (2005) has reported that the surface soil OC, TN, Av.P under both *Croton macrostachyus* and *Cordia africana* trees were significantly higher ($P<0.05$) than that of the subsurface.

4.3 Cation exchange capacity and exchangeable cations (K, Ca, Mg)

A gradual and significant decrease in the values of CEC was observed as the distance increases from the tree trunk to the open field (Table 2). The same trend was reported by Abebe Nigussie (2006) for surface soil at Harergie Hirna site in Ethiopia. CEC of a soil is a measure of soils negative charge and thus of the soils capacity to retain and release cations for uptake by plant roots. The CEC of a soil is strongly related with the organic matter content of a soil (Brady and Weil, 2002). With increase in organic matter under canopy of the studied trees, the total negative charges of the soil increased which in turn increased the CEC of the soil. Significant CEC increments under the tree canopy than the open one has also been reported by Belay Manjur *et al.* (2014) and Abebe Yadessa *et al.* (2001) for *Cordia africana,* Tadesse Hailu *et al.* (2000) and Jiregna Gindaba (1997) for *Millettia ferruginea.*

The values of exchangeable cations at different distances and soil depths under tree canopies are presented in Table 2. The amount of cations in the soils decreased gradually and significantly ($P<0.01$) as the distance from the tree trunk increased. This could be due to the high accumulation of litter under the tree canopies as the cations would be released when the accumulated litters from the canopies of the trees undergo microbial decomposition followed by mineralization and release of simple products to the soil. As a result, the amount of exchangeable cations would be higher under tree canopies than the open field. Kindu Mekonnen *et al.* (2009) also reported that the content of K, Ca and Mg varied at the three soil depths of the closest, midst and distant horizontal positions, i.e. it decreased from the top to the lower soil depths and from the closest to the midst and distant positions of the soil under *Hagenia abyssinica, Senecio gigas* and *Chamaecytisus palmensis* trees.

5 Leaf litter nutrient content and nutrient release

According to Abraham Mahari (2014) and Jiregna Gindaba (1997), potential C, and, N and P nutrient return from the leaf of *Croton macrostachyus was* significantly higher compared to leaf of *Cordia Africana* and *Millettia ferruginea*. Leaves of *Croton macrostachyus* had significantly ($P < 0.05$) lower concentration of lignin and significantly ($P < 0.05$) lower lignin:N and C:N than *Cordia africana* and *Millettia ferruginea* (data not shown). Also, experiment on mass loss and nutrient release showed that *Croton macrostachyus* has more rapid mass loss and nutrient release than *Cordia* *africana* and *Millettia ferruginea*. According to the same, fifty percent of the biomass applied was lost during the first 6–7 weeks in *Croton macrostachyus* which is lower by three weeks than in *Cordia Africana and Millettia ferruginea.* Similarly, the half lives of N and P in *Croton macrostachyus* were shorter by seven weeks than in *Cordia Africana* and *Millettia ferruginea.*

6 Maize yield

The grain yield of maize decreased significantly and gradually as the distance from the trees trunk increased, being 8.156 t ha^{-1} under the canopy and 6.802 t ha^{-1} as distance increases away from the tree trunks (Belay Manjur *et al.*, 2014; Yeshanew Ashagrie unpublished.). The increase in grain yield under the trees could be due to improvement of soil properties under the tree canopies than the open fields.

7 Conclusions

The extent to which *Croton* influenced the area in any one direction appeared to be nearly equal to the radius of its canopy. According to these studies, some nutrient conserving mechanisms have been postulated for this particular system against the high rates of organic matter decomposition, leaching and erosion losses. Thus the living biomass of the system i.e., trees act as a buffer or a major storage for essential nutrients and release them slowly to increase the nutrient efficiency of the system.

8 References

Abebe Nigusie, 2006. Status of soil fertility under indigenous tree canopies on farm lands in Highlands of Harargie, Ethiopia. MSc. Thesis, Haramaya University, Ethiopia.

Abebe Yadessa and Diriba Bekere, 2002. Influence of Scattered *Cordia africana* Trees on Maize Yield in Western Oromia, Ethiopia. *Proc. 4th FSE conference*. pp 91-98.

Abebe Yadessa, Fisseha Itanna, Olsson M., 2001. Contribution of Indigenous Trees to Soil Properties: The Case of Scattered Trees of *Cordia africana* Lam. in Croplands of Western Oromia. *Ethiopian J. Natural Resource* 3 (2): 245-270.

Abraham Mahari, 2014. Leaf Litter Decomposition and Nutrient Release from Cordia Africana Lam. and Croton Macrostachyus Del. Tree Species. Journal of Environment and Earth Science 4(1): 1-7.

Belay Manjur, Tesfaye Abebe and Abdu Abdulkadir, 2014. Effects of scattered *F. albida* (Del) and *C. macrostachyus* (Lam) tree species on key soil physicochemical properties and grain yield of Maize (*Zea Mays*): a case study at umbulo Wacho watershed, southern Ethiopia. Wudpecker Journal of Agricultural Research 3(3): 63 – 73.

Brady NC, Weil RR., 2002. *Nature and Properties of Soils*. 13th Ed. New York, USA.

Jiregna Gindaba, 1997. Decomposition of Croton macrostachys and Milletia ferruginea leaves for soil improvement in agroforestry system. MSc Thesis, Sewedish university of Agricultural, Sciences, Uppsala, Sweden.

Jiregna Gindaba, Rozanov A, Legesse Negash, 2005. Trees on farms and their contribution to soil fertility parameters in Badessa, eastern Ethiopia *Biol Fertil Soils* 42: 66–71.

Kindeya Gebrehiwot, 2004. Dry land Agroforestry Strategy for Ethiopia. *Paper Presented at the Drylands Agroforestry Workshop* 1st-3rd September 2004. ICRAF Headquarters, Nairobi- Kenya.

Kindu Mekonnen, Glatze, G., Sieghardt, M. and Ottner F., 2009. Soil Properties under Selected Homestead Grown Indigenous Tree and Shrub Species in the Highland Areas of Central Ethiopia, *East African J. Sci.*, 3(1): 9-17.

Tadesse H, Legess NL, Olsson M., 2000. *Millettia ferruginea* from Southern Ethiopia: Impacts on soil fertility and growth of maize. *Agroforest Syst* 48: 9–24.

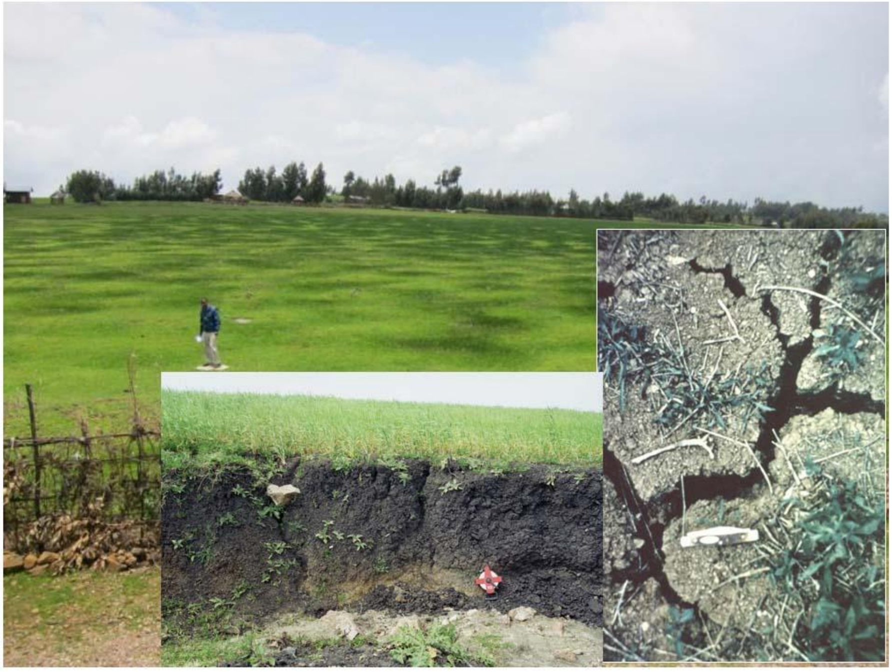
Yeshanew Ashagrie, Tekalign Mamo, Olsson, M., 1999. Changes in Some Soil Chemical Properties under Scattered C. macrostachyus Trees in the Traditional Agroforestry System in North-Western Ethiopia. *Ethiopian J. Natural Resourc. 1(2): 215-233.*

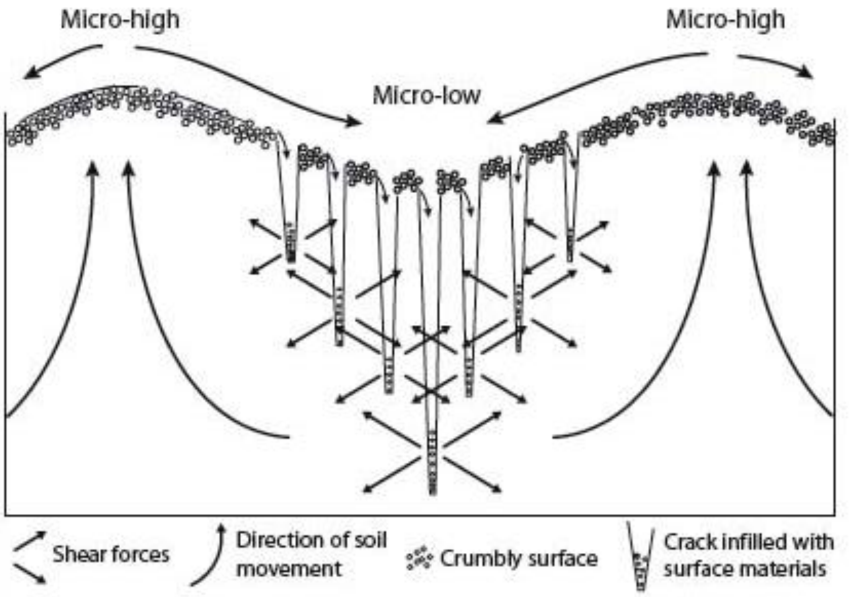
Zebene Asfaw and Agren GI, 2007. Farmers' local knowledge and topsoil properties of agroforestry practices in Sidama, Southern Ethiopia *Agroforest Syst* 71: 35–48.

Croton macrostachyus and recently introduced Sesbania agroforestry (in the dry season)

Vertisols and gilgai

(Prof. Seppe Deckers, KU Leuven)





A simplified view of the processes operating in soils with swelling clays. During dry periods, the clays shrink causing cracks to open in the soil surface. Over time, crumbs from the surface fall into the cracks. On wetting, clays in the soil body expand causing the cracks close. However, the newly buried surface material causes internal stresses which leads to a mixing of the soil body. This churning often creates a distinctive micro-relief known as gilgai, where the land surface becomes irregular with alternating mounds (puffs) and depressions (hollows). (MF)

Reference: Jones, A., Spaargaren, O., Breuning-Madsen, H., Brossard, M., Dampha, A., Deckers, J., Dewitte, O., Gallali, T., Hallet, S., Jones, R., Kilasara, M., Le Roux, P., Micheli, E., Montanarella, L., Thiombiano, L., Van Ranst, E., Yemerfack, M., Zougmore, 2013. Soil Atlas of Africa. European Commission, JRC, Luxembourg

Improving water management within the Koga irrigation scheme through an easy irrigation scheduling tool

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Introduction

Demographic pressure in the Nile Basin has resulted in tremendous pressure on natural resources to account for the increasing food and energy demand. This results in a rapidly increasing demand to put more land and fresh water for agricultural production. Koga reservoir (Fig. 1), constructed in 2009 is one of the latest large scale irrigation schemes for small holder farmers which, through its 1,750 ha reservoir, supplies irrigation to a 7,004 ha command area in the dry season (Table 1). The command area has a total of twelve irrigation blocks and eleven night storage reservoirs (Fig. 2). Each block has a secondary canal resulting in twelve lined secondary canals with a total length of 42 km. Secondary canals are fed by the main canal and night storage reservoirs and delivers water to the individual command areas via tertiary and quaternary canals.

Table 5: Overview of the various irrigation blocks

Irrigation Block	Irrigation potential area(ha)	Currently irrigated area (ha)	Total participating farmers	Total **m**ale farmers	Total **f**emale farmers	Irrigation volume released annually (Mm^3)	Night storage reservoir capacity (10^3 m^3)
Kudmi	373	368	715	657	58	3.97	20.01
Chihona	617	561	788	655	133	6.06	35.59
Ambomesk	812	676	1927	1834	93	7.30	40.18
Adibera	803	287	607	604	3	3.10	N/A
Tagel wodefit	616	562	1338	1288	50	6.07	37.73
Inguti	393	385	824	793	31	4.16	19.20
Lasi	484	435	417	357	60	4.70	25.20
Bered	468	453	557	499	58	4.90	24.73
Anident	497	418	465	431	34	4.51	40.70
Amarit	290	203	353	330	23	2.20	-
Teleta	787	662	1097	1049	48	7.16	41.89
Tekel dib	864	821	1268	1132	136	8.87	44.61
Total	**7004**	**5828**	**10356**	**9629**	**727**	**63.00**	**329.82**

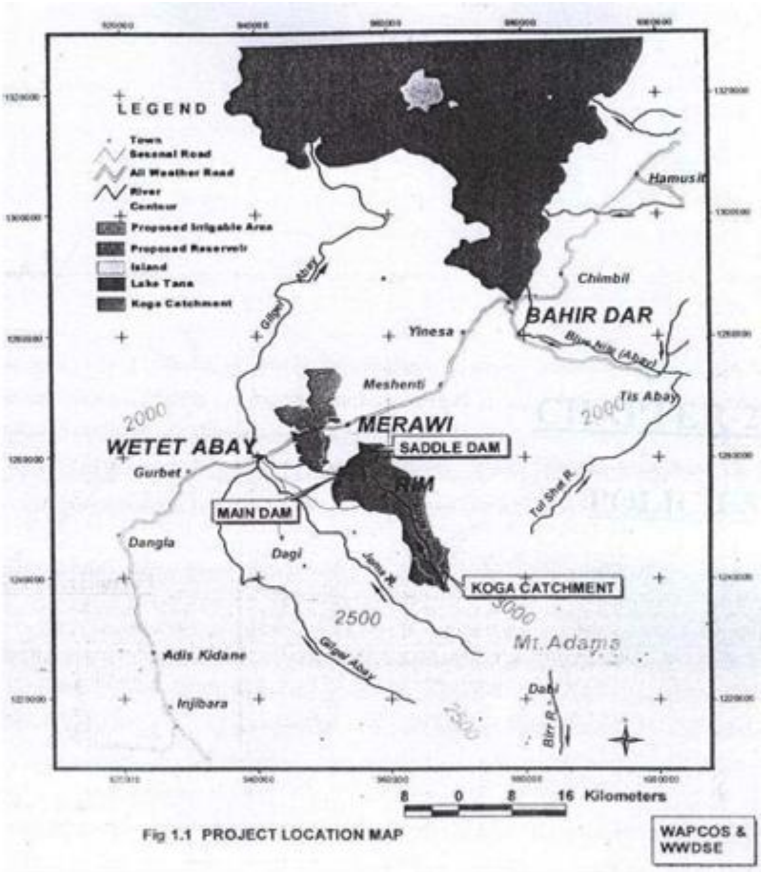

Figure 9: Location of Koga reservoir with respect to Lake Tana.

However, diagnostic study by the International Water Management Institute suggests that the average relative irrigation supply (i.e. supply/crop water demand ratio) for the entire Koga scheme is 1.9 in the main irrigation season (January – May) and 3.4 in the supplementary irrigation season (November to December). The work illustrated that about 70% of the over supplied water is lost on farm. Excesses supply of water, combined with untimely application has resulted in low yield, low water productivity and also conflict between head and tail irrigators. Estimated water productivity for wheat is 0.14 kg m^{-3}. Currently the gross value of production and net value added per ha for wheat in Koga is about US$ 591 and 461, respectively. Farmers lack sound knowledge on on-farm water management, particularly on how much to irrigate and when to irrigate, and they generally tend to over-irrigate as long as water is available which results in water shortage and conflicts in other parts of the schemes. As such, on farm water management has direct costs for scheme level performances.

This is, in fact, only one side of the problem. Increasing sedimentation rates in the reservoir, from the upstream 27,850 ha watershed area feeding into the reservoir, results in decreasing storage capacity, high water turbidity/poor water quality. From bathymetric survey data collected in 2012, the reservoir lost 0.5% of its storage capacity within four years (Mhiret, 2014). Data from a bathymetry survey shows 500 ton $km^{-2}yr^{-1}$sediment flow annually from upstream into the reservoir: a value which is higher than the erosion rates estimated by Alemayehu *et al.*, (2008) as 1.66 ton $km^{-2}yr^{-1}$.

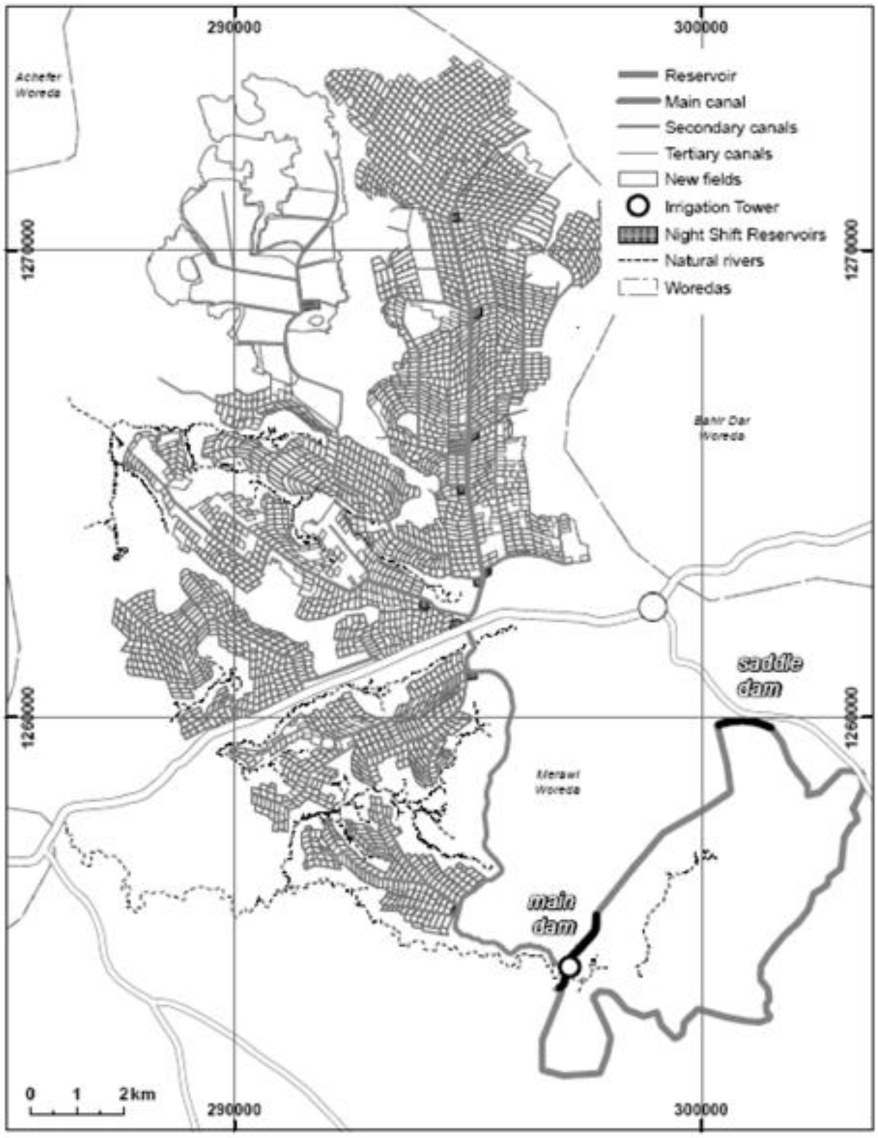

Figure 10: Overview of the Koga irrigation scheme downstream of the reservoir (Source Vigerske, 2008 in Eguavoen and Tesfai, 2012)

The ongoing siltation of the reservoir in combination with low water use efficiency in the scheme might only aggravate the rising issues of water scarcity and water conflicts. Water conflicts between the irrigation users occur around March up to May when levels in the reservoir are low due to over-irrigation at the onset of the season. This study makes use of wetting front detectors (WFD), an easy tool to guide irrigation scheduling (Stirzaker, 2003) and evaluates it's suitability to improve water use efficiency within the scheme and its impact on potato and wheat production.

Methodology

Site description

Koga reservoir, with a volume of 83 Mm³, feeds twelve irrigation blocks between November and May. The management and operation of the dam, reservoir, main canal and secondary canals falls under the jurisdiction of the Abbay Basin Authority whereas the tertiary canals & drains, quaternary and field canals are managed by the Koga Irrigation Development Project. Each quaternary canal has two outlets supplying 30 $m^3 s^{-1}$, enabling the irrigation of 8 ha per day. Water Users Associations are being established within the various irrigation blocks to improve water allocation within the block. The plots are on a rotational irrigation scheme of 8 -10 days. The main soil type (> 90%) in the command area is a Haplic Alisol while the remaining soils can be classified as Vertisols and Gleysols. The main cultivated crops are wheat, potato, onion and cabbage.

