Journal of Natural Sciences Research
ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online)
Vol.5, No.11, 2015

Ecological Benefits of Integrated Watershed Management: The Case of Sheka Watershed, Ethiopia

G/mariam Yaebiyo[1*] Yayneshet Tesfay[2] Dereje Assefa[3] Kiros Habtegebriel[4]
1.Mekelle Agricultural Research Center, Mekelle, Ethiopia
2.International Livestock Research Institute, Mekelle, Ethiopia
3.Department of Crop Science at Mekelle University, Mekelle, Ethiopia
4.Department of Land Resource Management and Environmental Protection at Mekelle University, Mekelle, Ethiopia
*E-mail of the corresponding author: gyaebiyo@gmail.com

Abstract
Watershed degradation through soil erosion is one of the main constraints for agricultural productivity. Integrated watershed management (IWSM) was taken as the basic operational unit to tackle this problem. However, its effectiveness in rehabilitation of degraded watershed was rarely evaluated. Therefore, this research was conducted in Sheka watershed, Ethiopia, with the objective of assessing impact of IWSM on selected ecological benefits. Land map units of treated and untreated sub-watersheds were prepared using Geographic Information System software. Sixteen plots with 20m x 20m were randomly formed in the land map units of the two sub-watersheds for soil and woody plants sampling. The results revealed that there were significantly higher woody plants density and diversity, total nitrogen, soil organic matter, available phosphorous and available potassium contents in the treated sub-watershed than the untreated one. Whereas, in terms of soil pH, soil texture and evenness of woody species, the two areas were not significantly different. Total nitrogen was positively and significantly correlated with soil organic matter, woody plants density and diversity. Therefore, IWSM is not only effective in restoring woody species density and diversity, but also in improving soil fertility status. Thus, it is better to introduce IWSM in to the untreated watershed.
Keywords: Integrated watershed management, woody plants, treated, untreated

1. Introduction

Watershed degradation is one of the main constraints for agricultural productivity, resulting from the interaction of natural and anthropogenic factors, including erratic rainfall, rugged topography and unsustainable land management practices (Sertse, 2007; Darghouth *et al.*, 2008). Soil erosion is one of the features of watershed degradation. In Ethiopia, soil erosion by water constitutes the most widespread and damaging process of soil degradation, and it is particularly severe in the highlands of Ethiopia (Woldeamlak, 2003).

In Ethiopia, watershed development planning has been started in 1980's with large watersheds, but large efforts remained mostly unsatisfactory due to lack of effective community participation, limited sense of responsibility on assets created and unmanageable planning units (MoARD, 2005). After some years experience, the ministry of agriculture and WFP technical staff developed simple participatory and community-based watershed planning guidelines (MoARD, 2005). Following this guideline approach, different soil and water conservation (SWC) measures with multipurpose trees and enclosures of degraded hillsides have been extensively carried out in Ethiopia, especially in the Tigray region under various packages (MoARD, 2005).

The study area is one of the integrated watershed management (IWSM) projects developed in Ethiopia. Before IWSM, the watershed was known for its high erosion and nutrient depletion resulting in gully formation, silted up of its downstream part of the land. Consequently, the production and productivity of the land decreased to the extent of disabling the farming community to cover their daily food throughout the year. Therefore, since 1995, IWSM approach which includes SWC measures together with enclosures and income generating technologies was launched by the integration of Relief Society of Tigray (REST) and Kolla Tembien office of Agriculture and Rural Development to overcome this problem. However, empirical data on the contribution of these measures in ecological benefits are lacking because no scientific research has been done in the study area. Hence, applying scientific assessment and measuring of the actual benefits gained so far by the community and the environment will create opportunity to improve and/or continue the existing IWSM in the study area and other parts of the country with similar agro-ecological and socioeconomic conditions. Therefore, this study was carried out to study the impact of IWSM on selected ecological benefits such as tree species density, diversity and evenness and some physico-chemical properties of soil.

2. Materials and methods

2.1. Description of the Study Area

This study was conducted at Sheka watershed in kolla Tembien district, Tigray, Ethiopia. The watershed is located 130 km far away from Mekelle to the North-West direction with $13^{0}41'42.1''$ - $13^{0}43'26.3''$ latitude and

$38^0$49'20.6''- $38^0$49'21.5'' longitude. Total annual rainfall of the area ranges from 500 mm to 800 mm, which is uni-modal pattern and occurs in the months of June up to half of September, its mean annual temperature is $24^0{}_c$, with a minimum of $17^0{}_c$ and a maximum of $30^0{}_c$. Its altitude ranges from 1763 to 2032 m.a.s.l. According to agro climatic zonation of Ethiopia, it is categorized as Dry Weina-Dega zone. The underlying geology is a grey shaly metamorphosed limestone, perhaps turbidite, interbedded with sandstone (Hollingham, 2004). The soil types are mostly leptosols (on the upper part) and cambisols (on the lower part) (BoFED, 2003). There are both indigenous and exotic tree and shrub species in the area.