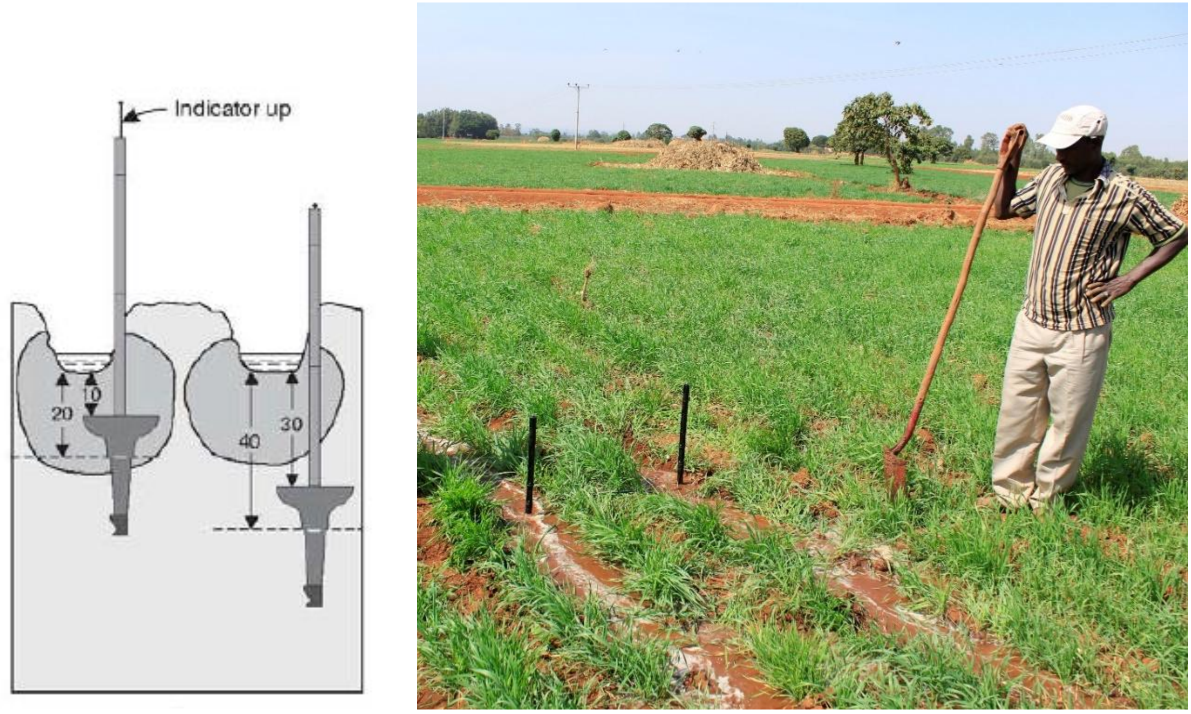

Figure 11: Installation of the wetting front detector according to Stirzaker et al. (2004) (left) with a wheat farmer within the Koga irrigation scheme (right).

Experimental design

During the dry season (November 2014 to April 2015), farmers growing wheat and potato were selected within the Ambomesk irrigation block with approximately the same date of planting (Table 1). Each farmer dedicated $100m^2$ for the wetting front indicator experiment while the remaining field was taken as a control. For the control fields furrow irrigation was performed according to the overall scheme management (approximately every 8-10 days) and irrigation was managed as per farmers experience. In the 100 m^2 experimental plot a pair of wetting front detectors were installed partially in the bed and partially in the furrow (Fig. 3) at approximately 2 m from the furrow end. The shallow detector was installed at 20 cm depth while the deep detector was installed at 40 cm.

Farmers were trained on how to use the irrigation tool and instructed to start irrigation whenever the indicator of the shallow detector was down and stop when the shallow detector responded. Recording books were distributed to each of the participating farmers to record when and how long irrigation took place for both water management treatments (i.e. control and WFD). Standard plant development indicators were monitored throughout the season and the harvest product was collected and weight. Data were analyzed using the Wilcoxon non parametric test due to non-normality using SAS v9.2. Feedback of farmers were collected during meetings to understand their perception of the tool.

Table 6: Irrigation characteristics for the various fields after the wetting front detector was installed.

		Irrigation events		**Irrigation interval (days)**		**Irrigation furrow (min)**		**Irrigation depth (mm)***		**Reduction irrigation depth (%)**
Crop	**Field**	**Control**	**WFD**	**Control**	**WFD**	**Control**	**WFD**	**Control**	**WFD**	
Potato	K01	5	3	10	17	7	7	1248	1093	12
	K03	5	4	11	14	8	7	1264	950	25
	K06	8	5	10	18	7	7	1968	1571	20
	K10	5	5	13	14	15	8	2858	1645	42
	K11	5	3	13	17	10	9	1433	1137	21
	K12	5	4	14	16	18	9	2718	1088	60
	K16	6	5	13	15	11	8	2889	1608	44
	K17	6	5	10	14	11	7	1560	1045	33
	K18	9	5	10	21	6	5	1136	559	51
	Mean	**6**	**4**	**11**	**16**	**10**	**7**	**1897**	**1188**	**34**
	SD	**1**	**1**	**2**	**2**	**4**	**1**	**693**	**338**	**15**
Wheat	K02	6	4	10	14	7	6	1209	793	34
	K05	5	3	11	16	8	8	1200	767	36
	K07	8	5	11	18	10	9	3208	1339	58
	K08	6	3	12	28	7	8	1048	924	12
	K13	7	5	13	15	11	7	2693	1011	62
	K14	6	4	12	15	5	5	932	420	55
	Mean	**6**	**4**	**10**	**15**	**7**	**6**	**1569**	**799**	**39**
	SD	**2**	**1**	**3**	**7**	**3**	**2**	**899**	**318**	**19**

* Irrigation depth for the period after the wetting front detector was installed.

Results and discussion

Changes in irrigation timing and quantity

The wetting front detectors were installed a few weeks after planting which allows only a partial irrigation evaluation. For both potato and wheat the number of events following installation were significantly lower for the WFD plots (potato: p = 0.0065, wheat: p = 0.0056). The time farmers used to irrigate the furrow was significantly shorter for the wetting front detector plots (p= 0.0067) in the potato fields whereas no significant difference was found between the WFD and control for wheat (

Table *6*).

The irrigation depth applied per event varied strongly between farmers and events for the various crops (Figure 12). The irrigation depth applied during the entire monitoring period was significantly higher in the control (potato: p= 0.0305 and wheat: p = 0.0374). On average irrigation depth was reduced by 34% and 39% in the potato and wheat fields when farmers used the WFD (

Table *6*). The effect of using the wetting front detectors on the irrigation depth reduction varied largely for both crops. This could indicate either that the farmers are already experienced in irrigation and only little room for optimization is possible under the current furrow irrigation system or that challenges still existed in applying the wetting front detector correctly.

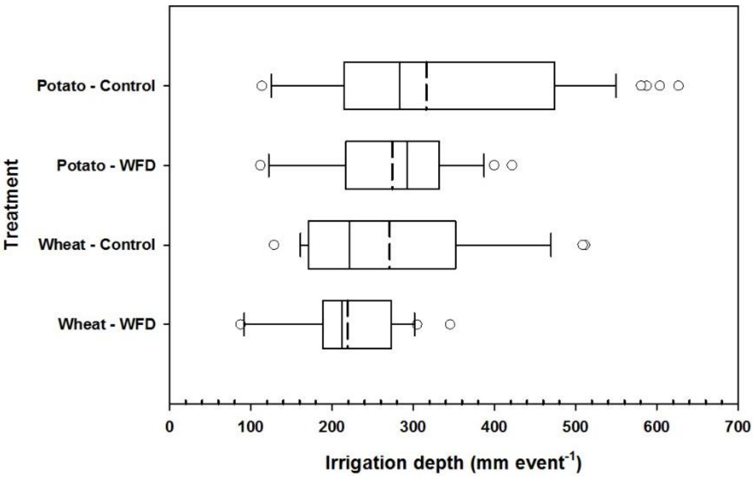

Figure 12: Irrigation depth (mm) applied per event in the control and WFD plots for wheat and potato. Crossbars, boxes and whiskers represent the median, quartile range (5th and 95th percentile) and range, respectively. The dashed line represents the mean. Number of observations for potato – control, potato-WFD, wheat- control and wheat – WFD were 54, 39, 38 and 24, respectively.

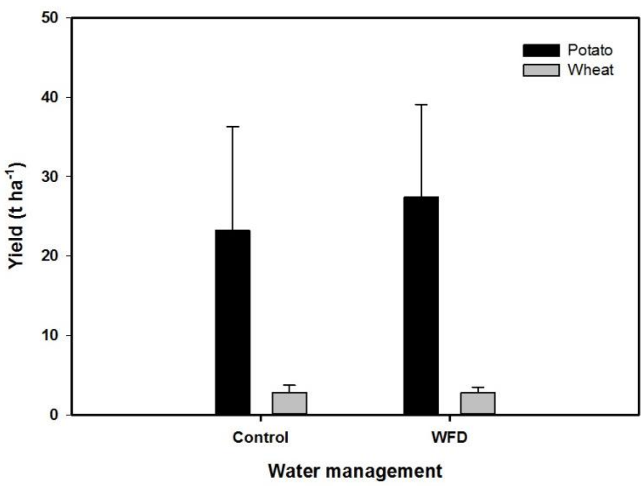

Figure 13: Measured potato and wheat yield (t ha^{-1}) under the two water management treatments.

No significant increase or decrease in yield was observed between the two water management treatments for both crops (Figure 13). These preliminary findings indicate that water could be saved when using the wetting front detectors without negatively influencing the yield. However, the irrigation depth applied in both water management treatments during the monitoring period (i.e. before the wetting front detectors were installed) exceeds the crop water demand of both potato and wheat in this area which is approximately 478 mm (wheat) and 403 mm (potato) given the local climatic conditions. Assuming a 50% irrigation efficiency for the local furrow practice this would lead to a gross irrigation requirement of 717 mm and 604.5 mm. Further research is needed to assess the effect of WFD placement in function of the furrow length on water saving and fertilizer use efficiencies from the onset of the irrigation season.

Improving the water use dialogue using wetting front detectors

Farmers involved in field trials were able to reassess their previous irrigation water use practices based on their current experiment with the WFD technology. They seem to have observed that the rush to have more and more water for irrigation may not be necessarily worthwhile. Preliminary interviews and discussions conducted with field trial participants in the Koga irrigation scheme revealed potential contributions of the WFD to manage conflicts due to competition over water (Figure 14). Farmers indicated that before using the WFD, they would often insist to irrigate every so often, thereby creating water shortage and leading to conflicts over water. They reported that such conflicts have been avoided while using the WFD. Further detailed research will be conducted to examine the potential of the tool in reducing conflicts along with farmers' adoption of the technology.

Figure 14: Feedback from participating farmers during the second round of WFD training in Koga.

Farmers involved in field experiment clearly linked the importance of the WFD to their water user association. They indicated that the WFD can support their water user association to deal with conflicts over irrigation water use. For example, a farmer cultivating wheat in the experiment field said, "The tool is useful for water committees and water group leaders. In particular, it helps water fathers as it helps to avoid conflicts due to competition over water." Farmers involved in management activities of the Koga irrigation scheme also emphasized the potential contributions of the WFD to their water user association. They highlighted its potential role in supporting their management activities. For example, a committee member of the water user association stated that "It will be very useful for our administration work. Farmers with adjacent plots can also live peacefully." Another committee member participating in the field trial also remarked that "Now a user will not bother me insisting that 'you have the responsibility to mediate me against another person.' He can use the instrument."

Conclusion

A reduction of 34% and 39% in irrigation depth was observed when the WFD was used for wheat and potato cultivation, respectively. The reduction in irrigation had no significant impact on crop yield. Preliminary results of the first season shows promise to train farmers and reduce over-irrigation within the scheme by using the wetting front detectors. Some farmers had more challenges in understanding and using the detector more efficiently compared to others.

Acknowledgement

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References

Alemayehu, B., Hagos, F., Haileslassie, A., Mapedza, E., Awulachew, S.B., Peden, D., Tafesse, T., 2008. Payment for Environmental Service (PES) for improved land and water management: the case of Koga and Gumara watersheds of the Blue Nile Basin, Ethiopia. Proceeding of CPWF second International Workshop November 2008, Addis Baba Ethiopia. International Water Management Institute (IWMI), Addis Ababa, Ethiopia.

Eguavoen, I., Tesfai, W., 2012. Social Impact and impoverishment risks of the Koga irrigation scheme, Blue Nile basin, Ethiopia. Africa Focus 25, 39-60.

Mhiret, D.A., 2014. Investigation of reservoir sedimentation problem in the Upper Blue Nile Basin Using Bathymetry Analysis and SWAT Model: A case study on Koga Reservoir. Department of Water Resource Engineering (Engineering Hydrology). Bahir Dar University, Bahir Dar, Ethiopia.

Stirzaker, R., 2003. When to turn the water off: scheduling micro-irrigation with a wetting front detector. Irrigation Science 22, 177-185.

Stirzaker, R.J., Stevens, J., Annandale, J., Maeko, T., Steyn, M., Mpandeli, S., Maurobane, W., Nkgapele, J., Javanovic, N., 2004. Building capacity in irrigation management with wetting front detectors. Report to the Water Research Commission Research Project No 188. Water Research Commision, South Africa, p. 94.

Impact of *Eucalyptus* plantation on undergrowth, adjacent crops and sub sequent crop production

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1. Introduction

Eucalyptus was introduced to Ethiopia around 130 years ago, during the reign of emperor Menelik II. The emperor, assisted by his French technical advisor, introduced the tree with the objectives of meeting ever-increasing demand for construction poles and firewood due to the foundation of the new Ethiopian capital city called Addis Ababa (Yitebitu, 2010; Amare, 2010).

In Ethiopia, both *Eucalyptus globules* (known locally as '*Nech Bahrzaf*'), adapted to cold highlands and *Eucalyptus camaldulensis* (locally called '*Key Bahrzaf*') adapted to intermediate altitude are grown. Since then *Eucalyptus* growing has continued to increase to all over the country. Ethiopia has now the largest area of *Eucalyptus* plantations (more than 0.5 million ha) in East Africa and is one of the 10 pioneer countries that introduced the *Eucalyptus* trees (Gessesse & Teklu, 2011).

In Mecha district of Amhara region, many fertile croplands have been converted to *Eucalyptus* woodlots by smallholder farmers due to attractive economic return. Farmers planted *Eucalyptus* by intercropping with some crop species in the first year of plantation and in the second year they also harvest forage for theire cattle (Figure 1). After two years there is a reduction of plant biomass under *Eucalyptus* trees (Figure 2).

Figure 1: Intercropping and forage production under Eucalyptus woodlots

In Ethiopia, usually natural forests have been converted to croplands and croplands to *Eucalyptus* woodlots; however, land use changes from Eucalyptus to cropland is rare. This might be due to the alledged negative impacts of *Eucalyptus* on soil physico-chemical properties that could cause reduction of crop yields. The question what would be the soil fertility status of the soil if eucalypt land is changed back to crop land after many years, remained to be answered.

Figure 2: Reduction of plant biomass after shedding of Eucalyptus leaves

Moreover, effects of *Eucalyptus* on bordering crops are poorly studied. Very recently, a land use conversion was made from *Eucalyptus* woodlots to irrigated crop lands at Koga Irrigation Scheme of Mecha district (Figure 3). Koga irrigation scheme is entirely dedicated for production of food crops so as to meet part of the national food security objectives. Therefore, the objectives of our studies were to investigate the effect of *Eucalyptus* in the neighboring croplands and to assess the effects of land use change from *Eucalyptus* to cropland on soil physico-chemical properties and evaluating the farmers' opinion on land productivity problems faced due to the present land use change.

Figure 3: Eucalyptus woodlots at one of the sampling sites (Left, Google Earth image in 2009) before and after uprooting (right, Google Earth image in 2011). Red place marker (11.4078°N, 37.1023°E) indicates correlative position. The road at the lower side and several buildings are permanent elements. Primary and secondary irrigation canals are clearly visible. Satellite imagery is conformably oriented; width of scene is approx. 500 m.

Materials and Methods

Description of the Study Area

Koga irrigation scheme is situated in Mecha district, West Gojam Zone, Amhara Regional State of Ethiopia close to Merawi town at elevations of 1950-2000 m a.s.l. (Figure 4). The mean annual rainfall at Merawi town is 1589 mm and mean temperature is 16-20^{o}C (Nigussie & Yared, 2010).

Evaluation of soil property from Eucalyptus plantation: Evaluation of soil properties from *Eucalyptus* plantation was done at varying distances (0.5, 1, 2, 5, 10, 15, 20, 40 meters) away from the border plantations at single depth (0 – 20 cm) or from three profile depths (0 – 20, 20 – 40 and 40 – 60 cm).

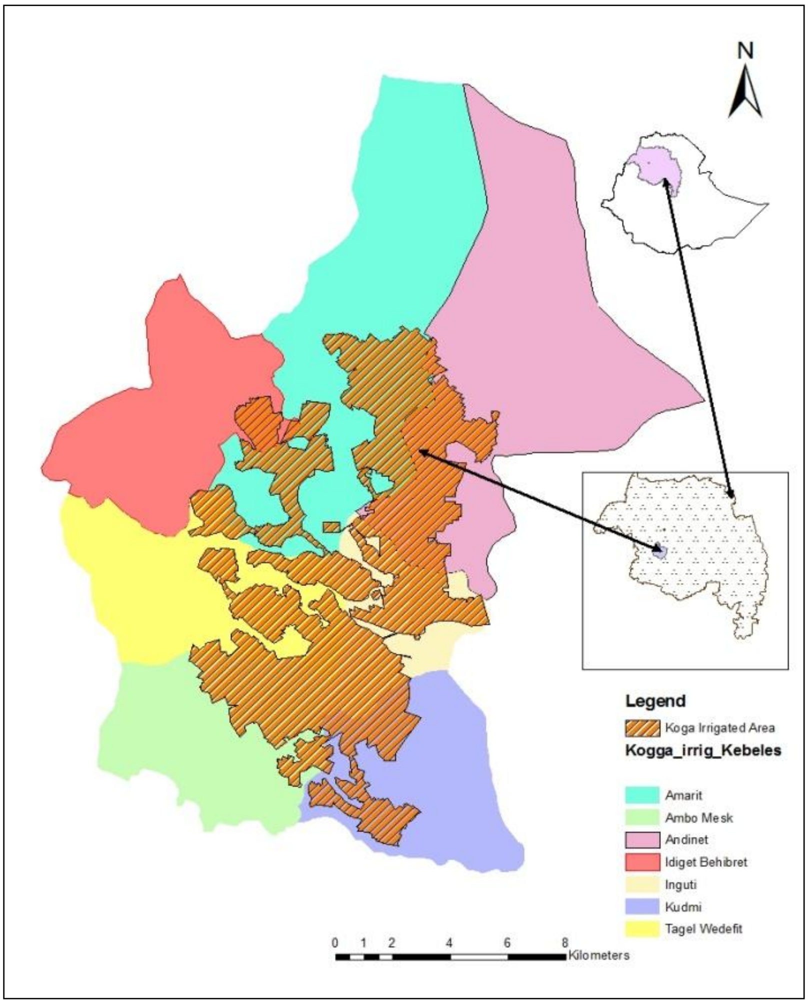


Figure 4: Koga irrigation scheme overlaid on the Kebele Administrations

Crop biomass, root samples and shading effects were recorded in the same distances away from the plantations while undergrowth density counts were conducted along transects under varying canopy densities in the tree plantations.

Comparison between soil physico-chemical properties on three land use types: Soil properties of cultivated land, *Eucalyptus* plantation and crop land coverted from *Eucalyptus* woodlots were sampled at different soil depths. The determined soil properties are bulk density, soil-water content, particle size, soil pH, organic carbon, total nitrogen, available phosphorus.

*Farmers' perception: We a*ssessed farmer's observations on the effect of land use changes from *Eucalyptus* woodlot to cropland or on the yield of agricultural crops cultivated on longstanding cropland and cleared *Eucalyptus* land.