2.2. Field Data Collection

Delineation of the watershed: The Digital Elevation Model (DEM) was projected to UTM Coordinate system using ArcGIS software. One GPS reading from the outlet of the watershed was taken and entered into the projected DEM. Arc Hydro tools within ArcGIS software were used to delineate the watershed and its drainage line by using DEM of the land surface terrain.

Slope of the watershed: Slope map was derived from DEM of the watershed using the slope function of the Spatial Analyst toolbox of ArcGIS 9.3. The slope was classified into flat to gentl e (0-8 %), moderate slope to moderate steep (8-25 %) and steep slope (> 25 %) based on the classification system of FAO (1988) using the "Reclassification" tool in ArcGIS. Table 1 shows that the watershed was dominated by moderate slope.

Table 1: Area of each slope class of the watershed

Slope class	Area(ha)	Distribution (%)
Flat to gentle slope (0-8%)	183.62	30.9
Moderate slope (8-25%)	314.55	53.12
Steep slope (>25%)	96.12	15.98
Total	594.29	100

Source: Survey, 2011

Land use of the Watershed: Land sat satellite image of 2006 with TM (Thematic Mapper) sensor with 30 m spatial resolution was used for identification of land uses. Two GPS readings from each land use of the watershed were taken from the ground so as to locate the land use on the satellite image. TNT (micro image-X server 2006) software was used to delineate each land use. However, GPS readings were taken from the ground to delineate the land uses of grass land and irrigation lands because they were not clearly seen on the satellite image. Table 2 shows that the largest area of the watershed was covered by cultivated land.

Table 2: Area of each land use of Sheka watershed

Land use type	Area(ha)	Remark
Rain fed cultivated	263.46	
Bush land	99.68	Treated
Forest land	127.35	Treated since 1995
Grazing land	80.43	Untreated
Others	23.37	
Total	594.29	

Source: Survey, 2011

Treated and untreated sub-watersheds: So as to assess the impact of IWSM on selected ecological parameters, the watershed was divided into two sub watersheds, one was treated with physical and biological SWC measures; and the other was not treated by such measures. The two sub watersheds have similar topographic features, altitude, rainfall, soil type and temperature because they are located in one watershed and have common outlet (Figure 1). Under this condition, any differences in soil properties, tree species density and diversity can be attributed to the differences in IWSM.

To delineate the untreated sub watershed, GPS readings were taken round it on transect walk; and delineated using GIS software. The area of the treated sub watershed was 437.96ha and the untreated sub watershed was 156.33ha.

2.2.1. Soil and Woody Plants Sampling

Land map units of treated and untreated cultivated and uncultivated lands with the classified slopes were prepared in the treated and untreated sub-watersheds. For this study, only the land map units of the dominant slope class (moderate to steep slope) with treated and untreated cultivated and uncultivated land use types were used for soil and woody plants sampling.

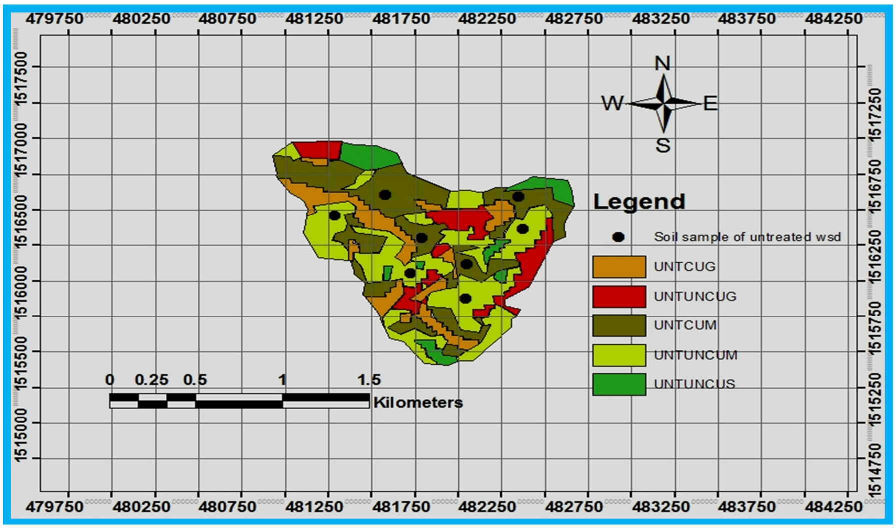

Figure 1: Land map unit of untreated sub watershed

UNTCUG= Land map unit of untreated cultivated land and flat to gentle slope
UNTUNCUG= Land map unit of untreated uncultivated land and flat to gentle slope
UNTCUM= Land map unit of untreated cultivated land and moderate slope
UNTUNCUM= Land map unit of untreated uncultivated land and moderate slope
UNTUNCUS= Land map unit of untreated uncultivated land and steep slope

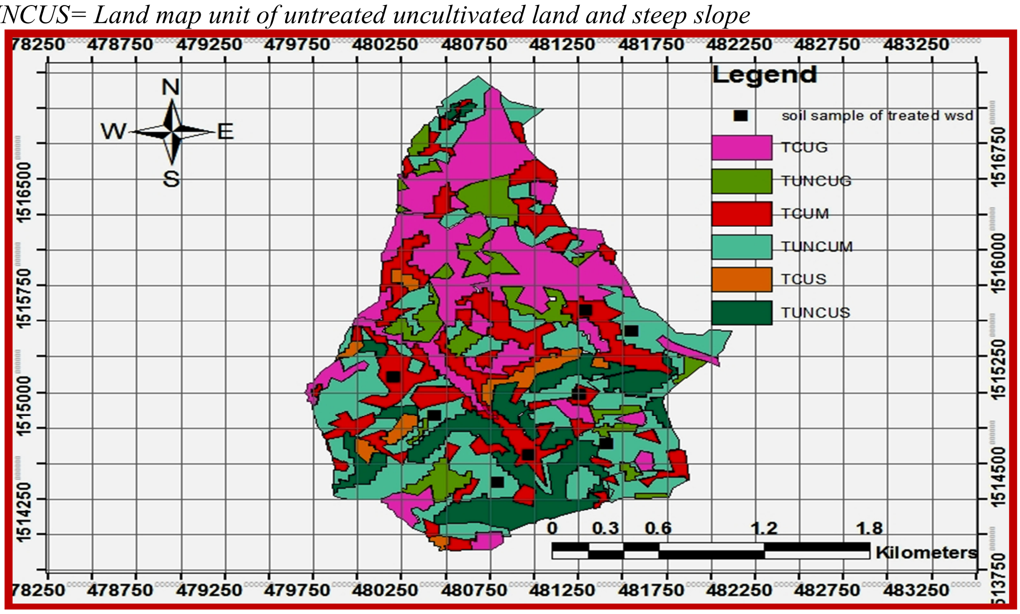

Figure 2: Land map unit of treated sub-watershed

TCUG= Land map unit of treated cultivated land and flat to gentle slope
TUNCUG= Land map unit of treated uncultivated land and flat to gentle slope
TCUM= Land map unit of treated cultivated land and moderate slope
TUNCUM= Land map unit of treated uncultivated land and moderate slope
TCUS= Land map unit of treated cultivated land and steep slop
TUNCUS= Land map unit of treated uncultivated land and steep slope

Two grid squares (one cultivated and the other uncultivated land use types) with four replications were randomly selected from the dominant slope class of each treated and untreated land map units of the two sub-watersheds. Finally, following Mekuria *et al.* (2011), Shawel (2006) and Ermias, (2011), a total of 16 rectangular sample plots of 20m by 20m (8 sample plots from each of treated and untreated sub watersheds) were formed; and observation points were located on each center using coordinates obtained from GPS reading as shown on the land map units of untreated (Figure 1) and treated (figure 2) sub-watersheds. The GPS used has 3 m plus or minus accuracy standard deviation.

Woody plants data collection: Tree/shrub species individuals were counted and recorded in each sample area of 400 m^2. Tree is a woody perennial with a single main stem, or in the case of coppicing with several stems, having a more or less definite crown; while shrubs refers to vegetation types where the dominant woody elements are shrubs, that is woody perennial plants, generally of more than 0.5 m and less than 5 m in height on maturity and without a definite crown (FAO, 2002). For this study, species which have a life form of shrub or tree were considered. A height (h) of 1.5 m and diameter of breast height (dbh) of 2 cm were used to separate tree species from saplings/shrubs and seedlings because woody plant species which have h < 1.5 m could be highly affected by browsing animals and damaged by free grazing, while tree species with h > 1.5 m could be cut for fuel wood and other purposes and considered as large trees. Measuring tape was used to measure stem height and dbh of plants. Name of species (Vernacular and scientific) and number of trees for each species in each sample area of 20 m x 20 m were recorded. Species identification was done with the help of local knowledgeable persons and the nomenclature was done following the Flora of Ethiopia, Honeybee Flora of Ethiopia (Reinhard and Admasu , 1994), Use full tree and shrubs of Ethiopia (Azene, 2007) and (Reubens, 2010).

Woody plants density: Woody species density was expressed with the formula:

Woody plants density = (No. of woody plants of all species)/ (Plot area) x 10000.

Diversity of plant species: Shannon-Wiener index of diversity (*H'*) was used (Krebs, 1999). H' is given by: $H' = -\sum P_i \ln(P_i)$: where Pi is the proportion of individuals of abundance of the *i*th species as expressed as a proportion of the total and pi could be relative density (RD), H' is Shannon's species diversity index. H' was converted to effective number of species diversity using the following formula (Jost, 2006): N1= Exp(H'). Where: N1= Effective number of species; H'= Shannon–Weiner function.