Results and Discussion

1. ***Effects of Eucalyptus on soil physical and chemical properties***

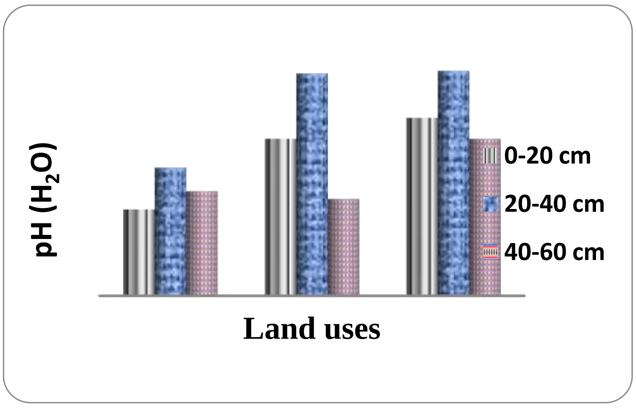
Soil under *Eucalyptus* woodlots and land use changed from Eucalyptus to cropland had similar lower (about 1.01gm/cm^3) bulk densities as compared to cropland (1.11-1.24 g/cm^3) at both depths. The lower bulk density under *Eucalyptus* may be due to organic matter accumulation and less trampling by livestock movements. All land utilization types are in good condition in terms of their bulk density.

Table 1: Mean soil chemical properties under different land uses

LUT	pH (1:2.5Water)	OM (%)	TN (%)	P (ppm)	CEC (cmlo$_c$ kg^{-1})	Ex-acidity (cmlo$_c$ kg^{-1})
Eucalyptus	5.20 b	3.21 a	0.18	14.94	21.33	0.78
Continuous Crop	5.41 a	2.86 b	0.15	17.96	20.69	0.60
Eucalyptus changed to cropland	5.51 a	3.36 a	0.15	16.27	21.45	0.66
Probability (P≤0.05)	*	*	**	Ns	Ns	Ns
CV (%)	4.02	11.20	11.48	22.22	13.42	38.8

** Significant (P≤0.01), * significantly different at P≤0.05 and ns denotes for not significantly different

The soil under *Eucalyptus* showed relatively lower phosphorus (14.94 ppm), lower pH (5.20) and higher exchangeable acidity (EA) of 0.78 cmol$_c$ kg^{-1} as compared to the other land uses. Parmanently cultivated crop land has a better phosphorus content (18 ppm), intermediate pH (5.41) and lower exchangeable acidity (0.60 cml$_c$ kg^{-1}) values (Table 1). Even if, the pH of the area is recognized as acidic, the land changed from *Eucalyptus* to cropland, however, showed an improvement in soil pH by 0.29 unit and a reduction of EA by 0.12 cml$_c$ kg^{-1} as compared to soils under *Eucalyptus* cover. This might be due to litter and root biomass decomposition that could have influenced release of cations. The larger available P in croplands might be due to the application of phosphorus-containing fertilizer in the past.



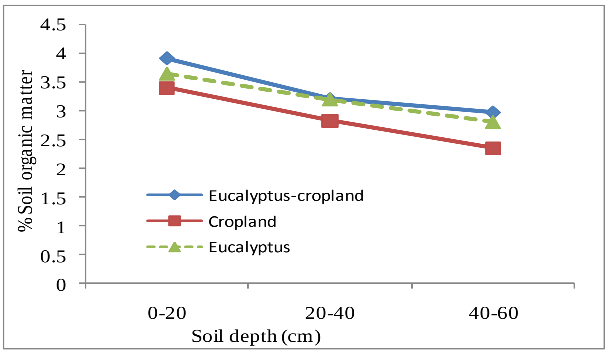


Figure 5: Effects of land use and soil depth on soil pH (left) and soil organic matter (right)

Crop lands converted from *Eucalyptus* plantation showed higher organic matter (3.36%) content and CEC (21.45 cmol$_c$ kg^{-1}). *Eucalyptus* woodlots have an intermediate OM (2.86%) and CEC (21.32

cmol$_c$ kg^{-1}) whereas the lower OM content and CEC of 2.86% and 20.69 cmol$_c$ kg^{-1} respectively were obtained on croplands (Figure 5 and Table 1) which could be due to a complete removal of crop residues for animal feeds and fire wood. As shown in Figure 5, organic matter decreased along with the soil depth. The vatiation of total N across the land uses follows similar pattern with organic matter.

Generally, results indicated that the land use changed from *Eucalyptus* to cropland with in the first three years after clearing *Eucalyptus* tree, were found better in all the analyzed parameters than the lands permanently under food crops except in available P.

2. Border effects of Eucalyptus plantation on soil property

Soil nutrient concentration is affected by the distance from *Eucalyptus* plantation. In general, macronutrient status increased with distance from the *Eucalyptus* stand. Total nitrogen (TN), nearest to *Eucalyptus* stand was above average. At 5 m distance TN was very low (Figure 6) and forty meter far away from the trees again TN increased up to the same value as the values at 1 m from the trees. Available phosphorus (P) content showed an upward trend with distance from the *Eucalyptus* stand (Figure 5). Exchangeable Ca concentrations, at 1 m distance was 7.8 cmol$_c$ kg^{-1} of soil and less than the values at the other sampling points along the transect (10 –20 cmolc kg^{-1} of soil).

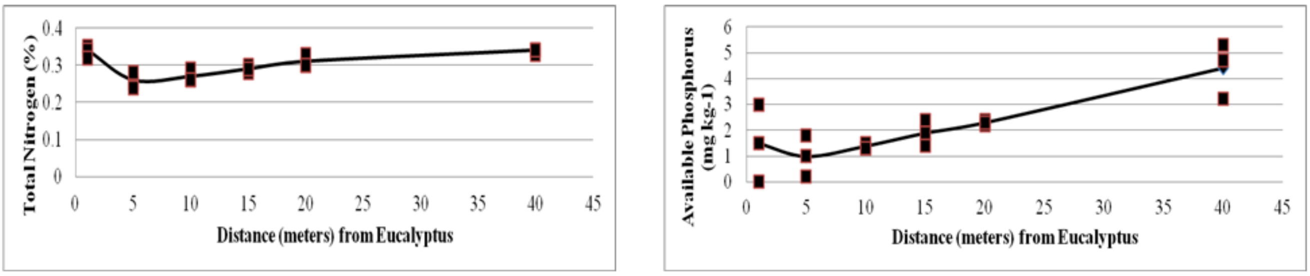


Figure 6: Total nitrogen and available Phosphorus vs distance from Eucalyptus

Exchangeable potassium (K) concentrations at all distances were in high range, and independent of distance to the *Eucalyptus* stand.

3. Crop performance from Eucalyptus distance and undergrowth density

Maize yield and biomass are a function of distance to the *Eucalyptus* stand (Figure 7). There was a 10-fold difference in biomass for the 1 and 20 m sampling points. The yield and biomass between 20 and 40 m was not significantly different. Thus impacts of *Eucalyptus* on soil properties and moisture content are limited to a maximum distance of 20 m away from the tree. The average undergrowth density of the *Croton machrostachyus* plantation was significantly ($P < 0.01$) greater than that of under *Eucalyptus* trees. Although the undergrowth density under both species of tree plantations decreased as the canopy closure increased, the undergrowth density in the *C. machrostachyus* stand is greater than that of the *Eucalyptus* stand at all the different densities of the canopy (Figure 6).

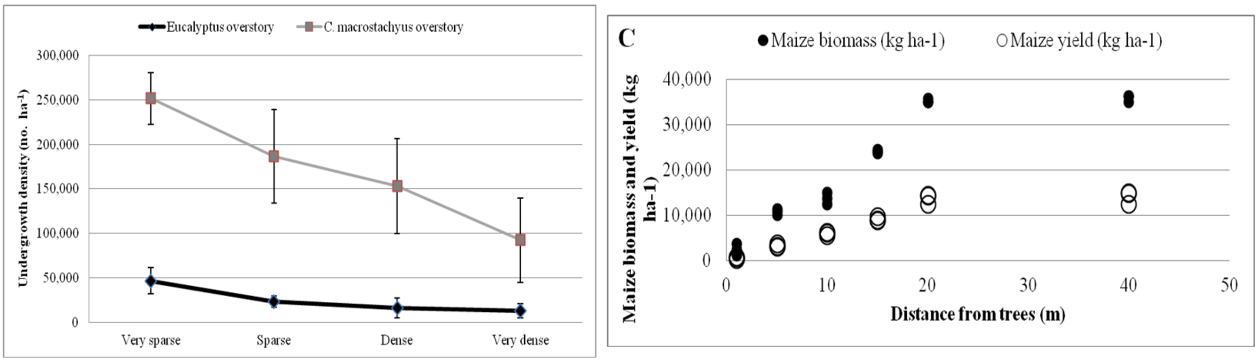


Figure 7: Effects of Eucalyptus on maize biomass production (left) and undergrowth (right)

It was thus revealed that the poor performances of the adjacent plants, particularly maize and undergrowth plants, were due to light, water and nutrients competition and soil water repellency

4. *Farmers perception on environmental impact of Eucalyptus*

Farmers were also asked about the perceived negative effects of *Eucalyptus*, its effects on soil fertility as well as why they expand the tree in such alarming rates. All interviewed farmers (25) perceived that *Eucalyptus* plantations have a negative environmental impact because of its shading effect, water and nutrient competition, stunted growth of nearby crops and forcing poor grain filling. Almost half of the respondents also perceived that there is no difference between crops species in resisting the adverse effects of *Eucalyptus*. *Eucalyptus* tree was also believed to affected soil property by drying out the soil (92%) through excessive root suction.

From the interviewed farmers, 73% believed that *Eucalyptus* plantation on croplands is economically more profitable than other farm activities. They consider *Eucalyptus* as an asset (like money deposited in a bank), requiring low labor as compared to crop production, low fertilizer requirement and continuous harvest from once established woodlots, while only 13% of respondents appreciated annual crops for their frequent and immediate return compared to eucalyptus.

Almost all respondents had assumed that land use change from *Eucalyptus* woodlots to agricultural crop was impossible. After the change occurred, many farmers consider now that cleared *Eucalyptus* land has higher fertility (93%) and crop yield than continuous croplands. From the respondents, 33% estimated that the fertilizer amount required for the formerly *Eucalyptus* planted land is somehow lower as compared to continuous croplands. 26.7% respondents Reduced fertilize application by a quarter has been practiced by 26.7% of the respondents for their maize crop in the first and second year after *Eucalyptus* clearance. Even though, farmers recognized the benefits of *Eucalyptus* land for crop production they are not willing to change their *Eucalyptus* land to cropland for the simple reason that labor and input requirements for producing food grains are cumbersome. Similar findings were also reported by Desalegn Tadele and Demel Teketay (2013) who found higher yield of barley and finger millet in *Eucalyptus* cleared area than the adjacent former croplands.

Therefore, it is possible to conclude that changing land use from *Eucalyptus* to cropland had no demonstrated detrimental effect on soil fertility and productivity of crops. Thus, a farmer can shift a *Eucalyptus* woodlot to crop production whenever the need arises.

References

Amare, G. (2010). Eucalyptus farming in Ethiopia: The case of Eucalyptus farm and village woodlots in Amhara Region. In L. Gil, W. Tadesse, E. Tolosana, & R. López (Eds.) *Eucalyptus species management, history, status and trends in Ethiopia* (pp. 65-74). Proceedings from the congress held in Addis Ababa. September 15-17, 2010. Addis Ababa, Ethiopia.

Birru Yitaferu, Anteneh Abewa & Tadele Amare (2013). Expansion of Eucalyptus Woodlots in the Fertile Soils of the Highlands of Ethiopia: Could It Be a Treat on Future Cropland Use? Journal of Agricultural Science, 5(8), 97-107.

Desalegn Tadele & Demel Teketay (2014). Growth and yield of two grain crops on sites former covered with eucalypt plantations in Koga Watershed, northwestern Ethiopia. *Journal of Forestry Research (2014) 25(4): 935−940.* DOI 10.1007/s11676-014-0483-9.

Gessesse, D. & Teklu, E. (2011). Eucalyptus in East Africa, socio-economic and environmental issues. Planted forests and trees working papers. Working paper 46/e, Forest Management Team, Forest Management Division 30 pp. FAO, Rome.

Nigussie, T. & Yared, A. (2010). Effect of land use/land cover management on Koga reservoir sedimentation. Nile basin capacity building network. Cairo, Egypt. Retrieved from http://www.nbcbn.com/Project_Documents/Progress_Reports_2010/Local_Actions/Ethiopia-local-2010.pdf

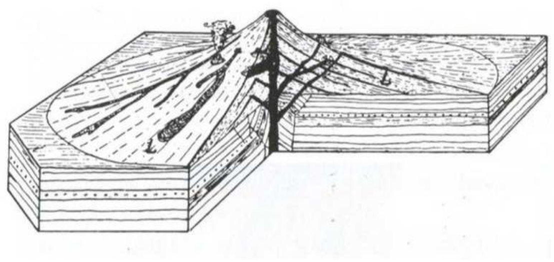
Tilashwork Chanie, Collick, A.S., Enyew Adgo, Lehmann, C.J., & Steenhuis, T.S. (2013). Eco-hydrological impacts of Eucalyptus in the semi humid Ethiopian Highlands: the Lake Tana Plain. Journal of Hydrology and Hydromechanics, 61(1), 21-29.

Yitebitu, M. (2010). Eucalyptus trees and the environment: a new perspective in times of climate change. In L. Gil, W. Tadesse, E. Tolosana. & R. López (Eds.), Eucalyptus species management, history, status and trends in Ethiopia (pp. 104-113). *Proceedings from the Congress held in Addis Ababa. September 15-17, 2010.* Addis Ababa, Ethiopia.

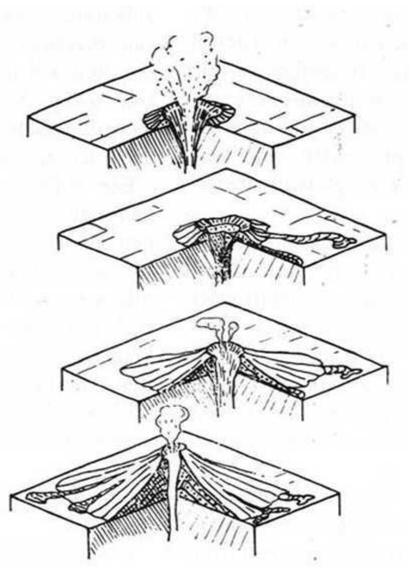
Secondary minerals of volcanic caves, and other chemistry

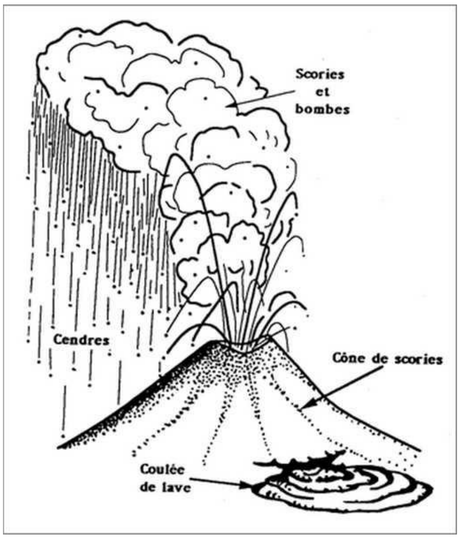
(Prof. Jean Poesen, KU Leuven)

Reminder on volcanism: Stratovolcano or Composite volcano



A stratovolcano with adventive craters. (after: B. G. Escher, Grondslagen der Algemene Geologie).





Development of a stratovolcano (after: Cloos, Rutten) *(Anon.)*

The term volcanic cave includes lava tubes, tumulous caves, fracture caves, volcanic vents and other cavernous openings produced by volcanic processes. Decoration of these caves can be broadly separated into two categories.

Primary decorations are those features formed at the same time or in the closing stages of the process that formed the caves themselves (there seems to be some argument as to whether or not such features should be called speleothems). These include lava stalactites, lava stalagmites and other features formed by dripping and freezing of lava. Secondary decorations are mineral deposits that formed after the primary cave opening had cooled or at least partially cooled. Some of these result from steam and volcanic gases in fumarole caves and other openings that are still well above regional ambient temperatures, although below that of the original lava. Others result from the leaching of material by infiltrating groundwater and the subsequent deposition of minerals in underlying lava tubes.

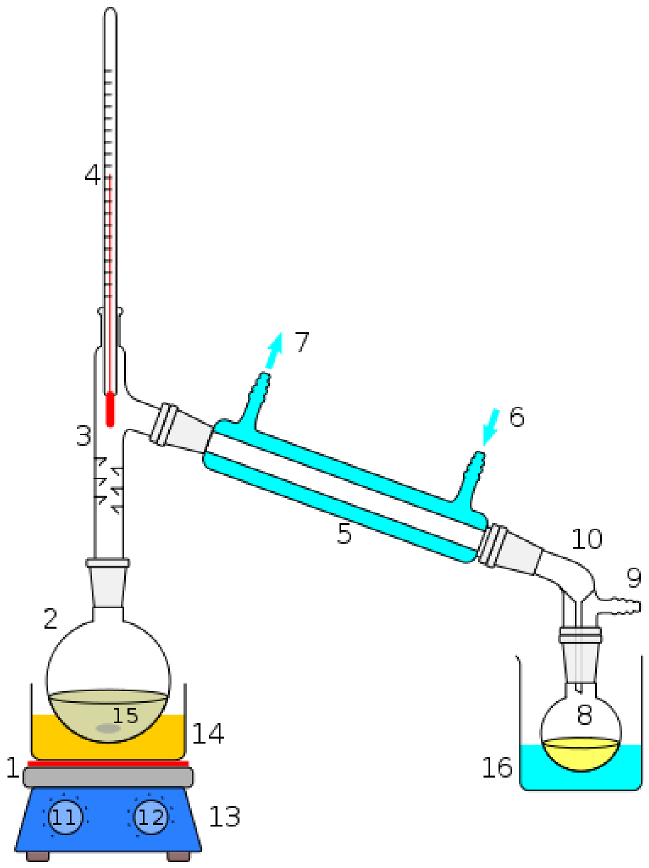
Although investigations of secondary minerals in volcanic caves are less numerous than investigations of minerals in limestone caves, the number of observed minerals is surprisingly large.

The reason for the mineralogical diversity is the variety of environments in volcanic settings, each with a unique set of conditions for mineral deposition.

(White, W.B., 2010.– Secondary minerals in volcanic caves: data from Hawai'i. Journal of Cave and Karst Studies, v. 72, no. 2, p. 75–85.)

The white mineral of the volcano (11.41557°N, 37.13602°E)

This is a secondary mineral in a lava tube (see above). It is under analysis by Poesen, Gullentops and Elsen (KU Leuven). Preliminary analysis shows that it is an amorphous silica mineral; its chemical content is > 90% SiO_2 (ICP-OES analysis). J. Thys identified this mineral as hyalite (SiO_2.H_20). The bright white colour corresponds to the near-absence of other metals. Further analysis should indicate whether precipitation took place at the moment of eruption (and hence derived from vapours related to the eruption), or rather related to subsequent percolation through the body of the volcano.



Distillation: reminder of your chemistry courses!

Laboratory display of distillation: 1: A heating device 2: Still pot 3: Still head 4: Thermometer/Boiling point temperature 5: Condenser 6: Cooling water in 7: Cooling water out 8: Distillate/receiving flask 9: Vacuum/gas inlet 10: Still receiver 11: Heat control 12: Stirrer speed control 13: Stirrer/heat plate 14: Heating (Oil/sand) bath 15: Stirring means e.g.(shown), boiling chips or mechanical stirrer 16: Cooling bath.

Harwood, L.M., Christopher J. Moody, C.J., 1989. *Experimental organic chemistry: Principles and Practice* (Illustrated ed.). Oxford: WileyBlackwell. pp. 141–143.