Evenness of plant species: Shannon-Wiener index of evenness (J) was used. J is given by: $J = H'/H'_{max} = -\sum P_i \ln(P_i)/\ln(s)$: where H' is Shannon's species diversity index, lns is the natural logarism of total number of species.

Soil sampling and laboratory analysis: Sixteen composite soil samples were transported to the laboratory of Tigray Agricultural Research Institute, Mekelle Center. Soil samples were air-dried and passed through a 2 mm sieve before analysis. Soil organic matter (SOM%) was determined following the Walkley and Black (1934) procedure. Total nitrogen (TN%) was determined following the Kjeldahl procedure after digestion with sulfuric acid for converting organic nitrogen to ammonium-nitrogen that can be readily estimated (Bremmer and Mulvaney, 1982). Available phosphorus (AP) was determined by Bray-2 method using spectrophotometric method because the soil pH was acidic to neutral (Bray and Kurtz, 1945). Available potassium (AK) was determined by flame spectrometer after extract with ammonium acetate (Morgan, 1941). pH was determined using a suspension of 1:2.5 soil: water ratio and Particle size analyses were determined using the Hydrometer method described both by Okalebo *et al.* (2002).

2.3. Data Analysis

Statistical analysis such as one-way ANOVA, Matched pairs Test, Tukey 'Honestly Significantly Different' (HSD), Pearson correlation and regression plot were used to analyze the data using JMP 5 and SPSS 16 softwares at P < 0.05 level of significance.. Non-parametric measure (Kruskal–Wallis test) was also used for woody plant species evenness analysis.

3. Results

3.1. Impact of IWSM on Woody Plants Density, Diversity and Evenness

A total of 29 woody plant species (15 species naturally grown and 14 species planted) were recorded in both the treated and untreated sub-watersheds in 16 plots. Multipurpose trees like *Leucaena leucocephala*, *Acacia saligna* and *Sesbania sesban* were planted with a spacing of around two meters horizontally; while construction trees like *Melia azedarach* species were planted around 5 m horizontal spacing along soil and water conservation structures. Sixty nine percent of the species were only found in the treated sub-watershed. The minimum species richness (1 species per plot) was recorded in the untreated cultivated land, whilst the highest (11 species per plot) was recorded in the treated uncultivated land. There were significantly higher woody plants density and diversity in the treated sub-watershed than untreated sub-watershed (Table 3).

Table 3: Impact of IWSM on woody plants density, diversity and evenness (Mean ± S.E)

Parameters	Treated sub-watershed	Untreated sub-watershed	P
Density	*828 ± 261*	219 ± 55	0.0234
Diversity (effective number)	*4.6 ± 0.48*	2.07 ± 0.24	0.0004
Evenness	*0.8225 ± 0.04*	0.712 ± 0.13	0.421

S.E__ Standard error of the mean; Mean value calculated from n = 8

The untreated uncultivated land was dominated by the density of *Dodonea angustifolia* followed by *Otostegia integrifolia* species; whilst the density of woody plant species of the treated uncultivated land was dominated by the species of *Acacia abyssinica* followed by *Leucaena leucocephala*, *Senna singueana* and *Calpurnea aurea* species. Whereas, tree species of *Croton macrostachys* and *Ziziphus spina-chiristi* were common in the cultivated land. Fifty and forty four percent of the species found in the untreated and treated sub-watersheds, respectively, were grouped under shrub or tree life forms.

Table 4: Woody plants density, diversity and evenness with regard to land uses (Mean ± S.E)

Parameters	Treated cultivated	Treated uncultivated	Untreated cultivated	Untreated uncultivated	P
Density	188 ± 30[a]	1469 ± 209[b]	106 ± 33[a]	331 ± 67[a]	0.001
Diversity	4.41± 0.63[ab]	4.79 ± 0.82[a]	2.07 ± 0.39[b]	2.1 ± 0.33[b]	0.008
Evenness	0.92 ± 0.03[a]	0.73 ± 0.046[a]	0.69 ± 0.23[a]	0.73 ± 0.16[a]	0.326

S.E__ Standard error of the mean; Mean value calculated from n = 4
Columns with the same letters are not significantly different

The highest woody plants density and diversity were recorded in the treated uncultivated land (Table 4). In the untreated and treated sub watersheds, trees which have stem height of greater than 1.5 m constituted 8.6 and 53.6% of the total woody plant species, respectively.

3.2. Impact of IWSM on Physico-chemical Properties of Soil

The statistical analysis revealed that there were significantly higher OM, TN, AP and AK contents in the treated sub-watershed than the untreated one (Table 5).

Table 5: Impact of IWSM on some physic-chemical properties (Mean ± S.E)

Parameters	Treated sub-watershed	Untreated sub-watershed	P
OM%	*3.64 ± 0.394*	1.61 ± 0.106	0.0027
TN%	*0.23 ± 0.029*	0.1 ± 0.009	0.0053
AP (ppm)	*12.89 ± 1.99*	6.08 ± 1.315	0.023
AK (ppm)	*176.461 ± 18.22*	90.455 ± 9	0.0024
pH	*6.47 ± 0.089*	6.29 ± 0.13	0.318
Sand (%)	*62.75 ± 2.31*	63 ± 2.03	0.94
Silt (%)	*29.25 ± 1.485*	26.75 ± 1.98	0.379
Clay (%)	*8 ± 1.36*	10.25 ± 1.097	0.108

S.E_ Standard error of the mean; Mean value calculated from n = 8, OM_ Organic matter, TN_ Total nitrogen, AP_ Available phosphorous, AK_ Available potassium

Statistical difference ($P < 0.05$) was also observed in SOM, TN, AP and AK contents among the treated and untreated land uses of the two sub-watersheds (Table 6). The textural classes of the treated and untreated sub watersheds were sandy loam (SL) soil. Table 6 showed that soils of treated uncultivated land had significantly higher mean SOM% and TN% compared to soils of treated cultivated land, untreated cultivated and uncultivated land use types. Furthermore, treated uncultivated land had more and significantly different AK content than untreated cultivated and uncultivated lands. Soils of treated cultivated land had significantly higher mean AP content than untreated cultivated and uncultivated land uses; and they had also more and significantly different SOM% compared to untreated uncultivated land (Table 6). Opposite to the untreated sub-watershed, higher SOM% was obtained in the uncultivated land compared to the cultivated land use in the treated sub-watershed. When the contents of SOM, TN and AP of cultivated and uncultivated land uses in the treated sub-watershed were compared with the corresponding land uses in the untreated sub-watershed, SOM% was higher by 64% and 203%, TN% was higher by 60.6% and 207% and AP content was higher by 129% and 87.5% in the cultivated and uncultivated lands, respectively.

Table 6: Analysis of some physico-chemical properties with regard to land use types (mean ± S.E)

Parameters	Treated cultivated	Treated uncultivated	Untreated cultivated	Untreated uncultivated	P
OM%	2.94 ± 0.28[b]	4.34 ± 0.56[c]	1.79 ± 0.09[ab]	1.43 ± 0.15[a]	0.000
TN%	0.175 ± 0.02[a]	0.28 ± 0.04[b]	0.109 ± 0.013[a]	0.091 ± 0.012[a]	0.001
AP (ppm)	16.76 ± 2.7[a]	9 ± 1.098[ab]	7.3 ± 2.3[b]	4.8 ± 1.29[b]	0.006
AK (ppm)	165.2 ± 22.6[ab]	187.7 ± 30.8[b]	90.45 ± 11.3[a]	90.45 ± 15.9[a]	0.013
pH	6.62 ± 0.09[a]	6.4 ± 0.11[a]	6.3 ± 0.24[a]	6.3 ± 0.144[a]	0.417
Sand (%)	63 ± 1.15[a]	62.5 ± 4.85[a]	60 ± 3[a]	66 ± 2.08[a]	0.6
Silt (%)	29.5 ± 1.26[a]	29 ± 2.94[a]	31 ± 2.16[a]	22.5 ± 1.26[a]	0.052
Clay (%)	7.5 ± 1.5[a]	8.5 ± 2.5[a]	9 ± 1.29[a]	11.5 ± 1.7[a]	0.47

S.E__ Standard error of the mean; Mean value calculated from n = 4

Correlation among SOM%, TN%, woody plant species density and diversity: A linear regression analysis made to see correlation of nitrogen with soil organic matter. There was a strong positive linear relationship between TN% and OM% (Figure 3). Both SOM% and TN% were positively and significantly correlated with woody plant species density and diversity at P values 0.000 and 0.001, respectively.

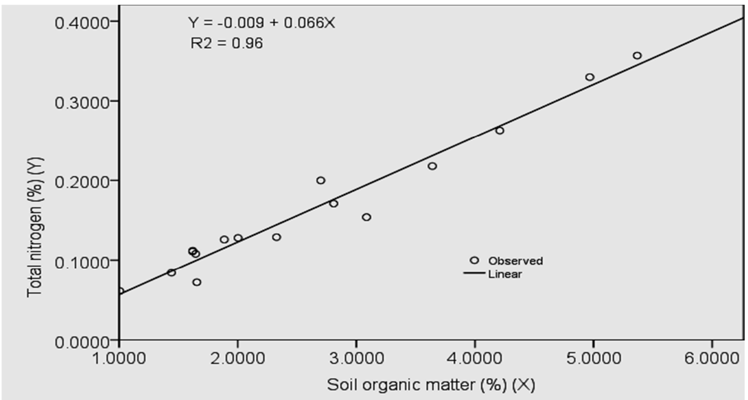

Figure 3: Regression plot for total nitrogen Vs soil organic matter.