Reservoir sedimentation and hotspot areas in Koga Watershed of the Upper Blue Nile Basin, Ethiopia

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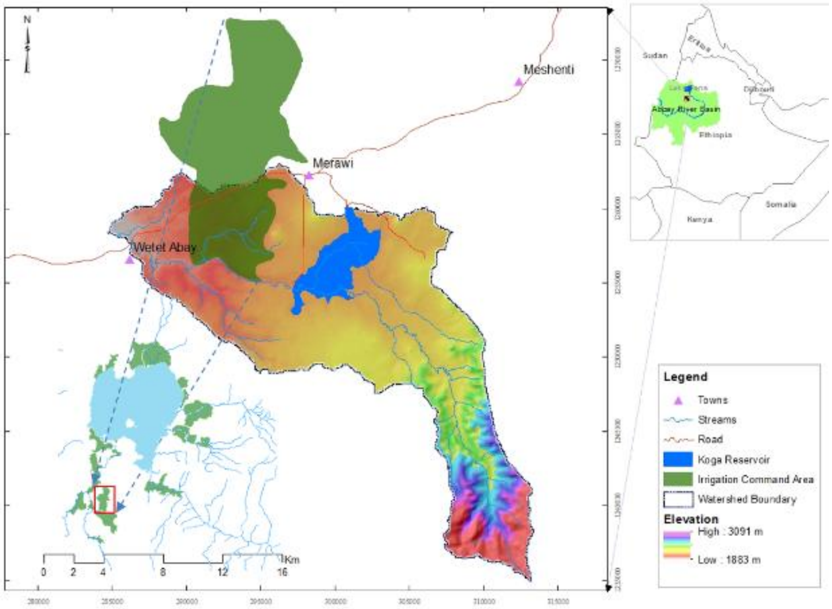


Fig 1: Location map of Koga Watershed (Mihret et al., 2015)

Fig. 2 Koga reservoir in April 2015

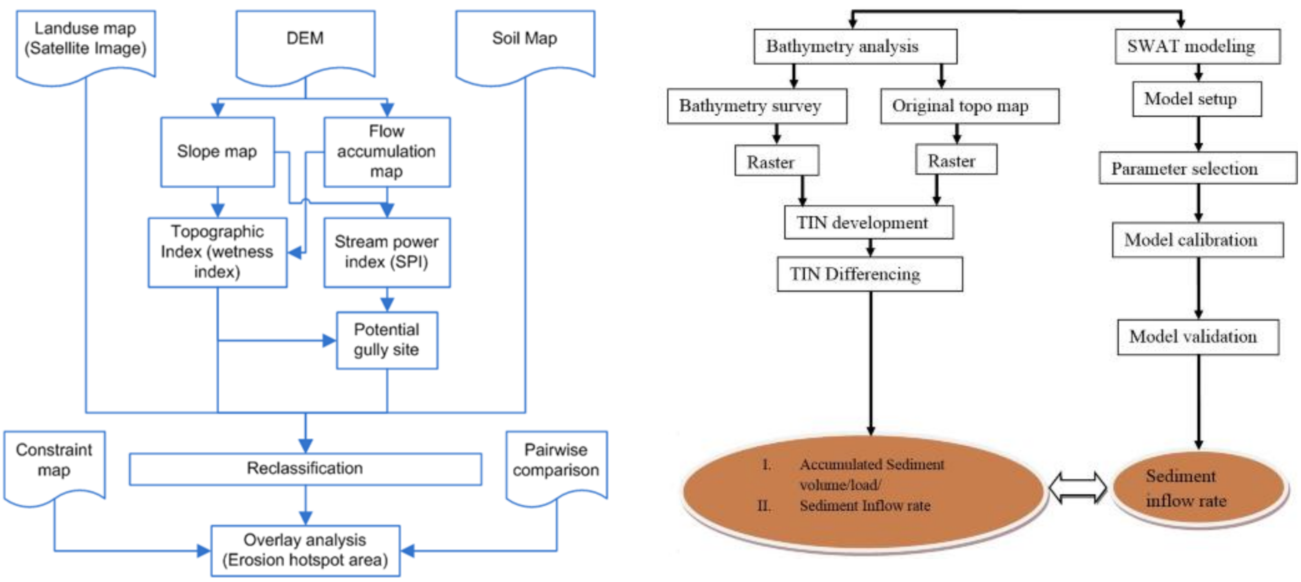
Introduction

In the Ethiopian highlands, lack of effective watershed management systems and land use changes in the landscape played a significant role in land degradation (Tebebu et al., 2010). Excessive soil erosion resulted in reduced agricultural productivity and sedimentation in natural and artificial reservoirs in the region. Sediment accumulation in reservoirs built on natural beds has led to major decreases in storage capacity (Almeida et al., 2005). Shahin (1993) stated that reservoir siltation is a serious concern in African river basins as the storage volume is substantially decreasing. The recently constructed Koga dam reservoir is one of the affected reservoirs in the Ethiopian highlands. The stored irrigation water in the reservoir is highly turbid (Fig. 2).

Koga River is a tributary to Gilgel Abay River which drains to Lake Tana in the Upper Blue Nile Basin. Koga dam has a drainage area ~22,000 ha and a capacity of supplying water for irrigating downstream farms ~7,000 ha (Ministry of Water Resources, 2008). Koga dam is geographically located at $12^{0}10^{'}$N and $37^{0}38^{'}$E (Fig. 1).The annual rainfall is ~ 1480 mm based on available data in an adjacent meteorological station, in Merawi. Average flow based on 44 years of record (1959-2002) is 4.78 m^{3} s^{-1}. The highest and the lowest flow occur during July and April respectively.

Method

Here we summarised two papers (Assefa et al., 2015; Mihret et al., 2015) that focus on *(a)* indentification of erosion hotspot areas and *(b)* estimation of sedimentation to Koga reservoir. Fig. 3a shows the methodology used to obtain the locations of erosion hotspot areas, while Fig. 3b describes the sediment inflow and accumulation for the resrvoir.



(a) (b)

Fig 3: Methodology: (a) erosion hotspot mapping (Assefa et al., 2015) (b) estimation of sediment inflow (Mihret et al., 2015)

Field work was carried out in Koga Watershed where control points for Landsat 8 satellite image supervised land use classification were collected. Since gullies are the major sediment sources (Tilahun et al., 2015), the potential location of gullies are predicted when both of the following two treshold conditions are satisfied (Lulseged and Vlek, 2005): Stream Power Index (SPI) > 18 and Topographic Wetness Index (TWI) > 6.8. Table 1 below shows the input data used in this work and their sources. Erosion sensitivity of the catchment is classified into two classes (sensitive and not-sensitive) based on

Fig 4 : Gully upstream of the reservoir (Photo taken in 2013)

Food and Agricultural Organization (FAO) (1981) land classification framework.

Table 1. Type and source of data

Data type	Resolution	Sources
DEM	30 m	United States Geographical Survey (USGS) website [a]
Land use	30 m	USGS website [b]
Soil type	90 m	Ministry of Water and Energy (MoWE), Addis Ababa

a. http://gdex.cr.usgs.gov/gdex/

b. http://landsat.usgs.gov/landsat8.php

Four major factors (topography, potential location of gullies, land use and soil) are used to locate erosion hotspots. Factors are classified depending on the degree of sensitivity to soil erosion and the percent value of each factor is divided into four using equal interval method to assign value for each sensitivity classes (S1, S2, S3, S4) (Table 2). Each map is then summed up using raster calculator so that each pixel in that map had the sum of the four map values based on sensitivity classes (overlay analysis) (Fig. 5, left). Finally, the total raster value is re-classified equally into four regions: highly sensitive, moderately sensitive, marginally sensitive and currently insensitive (Fig. 5, right).

Table 2. Factors sensitivity class based on FAO (1981)

Sensitivity classes and notation	Explanation
S1-Highly sensitive	Factors significantly accelerate erosion
S2-Moderately sensitive	Factors clearly sensitive but has opportunity to reduce erosion
S3-Marginally sensitive	Factors significantly reduce erosion
S4 (N1)- currently not sensitive	Factors that cannot support erosion

To estimate reservoir sedimentation, two sets of reservoir topography maps were used; the first map (2009) was prepared for the construction of Koga dam while the second was produced in 2013 following a bathymetric survey. A total of 3087 data points were collected using echo-sounder bathymetric survey in a regular grid on average of 35 x 35 m. An exploratory data analysis is used to remove outliers and examine the distribution of the depth readings. About 3000 depth measurements are used to generate a DEM. Given the small size of the reservoir area and the accuracy required a TIN based analysis is preferred and the DEMs are converted to a TIN. The DEM difference gives a measure of accumulated sediment in the last four years and is used to calculate the aerial average annual sediment contribution rate of the Koga watershed. The volume of successive polygon has been determined by calculating the difference in height between measurements of the two input surfaces. The first surface is the bathymetric surface from which the second (digitized topographic surface) or reference surface has been subtracted. Soil and Water Assessment Tool (SWAT) was used to estimate sediment inflow to Koga reservoir. The sediment inflow rate from the SWAT model is aggregated to annual sediment volume to compare with the sediment volume computed using DEM differencing.

Result and Discussion

Erosion hotspot mapping

Pairwise comparison matrix is prepared by comparing factors one-to-one based on Pairwise comparison scale which is broken down from 1 to 9. The highest value indicates absolute significance and the reciprocal keep in the transpose position indicating absolute insignificant. Among the major factors, topography was considered as the most significant factor while soil type was the least significance factor. The reliabilities of weights are checked by computing the consistency of comparison matrix which we found consistent.

The erosion sensitivity map (Fig 5) indicated that 2% of the total watershed is highly sensitive (S1); 43% is moderately sensitive (S2); 16% marginally sensitive; 32% currently insensitive and 7% constraint to erosion in Koga watershed. The lowland area of the catchment was identified as a major erosion source due to saturation.The upland part of the watershed contributed the least to erosion as saturation is negligible and the degraded and rocky areas form a limited source. Additionally, most of the gully formation which significantly affects erosion initiation is related to saturation resulting in negligible gully formation is in the highland part of the watershed. Therefore, considering the saturated area (lowland) during design of watershed management strategies and implementations are essential to prevent soil loss from the catchment.

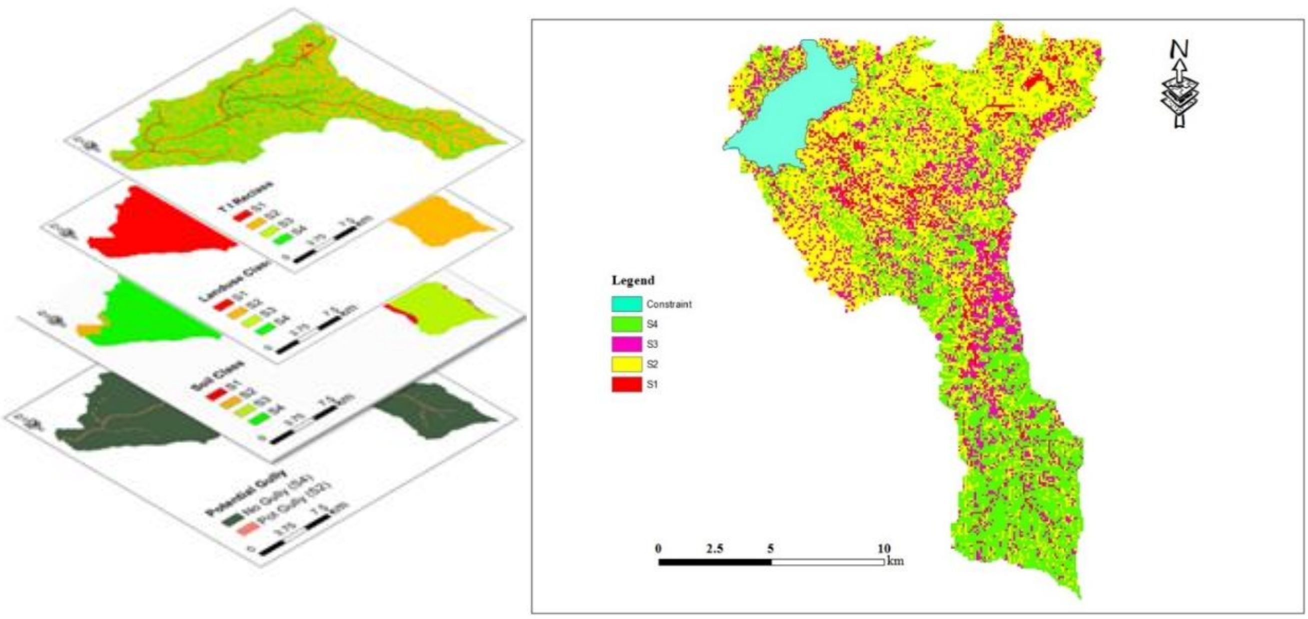


Fig 5: Overlay analysis (left) Erosion Sensitivity map (right) (Assefa et al., 2015)

Estimation of reservoir sedimentation

The sediment accumulation (Fig. 6) in the reservoir is obtained as the difference between the TIN derived from the topographic map and the TIN derived from the bathymetric survey. The result shows that the storage volume shrunk from its design storage of 83.1 Mm^3 in 2009 to 82.7 Mm^3 in 2012 (i.e., sediment inflow volume of 339,500 m^3) resulting in an annual average sediment inflow rate of 84,800 m^3. Taking the average density of clay soil 1.2 tons/m^3 annual sediment yield is estimated to be 101,500 ton/year (500 ton/km^2/year). The dead storage for Koga reservoir is 393,000 m^3 (MacDonald, 2004). Based on the annual sediment inflow rate of 84,800 m^3 obtained through DEM differencing, around 0.5% of the total storage of the reservoir is lost within 4 years. The bathymetric survey indicated that the majority of siltation occurred around the reservoir periphery portion of the reservoir.

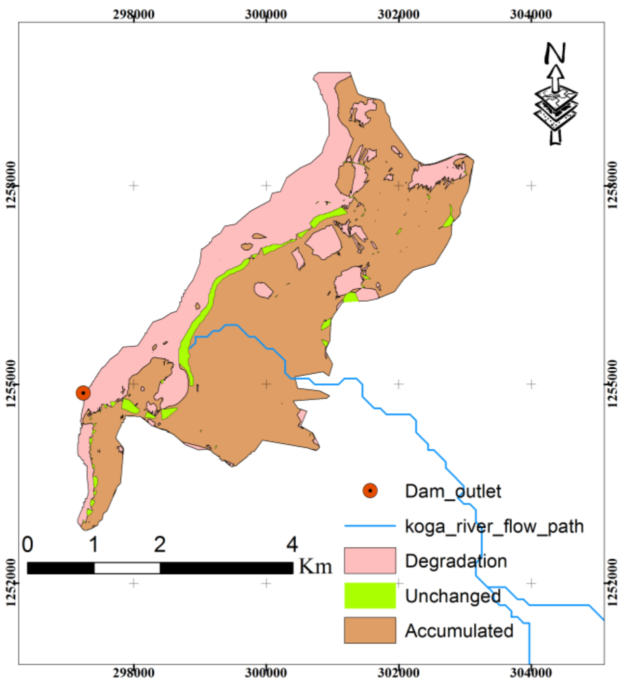


Fig 6: Sediment distribution in Koga reservoir and extents with reference to the original topography (Mihret et al., 2015)

The total sediment load estimated using SWAT was 90 ton/ha over eight years resulting in an average annual sediment inflow of 175,000 tons (860 ton/km^2/year). Result obtained from SWAT model was 41% higher compared to the bathymetry analysis. However, it falls within the range of reported values (200 to 1,800 ton/km^2/year) from other studies for Ethiopian highlands such as Hurni (1986); Hawando (1997); Hurni (1988) and Tebebu et al (2010).

Conclusions

The overall research indicated that most erosion hotspots areas were found in the lowland (more than 75% of erosion hotspot area) of the catchment, indicating that it is extremely important to consider the saturated areas during design of watershed management strategies. The estimated annual sediment inflow of 500 ton km^{-2} yr^{-1} from contributing areas resulted in a 0.5% storage capacity decrease between 2009 and 2012.

References

Almeida, J., Ota, J., Terabe, F., Muller, I., 2005. Flushing of coarse and graded sediments a case study using reduced scale model. Enterprise Security Architecture: A Business-Driven Approach, 139.

FAO, 1981. Guidelines for designing and evaluating surface irrigation systems. Irrigation and Drainage Paper 45. Rome: FAO (Food and Agricultural Organization of the United Nation (http://www.fao.org/3/a-p4228e.pdfUnited).

Hawando, T., 1997. Desertification in Ethiopian highlands. Rala Report.

Hurni, H., 1986. Soil conservation in Ethiopia—Guidelines for development agents. Ministry of Agriculture, Addis Ababa.

Hurni, H., 1988. Degradation and conservation of the resources in the Ethiopian highlands. Mountain Research and Development, 123-130.

MacDonald, M., 2004. Koga irrigation and watershed management project. Interim report.

Ministry of Water Resources (2008), Koga Irrigation Project Cost Recovery Study Vol 1, Available as a hardcopy at Koga Irrigation Project Office in Merawi.

Shahin, M.M.A. (1993). An overview of reservoir sedimentation in some African river basins in Sediment Problems: Strategies for Monitoring, Prediction and Control (Proceedings of the Yokohama Symposium, July 1993). IAHS Publ. no. 217.

Tebebu, T., Abiy, A., Zegeye, A., Dahlke, H., Easton, Z., Tilahun, S., Collick, A., Kidnau, S., Moges, S., Dadgari, F., 2010. Surface and subsurface flow effect on permanent gully formation and upland erosion near Lake Tana in the Northem Highlands of Ethiopia. Hydrology and Earth System Sciences 14, 2207-2217.

Tilahun, S.A., Guzman, C.D., Zegeye, A.D., Dagnew, D.C., Collick, A.S., Yitaferu, B. and 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

Fully-fledged papers related to the same topic:

Assefa, T.T., Jha, M.K., Tilahun, S.A, Yetbarek, E., Adem, A.A and Wale, A. (2015) Identification of Erosion Hotspot Area using GIS and MCE Technique for Koga Watershed in the Upper Blue Nile Basin, Ethiopia. American Journal of Environmental Sciences, DOI: 10.3844/ajessp.2015

Mihret, D.A, Ayana, E.K, Legesse, E.S, Moges, M.M, Tilahun, S.A. (2015). Estimating reservoir sedimentation using bathymetric differening and hudrological modeling in data scarce Koga watershed, upper Blue Nile. International Journal of Sediment Research. Under review

Soil Test Based Nitrogen and Phosphorus Fertilizer Recommendations for Maize (*Zea mays* L.) Grown on Alfisols of Northwestern Ethiopia

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Introduction

In Northwestern Ethiopia, population growth is rapid and there is a rapidly growing demand for food. Therefore, cultivation of subsistence crops must be stimulated and production augmented in a sustainable way. The trend in all research endeavors including research on soil nutrients, therefore, is going through a development process away from agricultural production *per se* towards *sustainable* production (Smaling and Oenema, 1998). Among others, mineral nutrition is becoming one of the most important factors for increasing maize production in Northwestern Ethiopia. Unfortunately, many soils of Ethiopian highlands are inherently poor in available plant nutrients and organic matter (Tekalign *et al*., 1988). Murphy (1963) conducted a survey or rapid appraisal work to assess the fertility status of Ethiopian soils and concluded that the major part of Ethiopian soils is deficient in nitrogen and phosphorus. Hence, farmers who attempted to grow crops without or with marginal fertilizer application could not produce enough even to feed their own family.

As in other soils of Ethiopia, nitrogen is probably more often deficient than any other essential element in Alfisols, mainly because organic matter of these soils is not preserved (Mesfin, 1998). In addition to this, the cereal dominated cropping systems, aimed at meeting the farmers' subsistence requirements, coupled with low usage of chemical fertilizers have led to the widespread depletion of soil nitrogen in the maize growing areas of Ethiopia. Moreover, the heavy rains during the early part of the main cropping season (June-August) cause substantial soil nutrient losses due to intensive leaching and erosion (Amsal and Tanner, 2001).

Phosphorus is also of primary concern in the appraisal of the soil resources of Ethiopia (Miressa and Robarge, 1996) since most of the soils on the highland plateau are reported to be deficient in phosphorus (Asnakew *et al*., 1991; Desta, 1982; Tekalign *et al*., 1988). Phosphorus is one of the most limiting elements in the majority of the Alfisols of Ethiopia. In P-deficient soils, crops usually recover less than 10 percent of the applied amount of phosphorus in the first season, even if they respond well and the total recovery after four years is often only 20-30 percent (Russel, 1972). In addition to the inherently low available P content, the high P fixation capacity of these soils made the problem complex. Tekalign and Haque (1987), and Taye (1998) have reported a sorption range of 150-1500 $\mu g\ g^{-1}$ in several Alfisols of Ethiopian highlands. Therefore, following nitrogen, phosphorus is the most limiting nutrient in the tropics (Sanchez, 1976). Deficiency of nitrogen and phosphorus in these soils eventually led to severe yield decline in Northwestern Ethiopia.

The role of chemical fertilizers in increasing yield is evident. Fertilizers accounted for more than 50% of the increase in yield (FAO, 1984). Experience has shown that in seasons with good rain, farmers of Northwestern Ethiopia managed to produce surplus yield through fertilization. The rates applied, however, should meet the demand of the crop, but should not exceed the demand to any major extent. For this purpose, in Ethiopia, some flat fertilizer recommendations have been developed and introduced into the extension system. This approach, however, had shortcomings in extrapolating the results to farmers' fields, because the available nutrient status on the experimental fields was either lower than, equal to or higher than that of the farmers' fields. Hence, fertilizer recommendations should take into account the available nutrient already present in the soil (Mengel, 1982).

For implementing this more scientific and precise option of fertilizer recommendation, soil laboratories are being built in many Regional States of the country including in the study area. Nevertheless, since no universally accepted method exists for indexing availability of nutrients, reliable methods must be selected through research to meet the specific conditions under which the crops are intended to grow. Following identification of soil test methods giving reliable availability indices, mathematical models that integrate the soil test indices with fertilizer rate requirements should be developed for each crop species on soil type and agro ecology where that particular crop is growing. The purpose of this study was, therefore, to identify reliable methods for indexing availability of N and P and to develop mathematical models for calculating N and P fertilizer rates from soil analysis for maize grown on Alfisols of North Western Ethiopia.

Methodology

Two sets of experiments were conducted to develop equations for estimating nitrogen (experiment 1) and phosphorus (experiment 2) fertilizer requirements of maize grown on Alfisols of Northwestern Ethiopia. The field experiments at 20 sites were arranged in randomized complete block design with five N and five P fertilizer rate treatments for experiment 1 and 2, respectively, and four replications (Figure 1).

Figure 1. Maize one month after planting

Soil parameters determined for indexing availability of nitrogen were organic matter, total N, NO_3^--N, NH_4^+-N, NH_4^++NO_3^--N, NH_4^++NO_3^--N production on aerobic incubation, and NH_4^+-N released on autoclaving with dilute calcium chloride. Methods used for indexing availability of P were Bray-1, Bray-2, Olsen, Mehlich-1, anion exchange resin extraction, 0.01*M* $CaCl_2$ extraction and the parameters of the Quantity/Intensity relationships.

Relative grain and dry above ground biomass yields were determined by calculating maximum values of each parameter using a second degree polynomial regression model: $Y = a + b_1x + b_2x^2$, where Y = the dependent variable (yield); x = the independent variable (N or P fertilizer rate); a = the intercept on the y-axis; and b_1 and b_2 = regression coefficients. The maximum values for grain yield were determined from the model after fitting obtained data. These values were regarded as 100% relative yield values. Other yield values were converted into relative yields as percent of their corresponding maxima (Suwanarit *et al*., 1999).

Relationships among relative grain yields, obtained N/P availability indices and amount of fertilizer applied were expressed by the Mitscherlich-Bray model. The model for each selected chemical method will be derived by calculating c_1 (coefficient of availability indices) and c (coefficient of fertilizer rates). First c_1 was calculated by substituting b (availability indices) from each replication of the experimental sites in the following equation: $\log (A - y) = \log A - c_1b$, where A= relative maximum grain yield; and y = the relative grain yield from unfertilized plots. Mean of all the c_1 values of all the locations was used for the model. Then the c value was calculated for each fertilized treatment by substituting calculated c_1 value of each replication in the following equation: $\log (A - y) = \log A - c_1b - cx$, where x = the N/P fertilizer rates used and y = relative grain yield of fertilized plots. Mean of all the c values of all the fertilized plots were used for the model.

Results and Discussion

Results of the experiments revealed that organic matter, total N and NO_3^--N were the most reliable N availability indices and the models were developed for these soil parameters (Table 1)

Table 1. Equations for estimating nitrogen fertilizer requirements of maize from soil analysis results of reliable methods

Method No.	Availability index	Unit of index	Equation [1]
1	Organic matter [2]	%	$\log (100 - y) = 2 - 0.1103b - 0.006411x$
2	Total N	%	$\log (100 - y) = 2 - 2.0566b - 0.006481x$
3	NO_3^--N	mg kg^{-1}	$\log (100 - y) = 2 - 0.0220b - 0.006414x$

[1] y = relative yield goal (as % of maximum yield); b = N availability index obtained from soil analysis; x = N fertilizer requirement (kg N ha^{-1}); [2] Organic matter (%) = Organic carbon (%) x 1.724.

Reliability of the equations was verified by comparing the actual grain yields obtained from the experimental plots with predicted yields by the developed equations (Figure 2). All the equations gave grain yield predictions that were highly significantly ($P < 0.01$) correlated with actual yields. From the 400 data points, there were 218, 223 and 221 cases of overestimation and 182, 177, and 179 cases of underestimation for the equations of organic matter, total N, and NO_3-N, respectively. When the absolute range of error around actual grain yield was designated, i.e., ± 1000 kg ha^{-1}, there were only 37, 36 and 31 cases of overestimation and 13, 12 and 12 cases of underestimation for equations of method 1, 2, and 3, respectively.

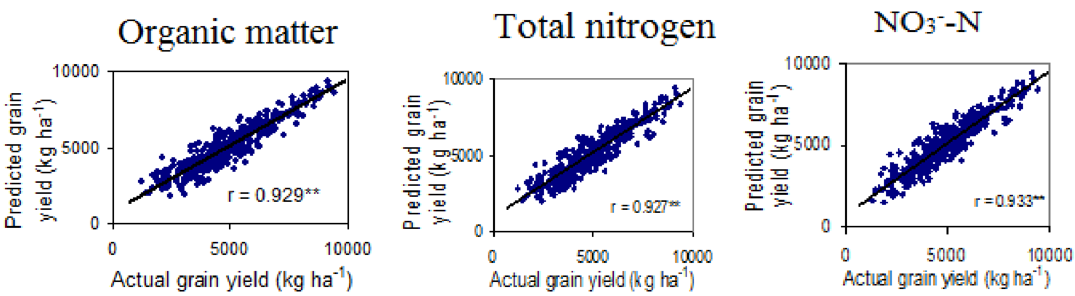

*Figure 2. Relationships between actual maize grain yields and grain yields predicted by the equations for Methods 1, 2 and 3 (** significant at 1% probability level; n = 400).*

Similarly, Bray-2 and Olsen methods gave the most reliable P availability indices from the seven indices tested (Table 2). The critical soil P levels required to achieve optimum yield (98% of the maximum possible yield) without applied P fertilizer were identified to be 11.6 and 14.6 mg kg^{-1} for indices of Olsen and Bray-2 methods, respectively measured at planting.

Table 2. Equations for estimating phosphorus fertilizer requirements of maize from soil analysis results of reliable methods

Method	P availability Index	Unit of index	Equation [1]
Olsen	Olsen P	mg kg^{-1}	log (100-y) = 2 - 0.1468b - 0.007546x
Bray-2	Bray-2 P	mg kg^{-1}	log (100-y) = 2 - 0.1167b - 0.007546x

[1] y = relative yield goal (as % of maximum yield); b = P availability index obtained from soil analysis (mg kg^{-1}); x = P fertilizer requirement (kg P_2O_5 ha^{-1}).

The simple linear regression technique employed to see the relationships between actual grain yields obtained from the experimental plots and predicted grain yields by the developed equations indicated that the relationships were linear, with highly significant ($P < 0.01$) and almost equal correlation coefficients both for Olsen and Bray-2 methods (Figure 3).

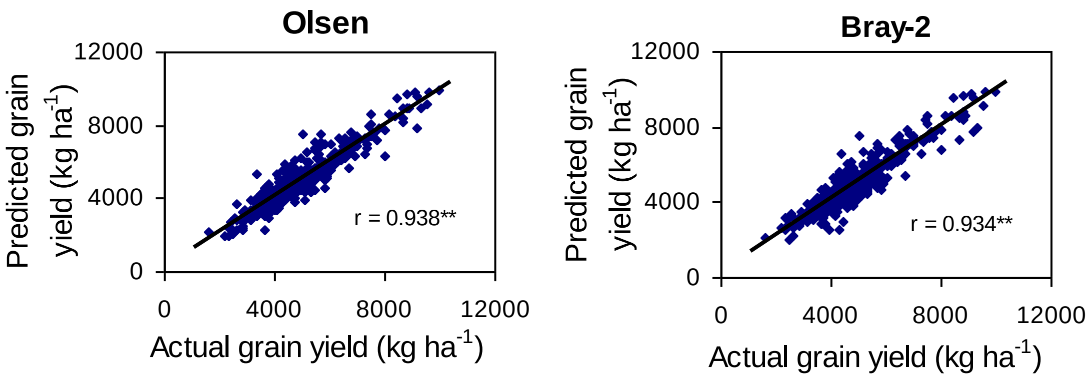

*Figure 3. Relationships between actual maize grain yields and grain yields predicted by the equations for Olsen and Bray-2 methods (** significant at 1% probability level; n = 400).*

Conclusions

From the results of the experiments it was possible to conclude that among the soil analysis methods incorporated in the experiment, determination of organic matter content, total N and NO_3^--N were the most reliable N availability indices; while Olsen and Bray-2 methods were found to give most recommendable indices of P status on Alfisols of Northwestern Ethiopia for maize. The Mitscherlich-Bray equations developed for organic matter content, total N and NO_3^--N for N and Olsen and Bray-2 methods for P were statistically proven to provide equally reliable estimates of fertilizer requirement of maize on Alfisols of North Western Ethiopia.

References

Amsal, T. and D. G. Tanner. 2001. Effects of fertilizer application on N and P uptake, recovery and use efficiency of bread wheat grown on two soil types in central Ethiopia. Eth. J. Nat. Res. 3 : 219-244.

Asnakew, W., T. Mamo, M. Bekele and T. Ajama. 1991. Soil fertility management studies on wheat in Ethiopia. *In* H. Gebremariam ed. Wheat Research in Ethiopia, a Historical Perspective. International Livestock Center for Africa, Addis Ababa, Ethiopia.

Desta, B. 1982. Diagnosis of P deficiency in Ethiopian Soils. Soil Sci. Bull. 3. Institute of Agricultural Research, Addis Ababa, Ethiopia.

FAO (Food and Agricultural Organization of the United Nations). 1984. Fertilizer and plant nutrition guide. *Cited by* D. van der Eijk. 1997. Phosphate Fixation and Response of Maize to Fertilizer Phosphate in Kenyan soils. Ph. D. Thesis. Agricultural University of Wageningen, The Netherlands.

Mengel, K. 1982. Factors of plant nutrient availability relevant to soil testing. Plant Soil 64: 129-138.

Mesfin, A. 1998. Nature and Management of Ethiopian Soils. Alemaya University of Agriculture. Alemaya, Ethiopia. 272 p.

Miressa, D. and W. P. Robarge. 1996. Characterization of organic and inorganic phosphorus in the highland plateau soils of Ethiopia. Communication Soil Science Plant Anal. 27: 2799-2814.

Murphy, H.F. 1963. Fertility and other data on some Ethiopian soils. *Cited by* B. Taye. 1998. Soil Fertility Research in Ethiopia. Paper presented at the Soil Fertility Management Workshop. April 21-22, 1998. Addis Ababa, Ethiopia.

Russel, J. S. 1972. A theoretical approach to plant nutrient response under conditions of variable maximum yield. Soil. Sci. J. 114: 387-394.

Sanchez, P.A. 1976. Properties and Management of Soils in the Tropics. *Cited by* W.R. Raun and H. J. Barreto. 1995. Regional maize grain response to applied phosphorus in Central America. Agron. J. 87: 208-213.

Smaling, E.M. and O.A. Oenema. 1998. Estimating nutrient balance in agro ecosystems at different spatial scales, pp. 229-251. *In* R. Lai, W. H. Blum, C. Valentine and B. A. Stewart eds. Methods for Assessment of Soil Degradation. CRC Press, Boca Raton, New York.

Suwanarit, A., S. Buranakarn, S. Kreetapirom, P. Kangke, J. Phumphet, P. Phiatanen, S. Somboonpong, S. Ratanasupa, P. Romyen, S. Wattanapayakul, K. Naklang, S. Rotjanakusol, P. Charoendham, W. Palaklang, S. Satawathananon and W. Irthalang. 1999. Equations for calculating N-fertilizer rates for Khaw Dauk Mali-105 rice from soil analysis. Kasetsart J. (Nat. Sci.) 33: 224-233.

Taye, B. 1998. Soil Fertility Research in Ethiopia. Paper presented at the Soil Fertility Management Workshop. April 21-22, 1998. Addis Ababa, Ethiopia.

Tekalign, M., I. Haque and C. S. Kamara. 1988. Phosphorus status of some Ethiopian highland Vertisols, pp. 232-252. *In* S. C. Jutzi ed. Management of Vertisols in sub-Saharan Africa. Proc. Conference Held at the International Livestock Center for Africa. 31 Aug. - 4 Sep., 1987. Addis Ababa, Ethiopia.

Tekalign M. and I. Haque. 1987. Phosphorus status of some Ethiopian Soils. Plant Soil 102: 261-266.

Papers published from the same work

Yihenew G.Selassie, Amnat Suwanarit, Chairerk Suwannarat and Ed Sarobol. 2003. Equations for Estimating Nitrogen Fertilizer Requirements from Soil Analysis for Maize (*Zea mays* L.) Grown on Alfisols of Northwestern Ethiopia. Kasetsart Journal 37: 157-167.

Yihenew G.Selassie, Amnat Suwanarit, Chairerk Suwannarat and Ed Sarobol. 2003. Equations for Estimating Phosphorus Fertilizer Requirements from Soil Analysis for Maize (*Zea mays* L.) Grown on Alfisols of Northwestern Ethiopia. Kasetsart Journal 37: 284-295.

Yihenew G.Selassie and Amnat Suwanarit. 2007. Evaluation of Soil-Test Methods for Indexing Availability of Phosphorus for Maize (*Zea Mays* L.) Grown on Alfisols of Northwestern Ethiopia. Ethiopian Journal of Natural Resources 9(1): 1-18.

Yihenew G.Selassie. 2007. Evaluation of Nitrogen and Phosphorus as Yield-Limiting Nutrients for Maize Grown on Alfisols of Western Amhara. Ethiopian Journal of Natural Resources 9(1): 155-170.

Yihenew G.Selassie and Amnat Suwanarit. 2007. Evaluation of Soil-Test Methods for Indexing Availability of Nitrogen for Maize (*Zea Mays* L.) Grown on Alfisols of Northwestern Ethiopia. Ethiopian Journal of Natural Resources 9(2): 171-189.

The soilscape of Lake Tana basin, Nitisols and Vertisols are dominating the scene

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Lake Tana basin is the homeland of Nitisols and Vertisols in the Ethiopian Highlands. They typically develop from basalt which is the predominating lithology throughout the basin (Figure 1). The Ethiopian highlands have been the scene of massive flood basalt which started flowing some 30 million years ago, when the East-African Rift Valley started forming. The highlands east of Lake Tana form the western shoulder of the Rift Valley, which was uplifted several thousands of meters in the process. The uplift caused fracture zones and fault lines to cross the area. In places with intersecting fault lines volcanoes started erupting to form the great shield volcanoes of Western Ethiopia such as Mount Guna or Mount Choke (Figure 2). The latter is the younger of the two with a cluster of parasitic volcanic cones (so-called strombolites) along its Western side.

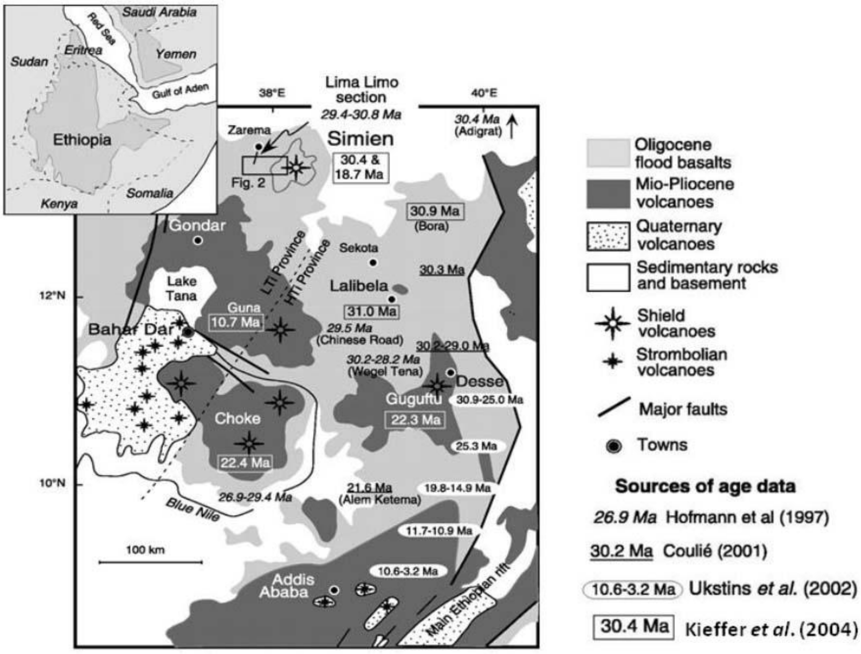

Figure 1: Location and age of major geological features in North Ethiopia (Kieffer et al., 2004)

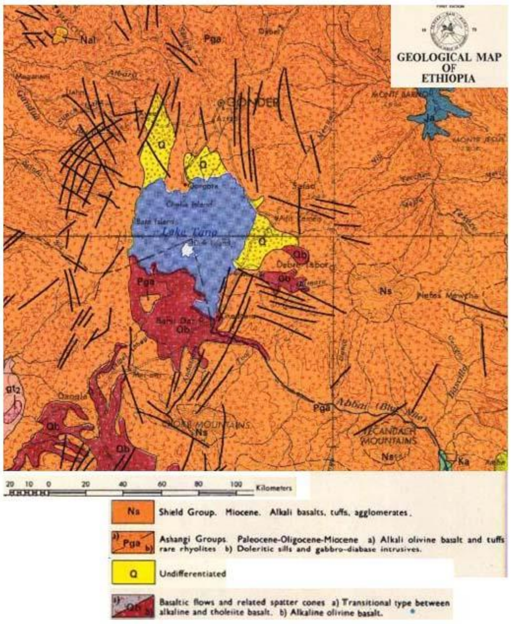

Figure 2: Geological-structural map of Ethiopia (1/2,000,000), fault lines are the black stripes (Kazmin, 1972)

The major soils of Lake Tana basin are Nitisols on the upland plateau, Luvisols on the slopes of rolling hills and Vertisols in the lowlands on old terraces of Lake Tana or old alluvial plains (Figure 3).

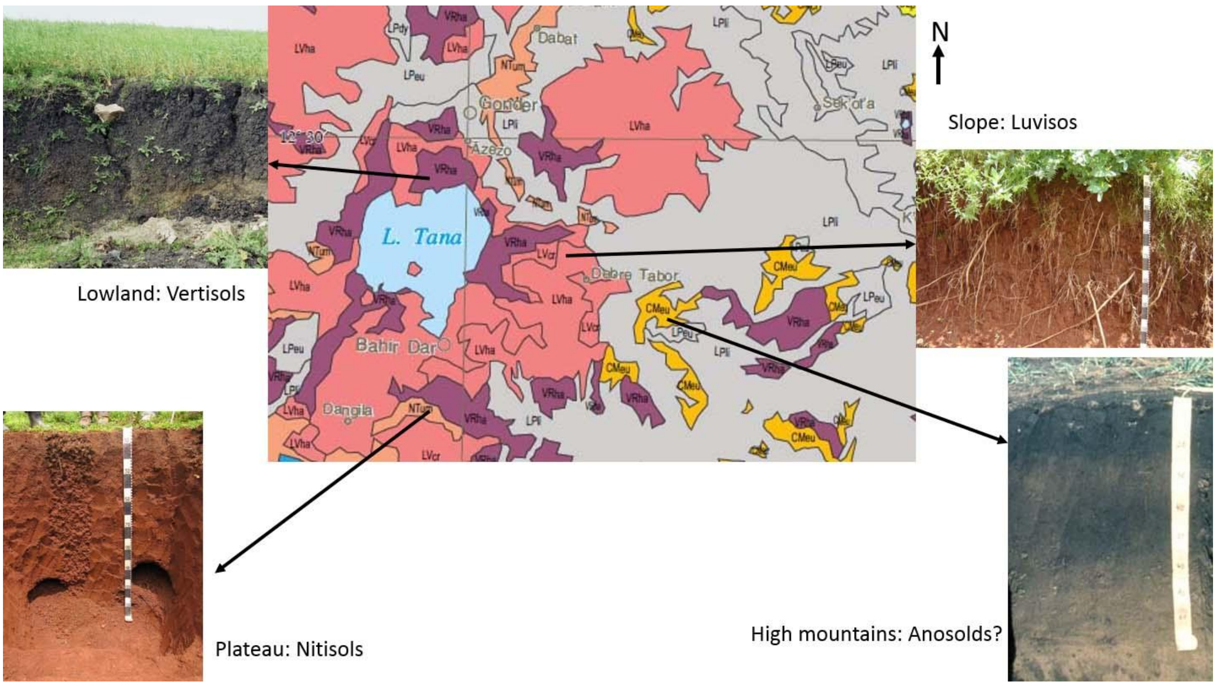

Figure 3: Soil map of Lake Tana area (+- 1/3,000,000) and illustration of major soil types (Source: Soil Atlas of Africa: Jones et al., 2013; Dewitte et al., 2013)

Figure 4 gives an aerial view of a typical Nitisols – Luvisol – Vertisol landscape. The village is on the Luvisol area on a well-drained slope position of the landscape. The Vertisols are in the lowland lining the river, whereas the Nitisols are the red patch on the plateau in the forefront of the picture.