4. Discussion

4.1. Woody plants Density and Diversity

Higher woody plant species density and diversity in the treated sub-watershed than the untreated sub-watershed suggesting that implementation of IWSM contributes positively to the rehabilitation of woody plant species density and diversity. Previous studies have shown similar results that degraded watershed had been rehabilitated using IWSM (Fikir, 2008). Yayneshet *et al.* (2009) also reported that the density of woody plant species was increased after protection of the land from free grazing. Higher diversity of economically important tree species were measured in enclosures compared to adjacent grazing lands (Mekuria and Veldkamp, 2012). However, Tessema *et al.* (2011) revealed that grazing pressure had no effect on the density and number of woody species in Semi-arid savanna (Awash National Park and Abernosa Cattle Breeding Ranch) of Ethiopia. This might be related to the fact that livestock are an important agent of regeneration in less degraded environments (Cierjacks *et al.* 2008). However, in degraded environments where there is overgrazing, livestock contribute negatively to the establishment of seedlings through intensive browsing, germination and mortality of many plant communities (Wassie *et al.* 2009).

The difference in tree species dominance between the treated and untreated sub-watersheds could be attributed to the high level of interference both by humans and animals in the untreated sub-watershed. From the farmers' point of view, the open area in the untreated sub-watershed was used to collect wood and non-wood products for household consumption and for grazing by domestic animals without any plantation of seedlings and physical SWC. Some naturally growing tree species like *Dodonea angustifolia* were used only for fuel wood if they increase their stem height, while other species like *Acacia abyssinica* were used for fuel wood and construction materials when they were large enough, otherwise cut for the purpose of crop fence. Unmanaged selective removal of larger trees from unprotected area could interrupt the continuous replacement of woody species (Mastewal *et al.*, 2006). This is due to the fact that with the depletion of larger trees, communities could be forced to use young trees which in turn lead to destruction of woody species and loss of larger trees means loss of seeds and flowering plants which in turn damage the continuity of the generation. Some tree species might be highly palatable to browsing animals. Furthermore, farmers were selective in growing the number and types of tree species in their farmland. Since crop production is most favored activity of farmers, higher tree density would decrease the crop yield by shading and nutrient competition.

4.2. Impact of IWSM on Physico-chemical Properties of Soil

Based on the classification of Barber (1984), the average SOM% of the soil in the treated cultivated and uncultivated land uses was medium and in the untreated cultivated and uncultivated land uses was low; AP content in the treated cultivated land was medium, in the untreated uncultivated land, it was very low, and in the treated uncultivated land and untreated cultivated land, the values were considered as low. Furthermore, the average TN content in the treated uncultivated land was medium, in the untreated uncultivated land the value was regarded as being very low, and in the treated and untreated cultivated lands the values were considered as low.

Higher SOM, TN, AP and AK contents in the treated sub-watershed compared to the untreated sub-watershed could be related to IWSM measures. The hillside of the treated sub-watershed was stabilized with integration of physical and biological SWC measures with different diversity of tree plants, so the soil surface including soil nutrients could be protected from soil erosion. Moreover, SOM% and TN% could be increased. This is because plant species have a significant impact on litter decomposition and nutrient cycling at ecosystem levels (Mekuria *et al.*, 2006). Furthermore, plantation of multipurpose trees like leucaena with enclosures could increase the total nitrogen contents of the soil in treated sub-watershed. As Mulugeta and Stahr (2010) studied, the ages of bunds stabilized with vegetative measures have a better effect in soil OM accumulation. Another study by Tefera (2005) showed that enclosures have improved soil fertility by increasing the OM of the soil. Even though it was not proved by this study, higher SOM% in treated watershed can also improve soil structure and total porosity by decreasing bulk density and compaction of soil. This in turn increases water infiltration rates into the soil and decreases runoff (Descheemaker *et al.*, 2006). Soils that are high in organic matter content could have water stable aggregates that bind soil particles together and are resistant to being broken down by the impact of raindrops (Gachane and Kimaru, 2003).

A lower SOM% and TN% in the untreated sub watershed might have resulted from different reasons. Since the untreated sub-watershed was exposed to free grazing, the above ground biomass and tree seedlings could be removed and damaged by livestock; consequently the input of above-ground litter to the soil could decrease (Mekuria and veldkamp, 2012). Tadesse and Penden (2002) reported that heavy grazing increased the compaction of the soil and accelerates soil erosion. Therefore, SOM% and TN% could be removed from the untreated sub-watershed due to the presence of high soil erosion. Different researchers such as Bishaw and Abdu (2003), Nyssen *et al.* (2004) and Kjell *et al.* (2002) revealed that soil erosion is the main cause for soil nutrient depletion. In other cases, depletion of SOM accelerates soil erosion due to reduction of soil aggregates (Mitiku *et al.*, 2002; World Bank, 2008). A strong positive relationship between TN% and SOM% in a linear regression indicates that reduction in OM% of a soil in the untreated uncultivated land, treated and untreated cultivated land uses is an obvious reason to expect low nitrogen content.