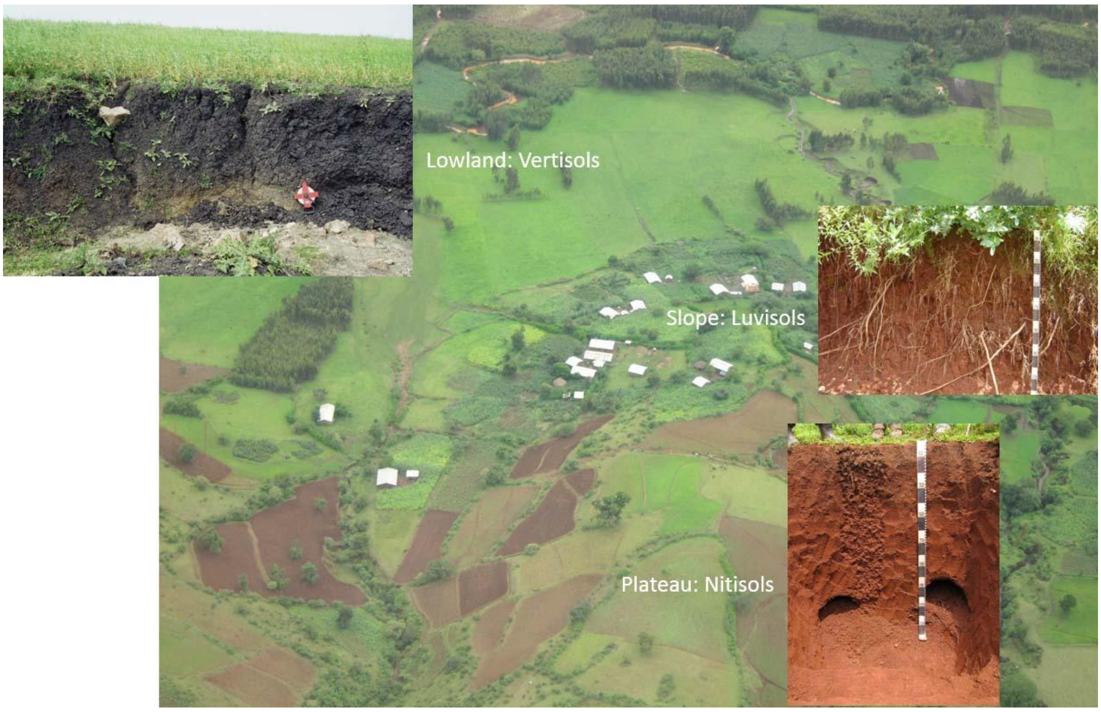

Figure 4: Soilscape in Lake Tana Basin: Nitisols in the upper plateau; Luvisols in the rolling hills and Vertisols in the lowlands

As usual, the real world is a bit more complex that what is indicated on soil maps, so which are the other soils expected in Tana basin? As Mount Choke and Mount Guna are extinct volcanoes, one could expect Andosols and Phaeozems for instance in the area, next to shallow or stony soils such as Cambisols and Leptosols (Figure 5).

Figure 5: Upper reaches of Mount Guna with shallow stony soils (Skeletic Leptosols) along the road cutting. In locations with deeper soils Cambisols are present, most likely associated with Andosols and Phaeozems

Properties and use of the major soils of Tana Basin

Nitisols are deep, well-drained soils with a typical nutty soil structure with shiny ped faces. They are dusky red and typically have a subsoil high in clay which stretches for more than 150 cm below the soil surface. This high clay content translates in a stable soil structure, a high quantity of available water and nutrients for plant growth, hence they can be considered as the better soils of the Tana soilscape. Although Nitisols are always associated with cash crops such as coffee, khat or sugar cane, they support many important upland crops in the area such as teff, wheat, barley, beans or flax.

Vertisols are deep clayey soils (>30% clay) dominated by swell-shrink clays. These soils develop wide cracks upon drying and they show waterlogging at the soil surface when it rains. Chemically, Vertisols are usually very rich, but their physical behavior is a challenge for farmers. They become very hard when dry and slippery and impassable during the rainy season. In view of the physical limitations, Vertisols have remained uncultivated for long, but over the last decades techniques have been developed to improve surface drainage of Vertisols by making beds and furrows. The result is that it now becomes possible to plant a wide range of crops on well-managed beds and furrows. In the Fogera plain, most Vertisols are planted to rice.

Luvisols are soils characterized by a clay-rich subsoil which typically occurs between 40 and 90 cm depth. Luvisols therefore are much less deeply developed compared to Nitisols. Chemically and physically they are rather fertile but in view of their location in rolling hilly landscapes, they are vulnerable to soil erosion. Most crops growing on Nitisols will grow on Luvisols, but their performance is expected to be inferior.

Phaeozems have a fertile thick dark colored organic matter-rich topsoil and they must have covered wide areas of the Tana basin. However after the deforestation, most of them have eroded away. Some remnants of these fertile soils may be found under church forests.

Andosols are soils composed of volcanic ash. In Ethiopia they are usually reasonably fertile but highly erodible, given their low density and fluffy nature. Patches of Andosols are found in the higher reaches of Mount Choke and Mount Guna.

Leptosols and Cambisols are either shallow or very stony soils which occur in any steep landscape position of Lake Tana basin. They are generally not suitable for growing agricultural crops, but they may have some value as grazing area as long as stocking rates are kept low.

Conclusion

Lake Tana basin is a renowned for its agricultural productivity in Ethiopia, which is no surprise in view of its soilscape with Nitisols and Vertisols dominating the plateau and the lowlands. The slightly less fertile Luvisols occupy the intermediate landscape positions, whereas the highest reaches close to the summits of the shield volcanoes Mt. Guna and Mt. Choke are supposed to host Andosols and Phaeozems next to Cambisols and Leptosols.

References

Colot, C., 2012. Soil-landscape relation at regional scale in Lake Tana basin (Ethiopia), M.Sc Thesis, KU Leuven, Faculty of Bioscience Engineering

Deckers, J., 2001. Vertisols: Genesis, Properties and Soilscape Management forSustainable Development. In 'The sustainable management of Vertisols (eds: J. K. Syres, F W.T. Penning de Vries), IWMI, CAB International 2001

Deckers, J., Nachtergaele, F., Spaargaren, O., 1998. World Reference Base for Soil Resources, An Introduction. ISSS-ISRIC-FAO, Acco Leuven https://books.google.be/books/about/World_Reference_Base_for_Soil_Resources.html?id=N_dfrC8iY_8C&hl=en

Dewitte, O., Jones, A., Spaargaren, O., Breuning-Madsen, H., Brossard, M., Dampha, A., Deckers, J., Gallali, T., Hallet, S., Jones, R., Kilasara, M., Le Roux, P., Micheli, E., Montanarella, L., Thiombiano, L., Van Ranst, E., Yemerfack, M., Zougmore, R., 2013. Harmonization of the soil map of Africa at continental scale. Geoderma 211-212 (2013) 138 – 153

Jones, A., Spaargaren, O., Breuning-Madsen, H., Brossard, M., Dampha, A., Deckers, J., Dewitte, O., Gallali, T., Hallet, S., Jones, R., Kilasara, M., Le Roux, P., Micheli, E., Montanarella, L., Thiombiano, L., Van Ranst, E., Yemerfack, M., Zougmore, R., 2013. Soil Atlas of Africa. European Commission, JRC, Luxembourg.

Kazmin, V., 1972. Geological map of Ethiopia. Addis Ababa, Ministry of Mines.

Kieffer, B., N. Arndt, H. Lapierre, F. Bastien, D. Bosch, A. Pecher, G. Yirgu, D. Ayalew, D. Weis, D. A. Jerram, F. Keller And C. Meugniot, 2004. Flood and shield basalts from Ethiopia: Magmas from the African superswell. Journal of Petrology 45(4): 793-834.

Field experimental assessment of soil erosion processes at different scales in Gumara-Maksegnit watershed, Lake Tana Basin

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Introduction

Rainfall-driven soil erosion and consequential land degradation are among the major threats of the mountainous landscape of Lake Tana Basin. In the course of a bilaterally funded project led by the International Center for Agricultural Research in the Dry Areas (ICARDA) an integrated watershed assessment has been undertaken in Gumara-Maksegnit watershed (Figure 1) to 1) allocate the 'hot-spots' of land degradation and to 2) investigate combined bio-physical and socioeconomic measures to counteract ongoing depletion of agricultural areas and to improve rural livelihood (Ziadat and Bayu, 2015).

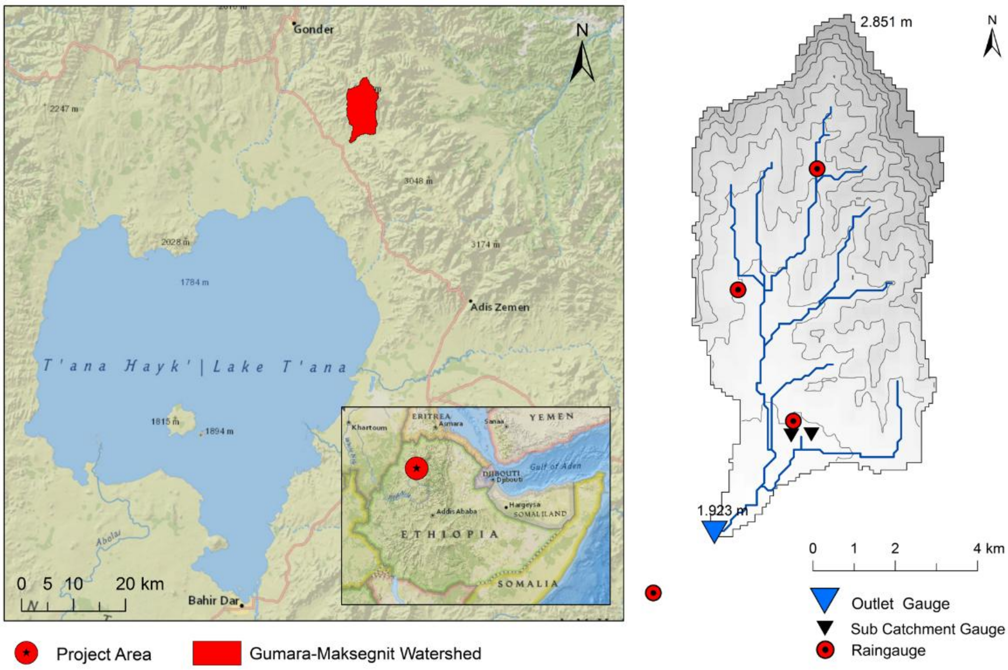

Figure 1. Location of the Gumara-Maksegnit watershed (left side) and the watershed topography, rain gauges and outlets (right side).

Watershed modeling considering Suitable Land Management (SLM) practices and Soil and Water Conservation (SWC) measures such as stone bunds (Figure 2) has been performed using the Soil and Water Assessment Tool (Neitsch et al., 2009; Addis et al., 2013). Proper simulation of SLM and SWC techniques requires detailed process understanding at different scales. For stone bund SWC assessment, two sub-catchments have been selected to compare treated and untreated landscape conditions. At the same time, plot and hill slope scale experiments were conducted to evaluate the impact of stone bunds on surface runoff and sediment yield at the field level. In the frame of the TropiLakes conference excursion, both sub-catchment monitoring and field level SWC experiments will be presented.

Figure 2. A stone bund located in the treated sub-catchment (Ayaye) of Gumara-Maksegnit watershed.

Materials and Methods

The 54 km^2 large Gumara-Maksegnit watershed and the location of the approximately 35 ha large sub-catchments are presented in Figure 1 (right side). The two neighboring sub-catchments ‘Ayaye’ (treated) and ‘Aba Kaloye’ (untreated) characterized by comparable topography, soil and land use condition were used to verify different SWC interventions (mainly stone bunds). Both sub-catchments have been monitored since 2010 using similar techniques observing runoff and sediment concentration. At the plot level, two stone bund experiments (Figure 3; Treated plot), and two untreated control erosion plots (Figure 3; Untreated plot), as well as one hill slope level cascade plot (Figure 3; Treated plot – in down-hill cumulative setting (three plots)) were installed in 2015. To strengthen the quantitative results obtained from plot monitoring, tracer experiments were set up to monitor the different pathways of the eroded soils (Strohmeier et al., 2015). Figure 4 shows the tracer stripes installed at the cumulative hill slope plots in 2015 - this topic will be presented at the conference.

The plots are 20 m long (Figure 3) in line with the local stone bund spacing. Total runoff suspension of the plot is collected by a pipe at the outlet, routing the runoff to a sample divider and further to a collection pond. The untreated runoff plots (Figure 3) monitor the unaffected erosion response on rainfall. On the contrary, the treated plots were set up with two collection pipes – one below the stone bund collecting excess runoff over spilling or leaching through the stone bund and a second ‘side-pipe’, located at a 2 m side-trunk of the plot, collecting excess runoff routed along the slightly inclined bund. Thus, water and sediment retention/routing capacity of stone bunds can be assessed through balancing the different flows. Certainly, experimental interferences and accumulative hill slope processes need to be considered.

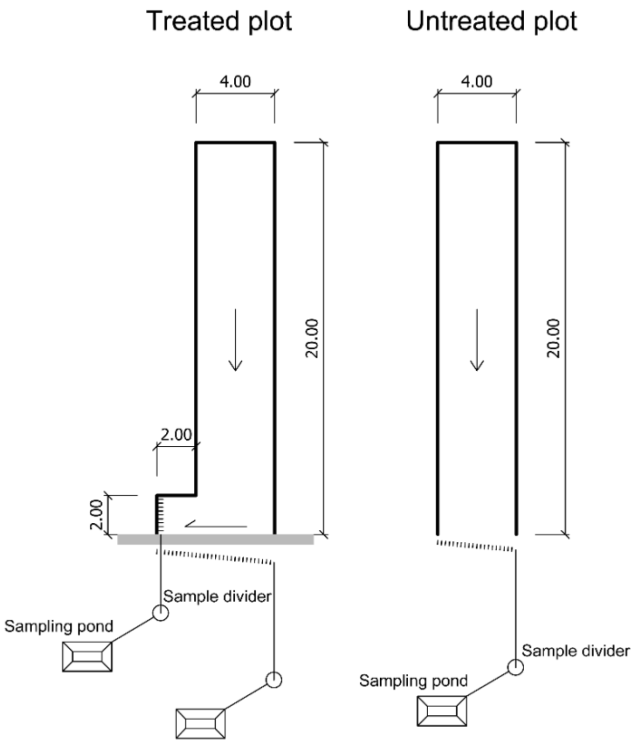

Figure 3. Sketch of treated and the untreated erosion plots (unit: meter). The cumulative hill slope plot consists of three accumulative treated plots.

Figure 4. Overview of the erosion site (top image), and the tracer experiment (colored tracer stripe (iron oxides)) carried out at the cumulative hill slope plot (bottom image).

Results and Discussion

Sub-catchment level – runoff and sediment yield at the outlets

Different seasons including wet and dry years have been observed in both sub-catchment. The corresponding data (daily runoff and sediment yield) were used for calibration and validation of the sub-watershed model (Schiffer et al., 2015) also presented at the TropiLakes conference. Figure 5 indicates runoff and sediment yield dynamics of selected events recorded in July 2012. The data shows an overall trend of stronger runoff and erosion response of the untreated sub-catchment. During the monitoring period approximately 45 % more runoff was observed at Aba Kaloye gauging station compared to Ayaye. Also the observed sediment yield at Aba Kaloye outlet seems larger (around 15 %). Considering comparable sub-catchment conditions, these values may give an idea about sub-catchment scale SWC effects.

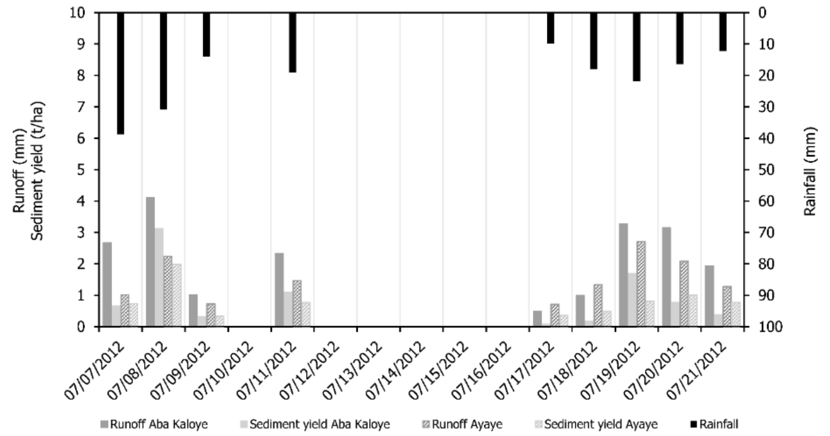

Figure 5. Runoff and sediment yield recorded at Ayaye (treated) and Aba Kaloye (untreated) sub-catchment in July 2012.

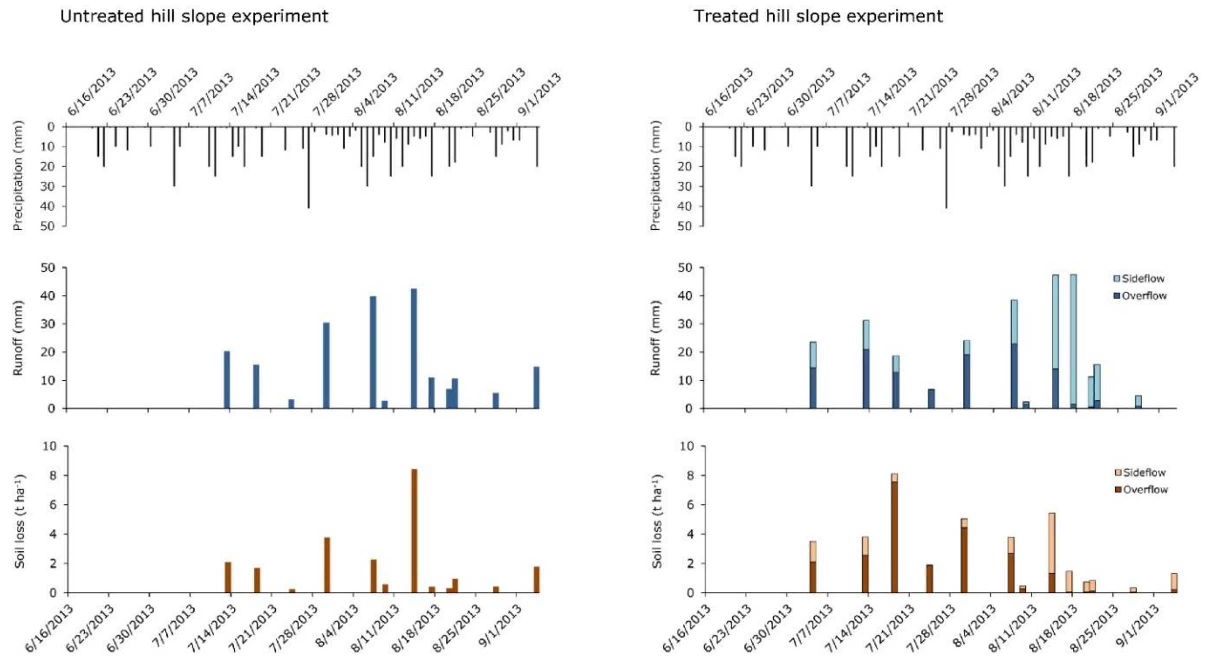

Figure 6. Rainfall, runoff and sediment yield recorded at untreated and treated erosion plots in 2013.

Field level - runoff and sediment yield from the plots

Preliminary results of 2015 field experimental campaign will be presented at the conference. However, pilot study results of at treated and untreated plots in 2013 (Rieder et al., 2014) are shown in Figure 6. Direct comparison of the side- and overflow may allow backdraws concerning plot level optimized SWC effects of stone bunds. Based on 2013 observations, down-hill directed runoff was reduced by approximately 60 %, while sediment yield was reduced by approximately 40 %.

Conclusions

The assessment of widely applied stone bund SWC intervention at sub-catchment, hill slope and plot level provide insight into scale dependent stone bund SWC effects as a required input for watershed modeling. As a future goal, advanced field experimental results of the erosion monitoring campaign conducted in 2015 will be transferred into model understandable 'language' for uptake and out scaling.

References

Addis, H.K, Strohmeier, S., Srinivasan, R., Ziadat, F., Klik, A. 2013. Using SWAT model to evaluate the impact of community-based soil and water conservation interventions for an Ethiopian watershed. 2013 SWAT Conference proceedings. Toulouse, France, July 17-19, 2013.

Neitsch, S. L., Arnold, J. G., Kiniry, J. R., Srinivasan, R., Williams, J. R. 2009. Soil and Water Assessment Tool - Theoretical Documentation, version 2009. http://swat.tamu.edu/documentation/

Rieder, J., Ziadat, F., Demelash, N., Strohmeier, S., Klik, A. 2014. Investigation of the impact of stone bunds on water erosion in northern Ethiopia. EGU General Assembly 2014, Vienna, Austria, April 27 – May 02, 2014.

Schiffer, R., Klik, A., Strohmeier, S., Srinivasan, R. 2015. Simulation of surface runoff and soil erosion in small watersheds in Northern Ethiopia – application and verification of the SWAT model. EGU General Assembly 2015, Vienna, Austria, April 11 – 17, 2015.

Strohmeier, S., Rieder, J., Kaltenleithner, M., Nigus Demelash, Guzmán, G., Ziadat, F., Klik, A. (2015): Using magnetite tracer to evaluate a novel plot experimental design for the assessment of soil and water conservation impacts of stone bunds in Ethiopia. EGU General Assembly 2015, Vienna, Austria, April 11 – 17, 2015.

Ziadat, F., Bayu, W. 2015. Mitigating Land Degradation and Improving Livelihoods. An Integrated Watershed Approach. Routledge – Taylor and Francis Group, NY, USA, 262 pp.

Land Use and Land Cover Changes of Mt. Guna since 1935

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Figure 15: Mt. Guna excursion point (indicated by arrow) and study site indicated by yellow star (2.76 km away from excursion point; Google Maps imagery)

Introduction

Land use/land cover (LULC) change is a dynamic and complex process that can be exacerbated by a number of human activities. Factors driving LULC change include an increase in human population and population response to economic opportunities (Lambin et al., 2001). Despite the social and economic benefits of LULC change, conversions of LULC frequently have unintended consequences on the natural environment such as decreased infiltration, decreased discharge of downstream springs and increased soil erosion (Nyssen et al., 2004; Descheemaeker et al., 2006).

Of the total area of afroalpine and sub-afroalpine ecosystems (11,887 km^2 above 3200 m) found in Africa south of the Sahara, 73% (8677 km^2) are located in Ethiopia; of these, 82% (7130 km^2) is located in 8 mountain ranges (Table 1).

High mountain forests are very important for the livelihoods of local communities in relation to the impact on the water balance of the mountain ecosystem and the agricultural areas in the surrounding lowlands (Nyssen et al., 2004). Although there are many LUC change studies for the Ethiopian highlands, most of these studies mainly deal with lower vegetation belts (Jacob et al, 2015). With the aim to increase knowledge about LUC changes in the afro-alpine zone, the current study is underway at Mount Guna which has an elevation between 3200 and 4113 m.a.s.l at the peak of the mountain (Belste et al., 2013). The unprecedented time scale reaching back to the 1930s can be achieved because aerial photographs realized in the period of Italian occupation of Ethiopia have recently come to light (Nyssen et al., 2015).

Table 1: Ethiopian afroalpine and sub-afroalpine mountain ranges (after Girma, 2010)

Mountain Range	Area in km^2	Name of Peak	Altitude [1]	Latitude and Longitude[1]
Bale	1990	Tulu Dimtu	4377 m.a.s.l	6.82°N, 39.81°E
Arsi	1000	Chilalo	4079 m.a.s.l	7.91°N, 39.26°E
Simen	960	Ras Dashen	4550 m.a.s.l	13.25°N, 38.38°E
Abune Yosef	1150	Abune Yosef	4286 m.a.s.l	12.15°N, 38.18°E
Mount Tossa	1220	-	3800 m.a.s.l	11.14°N, 39.60°E
Mount Choke	500	Arat Mekerakir	4050 m.a.s.l	10.71°N, 37.85°E
Mount Guna	210	Kinchift/Beredo Mefya	4113 m.a.s.l	11.43°N, 38.13°E
Menz Guassa	124	-	3700 m.a.s.l	10.34°N, 39.76°E

[1] Retrieved from Google Earth/Maps

Data and pre-processing for orthophoto preparation

Historical black and white aerial photographs of 1935, 1957 and 1982 from the Ethiopian Mapping Agency were used. The aerial photographs were orthorectified by digital image processing with ERDAS Imagine. As input for the orthorectification process ground control points were obtained from high-resolution satellite images of Google maps/Google Earth. These satellite images allow users to rapidly investigate geographic features at good planimetric and altimetric accuracies higher than that of common handheld GPS (Frankl et al, 2013).

Since there was no access to the camera calibration report, the fiducial coordinates were measured from the aerial photographs such that the origin of the coordinate system is the principal point of the aerial photograph (Teferi et al, 2013). As no fiducials or other metadata are available for the 1935 APs (Nyssen et al., 2015), these were co-registered by detecting well spread co-registration tie points on both the APs and Google Earth imagery. Using sufficient tie point density can yield reasonable results in small areas (Hughes et al., 2006; James et al., 2012).

The accuracy of the obtained orthophotos was assessed by overlaying the orthorectified photos over the available georeferenced 1:50 000 topographic map from the Ethiopian Mapping Authority and the lowest Root Mean Square Error (RMSE) in x and y (Meire et al 2013).

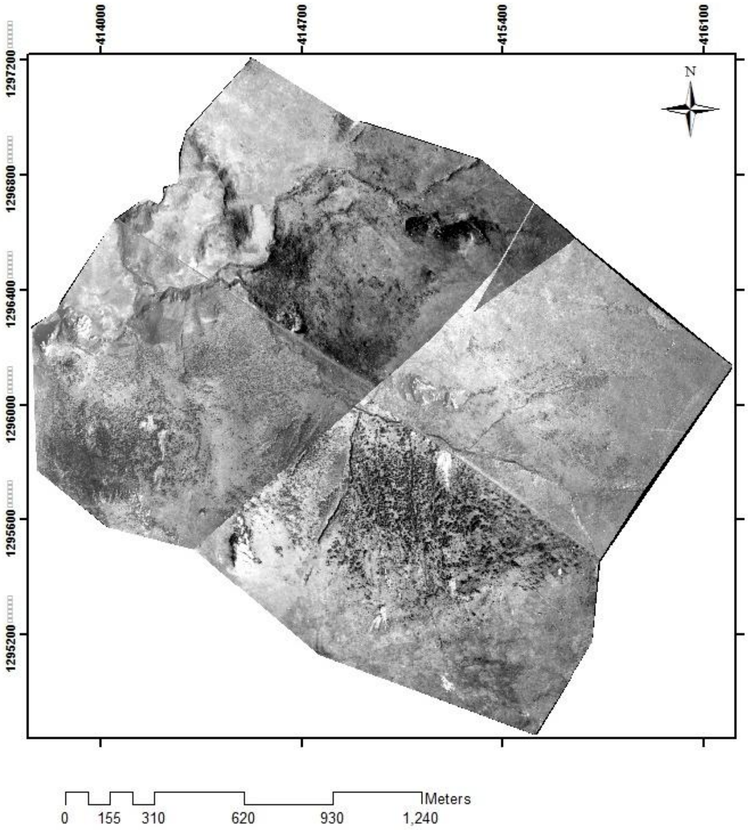

Figure 16: 1938 orthophoto of study area

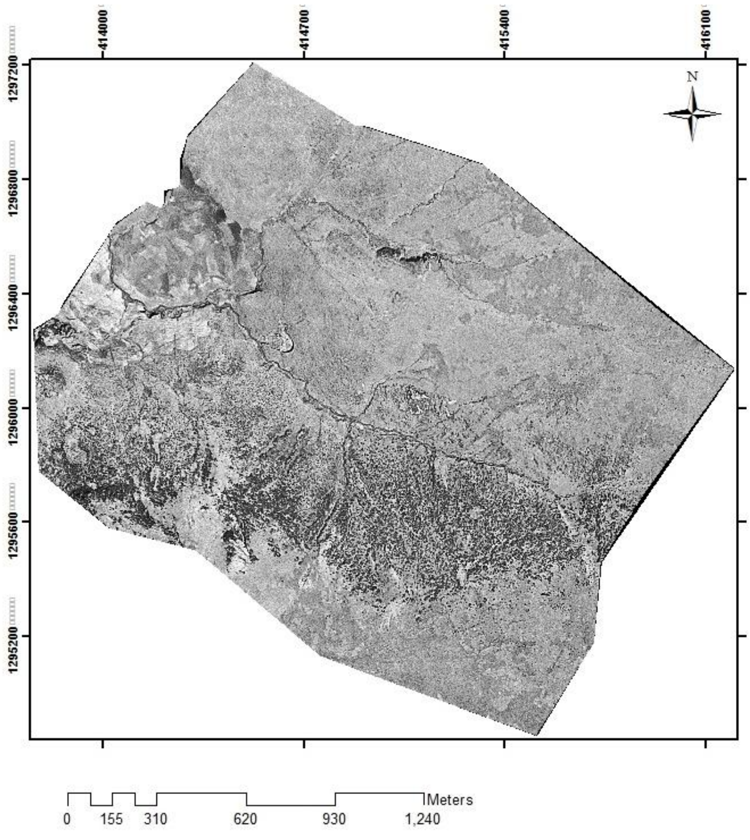

Figure 17: 1957 orthophoto of study area

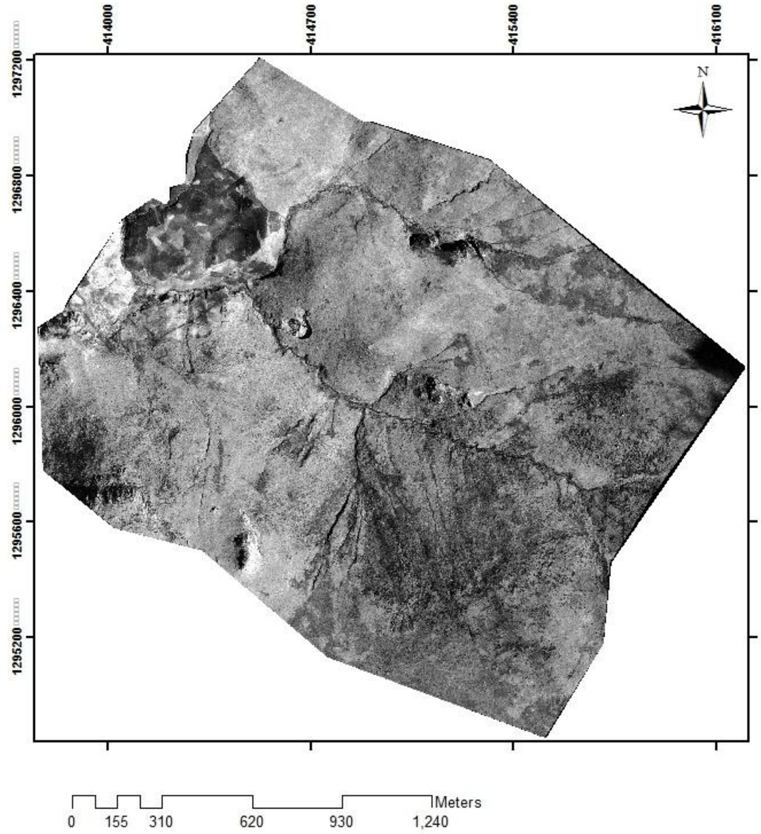

Figure 18: 1982 orthophoto of study area

LUC classification

By investigation the LUC on the aerial photos and by making observations in the field, the following LUC classes could be distinguished: cropland, forest, eucalypt plantation, grassland, village, bare ground and bedrock (Table 2 and Figure 5).

Table 2: Land use and cover classes in Ethiopia's afro-alpine regions (after Jacob et al, 2015)

Class	Land Use and Cover Description
Farmland	Areas covered with annual and perennial crops
Forest	Areas covered with natural vegetation/Ericaceous forest
Eucalyptus Plantation	Land covered by Eucalyptus plant
Grassland	Afroalpine and Sub-afroalpine Grasses and herbs comprising Helichrysum and Festuca
Village	Scattered rural settlement, including community buildings and houses
Rock Outcrop	No woody vegetation with exposed rocks and soils
River Bed	Exposed bedrock of rivers

Figure 5: View on the study site with grassland in the foreground (comprising a lobelia and a giant thistle), Erica forest at the middle, and rock outcrop at the back.

References

Belste F, Yosef H, Birhanemeskel A, Asmamaw K, Yeshanew A and Getasew A, 2012. Socioeconomic situation, tourism potentials and Biodiversities study report for mount Guna proposed community conservation area. Amhara National Regional State Bureau of Culture, Tourism and Parks Development

de Mûelenaere S, Frankl A, Haile M, Poesen J, Deckers J, Munro N, Veraverbeke S, Nyssen J. 2014. Historical Landscape Photographs for Calibration of Landsat Land Use/Cover in the Northern Ethiopian Highlands. *Land Degradation & Development* 25: 319–335.

Descheemaeker K, Nyssen J, Poesen J, Raes D, Haile M, Muys B, Deckers S. 2006. Runoff on slopes with restoring vegetation: A case study from the Tigray highlands, Ethiopia. *Journal of Hydrology* 331: 219–241

Frankl A, Zwertvaegher A, Poesen J, Nyssen J (2013): Transferring Google Earth observations to GIS-software: example from gully erosion study, International Journal of Digital Earth, 6:2, 196-201

Girma E. 2010. Community Management and Status of an Afro-alpine Ecosystem: The case of the Ethiopian Wolf at Mt. Abune Yoseph. Mekelle University, MSc Thesis.

Hughes ML, McDowell PF, Marcus WA, 2006. Accuracy assessment of georectified aerial photographs: implications for measuring lateral channel movement in a GIS. Geomorphology 74: 1-16.

Jacob M., Romeyns, L., Frankl, A., Tesfaalem, A., Beeckman, H., Nyssen J., 2015.Land use and cover dynamics since1964 in the afro-alpine vegetation belt: Lib Amba Mountain in North Ethiopia. Land Degradation & Development. DOI: 10.1002/ldr.2396.

James, LA, Hodgson, ME, Ghoshal S, Latiolais MM, 2012. Geomorphic change detection using historic maps and DEM differencing: the temporal dimension of geospatial analysis. Geomorphology 137: 181–198.

Lambin EF, Turner BL, Geist HJ, Agbola SB, Angelsen A, Bruce JW, Coomes OT, Dirzo R, Fischer G, Folke C, George PS, Homewood K, Imbernon J, Leemans R, Li X, Moran EF, Mortimore M, Ramakrishnan PS, Richards JF, Skånes H, Steffen W, Stone GD, Svedin U, Veldkamp TA, Vogel C, Xu J. 2001. The causes of land-use and land-cover change: Moving beyond the myths. Global Environmental Change 11: 261–269.

Nyssen J, Poesen J, Moeyersons J, Deckers J, Haile M, Lang A. 2004. Human impact on the environment in the Ethiopian and Eritrean highlands-a state of the art. *Earth-Science Reviews* 64: 273–320

Nyssen J, Petrie G, Sultan Mohamed, Gezahegne Gebremeskel, Stal C, Seghers V, Debever M, Kiros Meles, Billi P, Mitiku Haile, Demaeyer Ph, Frankl A. 2015. Recovery of the historical aerial photographs of Ethiopia in the 1930s. Journal of Cultural Heritage, in press.

Teferi E, Bewket W, Uhlenbrook S, Wenninger J. 2013. Understanding recent land use and land cover dynamics in the source region of the Upper Blue Nile, Ethiopia: Spatially explicit statistical modeling of systematic transitions. *Agriculture, Ecosystems & Environment* 165: 98–117.

Treeline dynamics and forest cover change in afro-alpine Ethiopia, as affected by climate change and anthropo-zoogenic impacts

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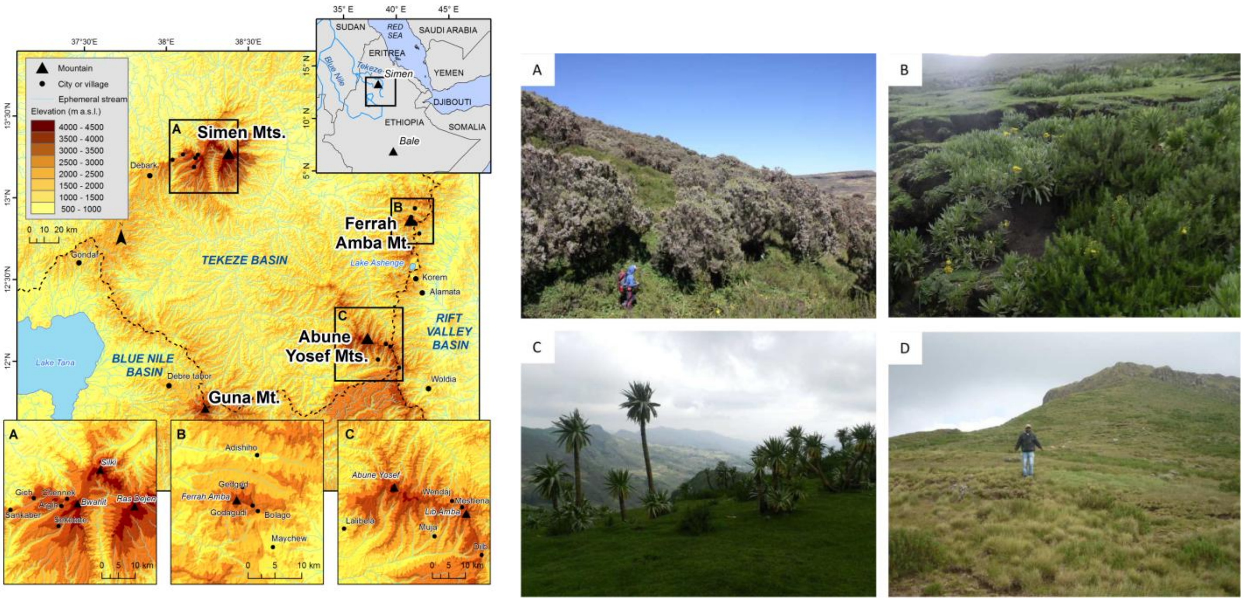

Fig. 1 (left) Location of the three main study areas and Mount Guna; (right) dominant natural vegetation: (a) Erica arborea (b) Helichrysum citrispinum and Hypericum revolutum shrubs, (c) Giant lobelia (Lobelia rhynchopetalum Hemsl.), and (d) Short and long tussock grasses (Festuca macrophylla, Carex erythrorhiza).

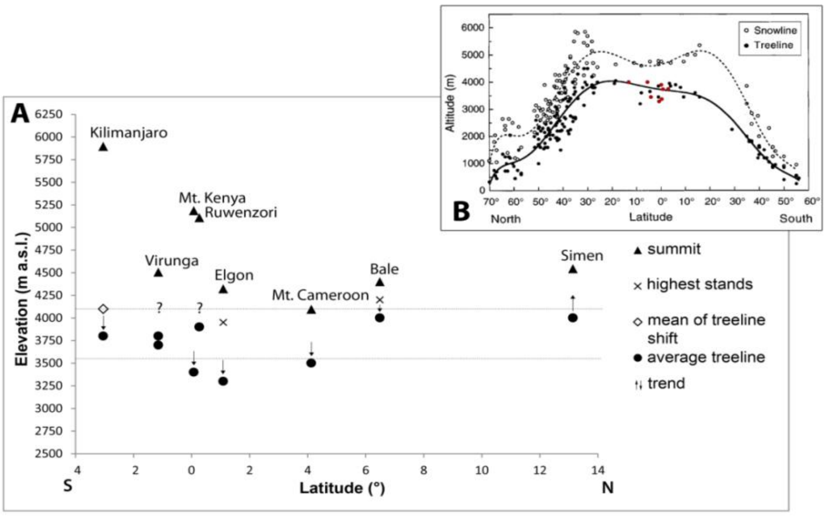

Fig. 2 (A) Synthesis of treeline dynamics in the tropical African highlands. Arrows indicate the treeline trend. The zone between the dashed lines refers to the upper treeline limit zone described by Hedberg (1951). (B) Every dot on the diagram represents a treeline study; the African tropical mountains from the diagram are shown in red.

Introduction

Vulnerable tropical mountain forests provide important ecosystem services for surrounding communities and for biodiversity. At present, this fragile environment is subjected to biophysical and socio-economic drivers of change. Mountain ecosystems are, according to UNESCO, among the most sensitive ecosystems in the world and the treeline, at the upper edge of the mountain forest, forms one of the most apparent vegetation boundaries worldwide. Treelines are temperature sensitive and thus potentially responsive to climate change.

This study disentangles the complex relations between forest cover change, including treeline dynamics, and the drivers of change in the North Ethiopian highlands since the mid-20th century.

Methodologies and results

Different research methodologies were used:

(1) Historical aerial photographs and recent satellite images

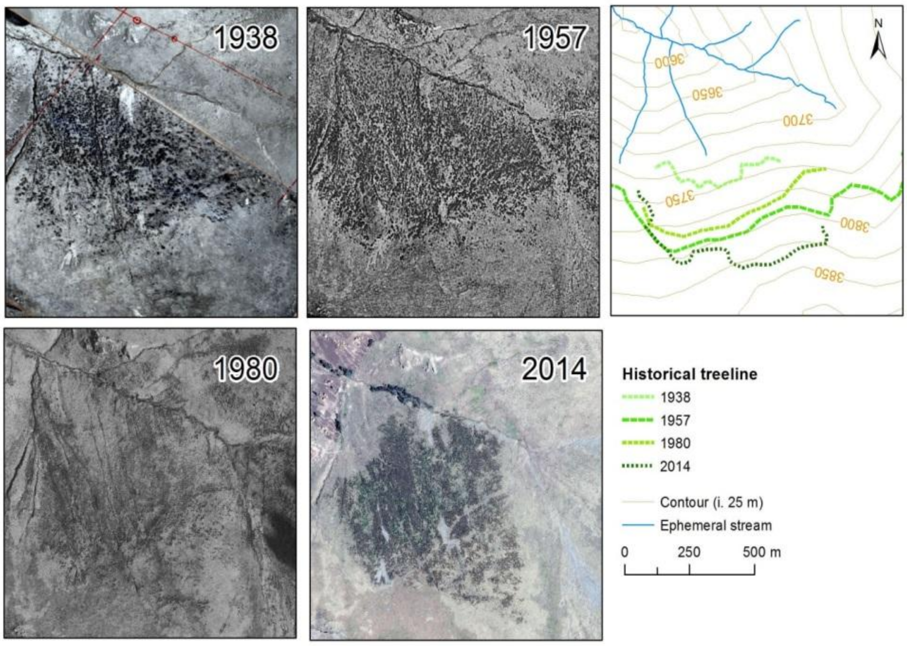

Fig 3. Treeline shift in Mount Guna as derived from co-registered historical aerial photographs. The 1938 aerial photograph was made by the Italian Military, the 1957 and 1980 aerial photographs are from the Ethiopian Mapping Agency (EMA) and the 2014 satellite image is from Google Earth. The treeline shifted 80 m upwards the mountain slope in 80 years.