The presence of high amount of AP content in the treated cultivated land might also be the effect of applying cattle dung and chemical fertilizer as a soil conditioner despite the higher SOM% of the treated uncultivated land soils indicating the significance of inorganic sources of phosphorous. Trees in forest area extract more phosphorous than crops or that a high proportion of the phosphorous pool is retained and immobilized by microbes in the litter layers of forests (Lisanework and Michelsen, 1994). Yihenew *et al.*, (2003) revealed that the critical phosphorous concentration beyond which applied fertilizer becomes non-responsive was identified to be 11.6 and 14.6 mg kg-1 for Olsen and Bray-2 methods, respectively on Alfisols of Northwestern Ethiopia.

The lower AP and AK contents in the untreated sub-watershed might be due to the fact that phosphorus and potassium are normally strongly bonded to soil particles (Rehm and Schmitt, 2002) and are therefore easily transported down slope during erosion (Kjell *et al.*, 2002; Wani *et al.*, 2003, Abiy, 2008). Rehm and Schmitt (2002) reported that high AK content was found in soils which had high soil moisture because increasing soil moisture increases movement of potassium to plant roots and enhances availability. Olaitan (1984) revealed that low potassium is 0.1 to 0.25me/100g in tropical soils. The AK makes only 1 to 2% of total soil potassium with 90% of it in exchangeable form (Kiros, 2010). The main source of potassium for plant growing under natural conditions comes from the weathering of potassium bearing primary and secondary 2:1 clay minerals (Kiros, 2010).

5. Conclusions

The results of this study revealed that IWSM measures are not only effective in restoring woody plant species density and diversity, but also improving soil fertility parameters such as SOM, TN, AP and AK contents. The treated sub-watershed, especially, the uncultivated land had improved tree species vegetation cover and soil fertility status compared with the untreated sub-watershed. This was mainly attributed to physical and biological SWC measures together with enclosures in treated sub-watershed, while uncontrolled cutting of trees, no plantation and export of nutrients through grazing and unprotected soil erosion in untreated sub-watershed. This can be concluded as changes in woody plant species density and diversity; and soil compositions are caused by interactions among IWSM measures, human and livestock interventions, soil and vegetation, and these interactions determine the rehabilitation of degraded watershed. Therefore, from the technical point of view, it is better to introduce IWSM measures into the untreated sub-watershed. If the untreated sub-watershed is continued without any IWSM measures, further soil fertility degradation and tree species extinction could occur.

Acknowledgements

We gratefully acknowledge offices of Relief Society of Tigray (REST) of GIS department and SLM-GIZ Tigray for their contribution in supplying of satellite images for the preparation of watershed maps. We consider it a profound pleasure to express our deep sense of profound thanks to Tigray Agricultural Research Institute, Soil Laboratory, Mekelle center, for their cooperation in doing the soil laboratory analysis timely. We would like to extend our recognition to Development Agents (DAs), local administrations and inhabitant of the study watershed, for the provision of all relevant data, documents and information essential for the study. The first author is also grateful to SIDA for providing financial support and Kolla Tembien office of Agriculture and Rural Development for granting a study leave.

References

Abiy Tsedargachew (2008). Area closure as a strategy for land management: A case study at Kelala Dalacha enclosure in the Central Rift Valley of Ethiopia. M.Sc. Thesis submitted to Environmental Science program, Addis Ababa University, Addis Ababa, Ethiopia.

Azene Bekele, 2007. Useful Trees of Ethiopia: Identification, Propagation and management in 17 agroecological zones. Nairbi: RELMA in ICRAF project, 552p.

Barber, R., 1984. An assessment of the dominant soil degradation processes in the Ethiopian highlands; their impacts and hazards. 23, LUPRD, MoA and FAO.

Bishaw Badege and Abdu Abdelkadir (2003). Agroforestry and Community Forestry for Rehabilitation of Degraded Watersheds on the Ethiopian Highlands. College of Forestry, Oregon State University, Corvallis, Oregon 97331, U.S.A. International Symposium on Contemporary Development Issues in Addis Ababa, Ethiopia.

BoFED (Bureau of Finance and Economic Development) (2003). Soil map of Tigray. Tigray regional states BoFED, physical planning development, GIS center, Tigray, Ethiopia.

Bray, R.H. and Kurtz, L.T. (1945). Determination of total, organic and available phosphorus in soil. Soil Sci. 59:39-45.

Bremmer, J. M. and Mulvaney, C. S. (1982). Nitrogen total. Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties. ASA Monograph vol. 9, pp. 595–624.

Cierjacks, A., Rühr, N.K. and Wesche, K. (2008). Effects of altitude and livestock on the regeneration of two tree line forming Polylepis species in Ecuador. Plant Ecology 194(2):207-221.