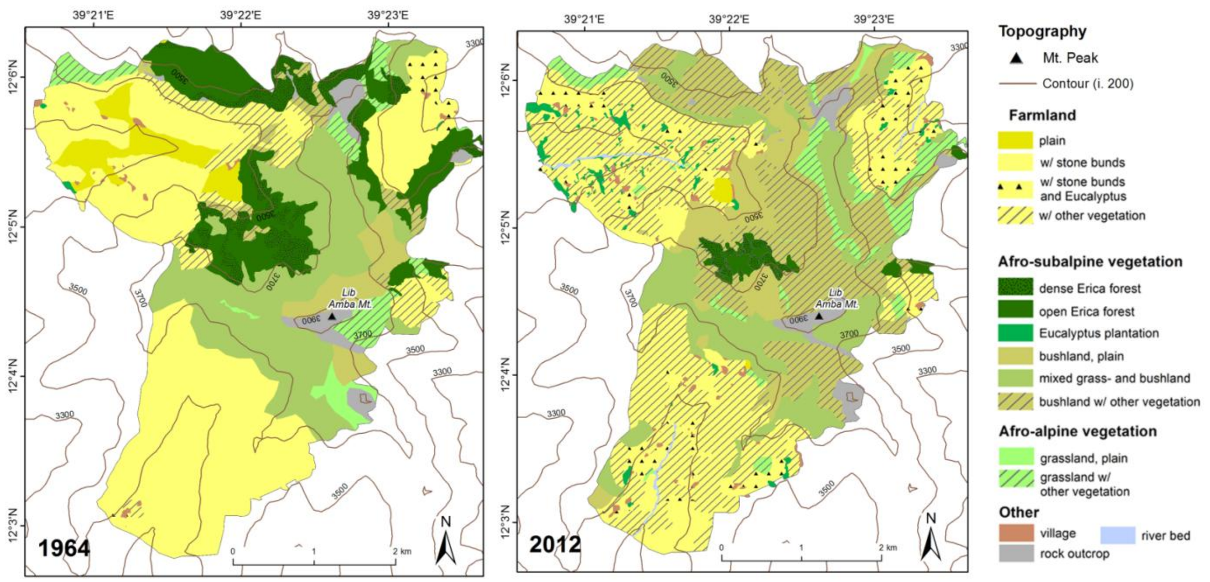

Fig. 4 LUC maps of Mt. Lib Amba for the successive time steps (1964 and 2012). The afro-alpine forests strongly decreased between 1964 and 2012. However, since 1982 is the woody vegetation in Lib Amba Mt. recovering.

(2) Repetition of historical terrestrial photographs

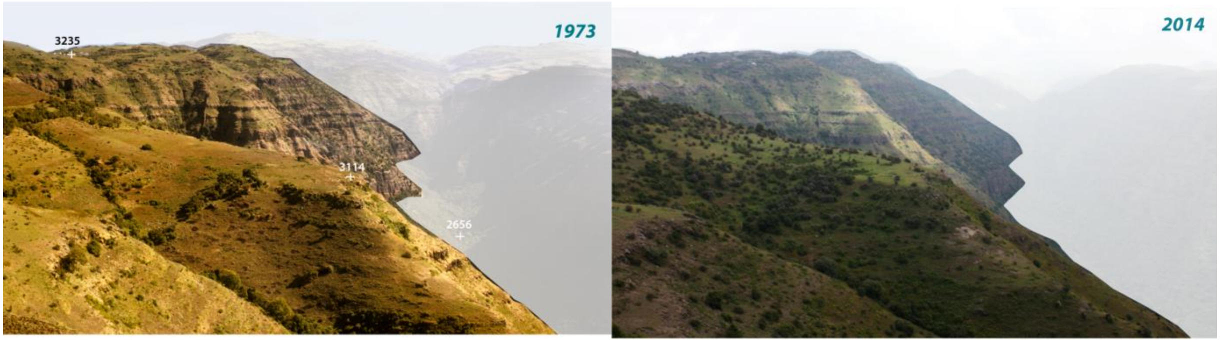

Fig 5. A repetition of the 1973 photograph by Larry Workman looking towards Sankaber camp in the Simen Mts. The truncated mean for the land cover class percentages of the 1973 photograph are 7% open forest, 4% shrubland, 72% grassland and 17% rock outcrop. While, for the 2014 photograph these land cover percentages are 19% open forest, 19% shrubland, 51% grassland and 11% rock outcrop. The photograph is masked to differentiate between different major topographic entities and to hide uninterpretable areas.

(3) Dendroclimatology

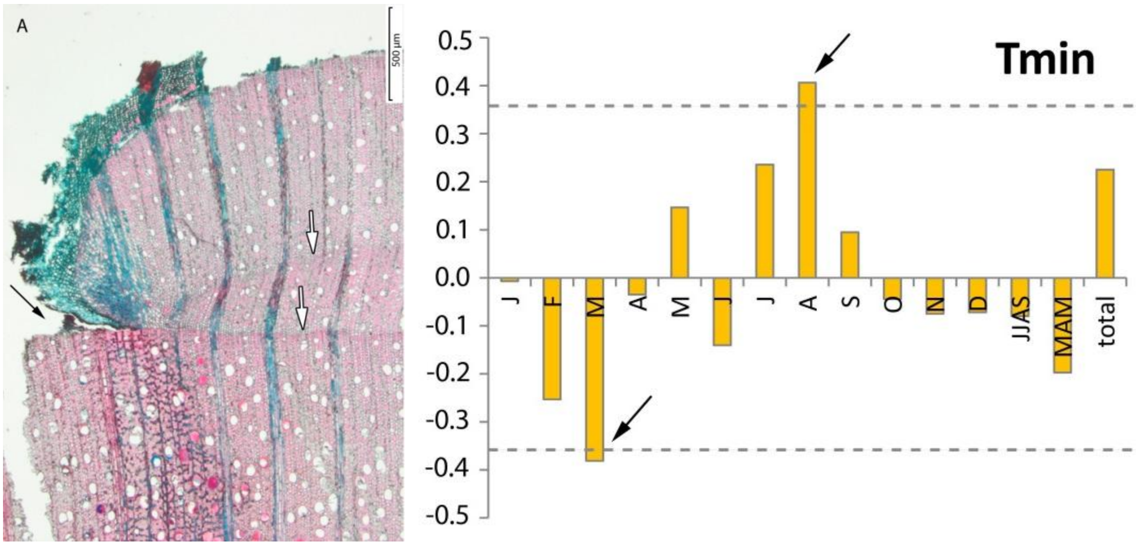

Fig 6. (left) Microphotograph of cambial marked stem discs. The cambial mark is indicated with black arrows in sample Tw64884. The trees were marked on March 15 2012 and sampled after 498 days on July 25 2013. Annual tree rings are formed in relation with the rain season. The tree-ring boundaries are indicated with white arrows. (Right) Correlation coefficients (n = 22) between monthly and seasonal climate variability and tree-ring width of Erica arborea (1992-2013). The dotted line represents the p<0.1 level. Significant correlations are indicated with a black arrow. Minimum temperature is significantly correlated with tree growth in March and in August. Maximum temperature and rainfall are not significant correlated with tree growth.

(4) Meteorological measurements

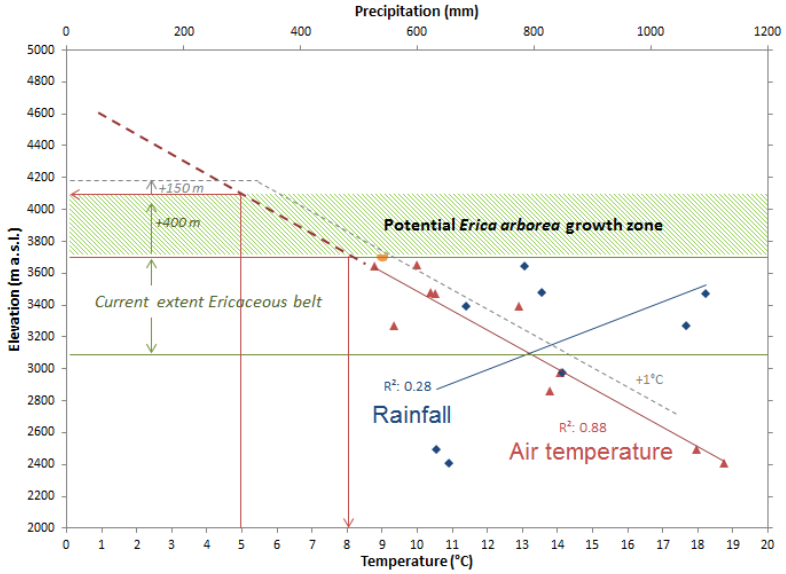

Fig. 7 Altitudinal gradient of air temperature (red) and rainfall (blue). With indication of the potential treeline limit corresponding with a mean air temperature of 5°C (red arrows). The potential effect of an increase of the air temperature with 1°C at the treeline elevation is indicated in grey.

Conclusions

This study revealed the dynamics and drivers of high altitude forest cover change and treeline shifts since 1964 in the North Ethiopian highlands. The afro-alpine forest declined between 1964 and 1982 and extended afterwards between 1982 and 2015, while the opposite trajectory was observed in the lower afromontane forest belt. The treeline is indicated to have shifted upwards up to 4000 m a.s.l. locally in the Simen Mts., but in general, the treeline is located 400 m below its potential climatic position. The potential climatic limit is a temperature limit, since temperature during the growing season is indicated to limit tree growth. This depressed treeline elevation can be attributed to the effect of changing population dynamics.

References

Jacob, M., Frankl, A., Beeckman, H., Mesfin, G., Hendrickx, M., Guyassa, E., Nyssen, J. (2015). North Ethiopian afro-alpine treeline dynamics and forest cover change since the early 20th century. Journal of Land Degradation & Development, online early view. DOI: 10.1002/ldr.232.

Jacob, M., Romeyns, L., Frankl, A., Asfaha, T., Beeckman, H., Nyssen J. (2015). Land use and cover dynamics since 1964 in the afro-alpine vegetation belt: Lib Amba mountain North Ethiopia. Land Degradation and Development, accepted.

Jacob, M., Annys, S., Frankl, A., De Ridder, M., Beeckman, H., Guyassa, E., Nyssen, J. (2014). Treeline dynamics in the tropical African highlands – identifying drivers and dynamics. Journal of Vegetation Science, 26 (9), 9-20.

Jacob, M., Frankl, A., Hurni, H., Lanckriet, S., De Ridder, M., Guyassa, E., Beeckman, H., Nyssen, J. (2015). Vegetation dynamics in the Simen Mountains (Ethiopia), half a century after establishment of the National Park. Regional Environmental Change, in review.

Jacob, M., Frankl, A., Broidioi, S., Asfaha, T., Beeckman, H., Nyssen, J. (2015). Climatic limitations for *Erica arborea* growth in Northern Ethiopia. International Journal of Biometeorology, in review.

Jacob, M., De Ridder, M., Vandenabeele, M., Frankl, A., Asfaha, T., Nyssen, J., Beeckman, H. (2015). Are the high altitude treelines sensitive to climate variability? A dendroclimatological study in the North Ethiopian highlands. Trees, in preparation.

Preservation and Utilization of Papyrus: Community Service Project of Bahir Dar University, Ethiopia

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Figure 1: One year old papyrus plantation and its utilization for local basket making

1. Introduction

Papyrus (*Cyperus papyrus* L.) is one of the most ancient plants known to humankind. Different people have described papyrus by associating with its value in the past and its physical nature. papyrus is defined in Encyclopedia Britannica as "a tall plant that is like grass and that grows in marshes, especially, in Egypt…. Paper made from papyrus". The following three facts about the plant are commonly found in literature: papyrus is found in the Nile Valley, it grows well in marsh area and people of Egypt were making paper using papyrus.

Though the history of paper making has made Egypt known for papyrus plant, the Ethiopian traditional boats (locally called *tankwa*) and household furniture are also made from this plant and it is still used by the surrounding community of Lake Tana. Bahir Dar City is known of its papyrus plant grown in the shorelines of Lake Tana. Arthur J. Hayes spent a few days in Bahir Dar in February 1903, which he described as a village surrounded by a marsh of papyrus plants; nearby were "two or three huts" inhabited by the Negede Weyto ethnic group.

Papyrus has been used for different purposes. It was used to make bed mats, food baskets, etc. Traditional boats made of papyrus were and are still now the essential means of water transport for the surrounding community in Lake Tana. People sell papyrus reeds and leaves to generate additional income (Figure 2). The Negede Woyto tribe has been using papyrus reed to make sleeping mat, food basket, rope, and its root to make charcoal after using the flame for baking *injera*. As towns emerge and develop around Lake Tana, the thin leaves which grow on the upper end of the reed have become a means to decorate the floor of homes and hotels during coffee ceremonies and holydays.

Figure 2: Papyrus reed marketing in Bahir Dar

However, the plant is currently highly endangered. Farmers who live near the lake are destroying this plant to get farmland. It is also becoming communal grazing area for livestock.

As a result, the dense papyrus vegetation which is found on the coast and marshes areas along the lake is getting thinner and thinner, even to the extent of being totally destroyed in some places. Critical observations of all the above mentioned facts have initiated BDU to propose a community service project with the major objective of restoring the papyrus belt in the devastated swampy coast of Lake Tana and establish a dense papyrus vegetative buffer on the shore of Koga reservoir. Moreover, the project aims at creating job opportunities for the surrounding dwellers who are interested to participate in establishing the buffer zone and crafting furniture from papyrus plant. The project was piloted in the following sites; Bahir Dar University Peda campus, Belay Zeleke sub-city, the shoreline of Bahir Dar city, and the shore of Koga reservoir.

2. Characteristics and uses of papyrus (literature review)

A closer look at *Cyperus papyrus* will bring into focus a few of its main botanical characteristics. A mature, flowering umbel is composed of slim, twig-like, shoots merging from its stalk. It is a tall flowering freshwater reed. The umbel, or whole cluster of spikelet-flowers on their respective, grows stems, or numerous fine umbel rays. Each plant has a tall, smooth stalk, which supports the umbel. Stalks reach a height of four meters. Umbels emerge from what is called the rhizome, a horizontal, root-like stem which lets out shoots from its lower surface and leafy shoots on its upper surface.

The spike is a long flower cluster composed of branching, spike-like buds, which have sprung from their central stalk. The support for the spike grows in a variety of lengths and the buds vary in number on each stalk. Each spike has as many as twelve flowers, which are like husks. They have no calyx or corolla, i.e., outer base leaves nor inner petals or leaves.

Attention has been given to investigate the capacity of papyrus in wastewater treatment and control pollution (Abe *et al.*, 1997; Abe & Ozaki, 1998; Mizuta *et al.*, 1998; Okurut *et al.*, 1999; Azza *et al.*, 2000; Kansi-ime & van Bruggen, 2001). In Uganda, a study by Denny *et al.* (1995) shows that papyrus vegetation absorbs heavy metal pollutants and uses them as food. According to them, this effect and the food web system, in turn, prevents the accumulation of heavy metals in Lake George. The findings of Robinson et *al.* (2013) demonstrate that none of the unplanted mesocosms used as control experiment had any effect on the water quality. But, the papyrus was able to decrease the highly toxic chemical oxygen demanded of the water by absorbing nitrogen and phosphors ions as well as residues of organic matter. Gaudet cited in Khaled (2014) states the role of papyrus for human development as: "the plant that changed the world". Gaudet also points out that papyrus can help African countries solve ecological and environmental problems, especially, pollution. According to Khaled (2014), papyrus can be used to filter waste water by releasing sewage into a swamp where papyrus stretches out over the water.

The pH within papyrus is accounted for very high. Papyrus can change CO_2 into an organic 'soup' under anaerobic conditions and at high temperatures (Mamdouh, 2003). Such conditions may give an evidence why papyrus is tolerant of a wider pH range than are the other major emergent plants in swamps. The pH of most plants is usually 6 to 7.5, but papyrus grows satisfactory between pH 4 and 8.0 (Thompson, 1976). In a dense papyrus forest site organic matter accumulates and forms layers under the mat (Mamdouh, 2003). This facilitates this plants' uptake capacity since sorption reactions occur on the colloidal surface. Papyrus has a considerable capacity of absorbing the floating mats and large amounts of nutrients are accumulated in the plant (Gaudet, 1979). The floating root mat of papyrus can easily extract nutrients from wastewater underneath and offer effective treatment (Azza *et al*., 2000).

According to Wassie *et al.* (2015), water hyacinth infestation is high when indigenous macrophytes such as papyrus are absent. On shorelines where papyrus is dominant, water hyacinth coverage is limited. This implies that papyrus competes with water hyacinth. Thus, rehabilitating some hotspot shores by papyrus is one of the remedies to overcome water hyacinth dominance and use it as biological control.

3. Project Achievements

Starting from February 2014, papyrus rhizomes were transplanted from a marsh area which is found near Lake Tana and Abay (Nile) river to a nursery site i.e. swampy brook which flows through Bahir Dar Town and Peda campus. This brook had a very bad smell due to the pollutants that come from different corners of the town. After the establishment of the nursery site, Peda campus residents are heard saying: "thanks to this papyrus plant, the bad smell of this brook is decreasing gradually."

Starting from June 2014, papyrus rhizomes are transplanted from the nursery site to the devastated coast of Lake Tana. This is done in limited areas which are near to Bahir Dar Town. Besides, another nursery site is selected on the cost of Koga Reservoir and papyrus rhizomes are transplanted from Peda Campus to this nursery site.

Job seekers have got opportunities to work in this project. They are involved in uprooting papyrus rhizomes, digging holes, crafting food basket, small baskets used for shopping, baby beds and small circular mats.

To collect one bundle of papyrus reed or one bundle of papyrus leaf was a whole day work task: they have to travel at least three hours to reach the papyrus forest. Now, these things are sold with the least price at the nursery site. The ripe papyrus leaf at the nursery site has been collected and sold. And Bahir Dar University has got 18,000 Ethiopian birr from this sale.

The project sites are being chosen by science students and teachers as research sites. Researchers from different departments of the university are using the nursery site which is found in Peda as a study site.

4. **Conclusion**

It is common to hear the community saying the following: “This is a fast start that shows us miracles within a year time span”. At present the capacity of papyrus in wastewater treatment and pollution control is becoming clear. Our vision of this project is to scale it up year after year and then to see the shoreline having its previous papyrus belt buffer as well as absorption heavy metal pollutants in liquid waste drainage canals. If possible we are planning to establish papyrus vegetative buffer around Koga reservoir and Great Renaissance Dam in order to use this plant as a silt trap.

References

Azza, N. G.T., Kansiime, F., Nalubega, M. and Denny, P. (2000): Differential permeability of Papyrus and Miscanthidium root mats in Nakivubo swamp, Uganda. Aquatic Botany 67: 169-178.

Gaudet, J. (1979): Seasonal changes in nutrients in a tropical swamp: North swamp, Lake Naivasha, Kenya. Journal of Ecology, 67: 953-981

Khaled, R. (2014). Resurgence of Papyrus plant poses potential ecological Benefits. Availaible on www.dailynewsegypt.com

Mamdouh, S. (2003): Ecology and biomass production of *Cyperus papyrus* L. on the Nile bank at Damietta, Egypt. *Journal of Mediterranean Ecology* vol. 4, No.3-4

Robinson, O., Kansiime, F.; Omara, J., Kyambadde, J. (2013). The potential of Four Tropical Wetland Plants for the Treat of Abattoir Effluent; Environmental Technology and Management. Available on www.sciencedaily .om /releases

Thompson, K. (1976): Swamp development in the headwaters of the White Nile. In : The Nile: Biology of an Ancient River, Rzoska, J. Ed., Dr. W. Junk Publishers, The Hague, The Netherlands: 177-196.

Wassie Anteneh, Dereje Tewabe, Addisalem Assefa, Abebaw Zeleke, Befta Tenaw, & Yitayew Wassie (2015). Water hyacinth coverage survey report on Lake Tana Biosphere Reserve. Technical report series 2. Bahir Dar, Ethiopia. http://www.bdu.edu.et/scee/sites/default/files/Water%20hacinth_Lake%20Tana_Report%20Series%202.pdf