Darghouth, S., Ward, C., Gambarelli, G., Styger, E. and Roux, J. (2008). Watershed Management Approaches, Policies and Operations: Lessons for Scaling Up. Water Sector Board Discussion Paper Series Paper No 11. The World Bank, Washington, DC.

Descheemaeker, K., Nyssen, J., Rossi, J., Poesen, J., Haile, M., Moeyersons, J., Deckers, J., 2006. Sediment deposition and pedogenesis in exclosures in the Tigray Highlands, Ethiopia. Geoderma 132: 291–314.

Ermias Aynekulu (2011). Forest diversity in fragmented landscapes of northern Ethiopia and implications for conservation. Ecology and Development Series No. 76.

FAO (Food and Agriculture Organization of the United Nations) (1988). Geographical Information Systems in FAO. Rome, Italy.

FAO (Food and Agriculture Organization of the United Nations), 2002. Trees Outside Forest, Towards Better Awareness, Conservation Guide 35, Rome.

Fikir Alemayehu , Nurhussen Taha, Nyssen, J., Atkilt Girma, Amanuel Zenebe,Mintesinot Behailu, Deckers, S. and Poesen, E. (2008). The impacts of watershed management on land use and land cover dynamics in Eastern Tigray (Ethiopia). Department of Land Resource Management and Environmental Protection, Mekelle University, Mekelle, Ethiopia.

Gachene, C. and Kimaru, G., 2003. Soil fertility and land productivity: A guide for extension workers in eastern Africa. Nairobi, Kenya.

Hollingham, M.H. (2004). Operational Research and Capacity Building for Food Security and Sustainable Livelihoods project. Report MHH/3: Water balance Studies. Development Corporation Ireland Ethiopia. Centre for Arid Zone Studies, University of Wales, Balgor LL57 2UW, Wales, UK.

Jost, L. (2006). Entropy and diversity. Oikos 113, 363–375.

Kiros Habtegebriel (2010). Mineral nutrients plant uses and fertility management of soils. Mekelle University, Mekelle, Ethiopia.

Kjell, E., Vagen, T. G., Yibabe Tilahun and Mitiku Haile (2002). Soil Conservation in Tigray, Ethiopia. Noragric Report No. 5.

Krebs, C.J. (1999). Ecological Methodology. Addison Wesley Longman Inc., California.

Lisanewerk, N. and Michelsen, A., 1994. Litter fall and nutrient release by decomposition in three plantations compared to a natural forest in the Ethiopian highland. Forest Ecology and Management 65: 149-164.

Mastewal, Y., Kindeya Gebrehiwot, Stein, M. and Mekuria, W. (2006). Impact of Area Enclosures on Density, Diversity, and Population Structure of Woody Species: the Case of May Ba'ati-Douga Tembien, Tigray, Ethiopia. Ethiopian Journal of Natural Resources 8 (1): 99 – 121.

Mekuria, W. and Veldkamp, E. (2012), Restoration of native vegetation following exclosure establishment on communal grazing lands in Tigray, Ethiopia. Applied Vegetation Science, 15: 71–83.

Mekuria, W., Veldkamp, E., Mitiku Haile, Nyssen, J., Muys, B. and Kindeya Gebrehiwot (2006). Effectiveness of exclosures to restore degraded soils as a result of overgrazing in Tigray, Ethiopia. Department of Land Resources Management and Environmental Protection, Mekelle University, Mekelle, Ethiopia. A journal of Arid Environment 69: 270-284.

Mekuria, W., Veldkamp, E., Tilahun, M. and Olschewski, R. (2011). Economic valuation of land restoration: The case of exclosures established on communal grazing lands in Tigray, Ethiopia. Land Degradation

and Development, 22: 334–344.
Mitiku Haile, Berhanu Gebremedhin and Amare Belay (2002). The Status of Soil Fertility in Tigray. Policies For Sustainable Land Management in The Highlands of Tigray, Northern Ethiopia. Mekelle University (MU), Mekelle, Ethiopia. EPTD Workshop Summary Paper NO. 14.
MoARD (Ministry of Agriculture and Rural Development) (2005). Guide line for integrated watershed management, Addis Ababa, Ethiopia.
Morgan, M. F. (1941). Chemical diagnosis by the Universal Soil Tests System. Conn. Agr. Exp. Sta (New Haven) Bull. 450.
Mulugeta Demelash and Stahr, K. (2010). Assessment of integrated soil and water conservation measures on key soil properties in South Gonder, North-Western Highlands of Ethiopia. Orthodox Church Development and Interchurch Aid Commission (EOC-DICAC), Addis Ababa, Ethiopia.
Nyssen, J., Poesen, J., Moeyersons, J., Deckers, J., Mitiku Haile, 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.
Okalebo, J.R, Gathua, K.W, Woomer, P.L. (2002). Laboratory Methods of Soil and Plant Analysis: A Working Manual. TSBF Program UNESCO – ROSTA Soil Science Society of East Africa technical Publication No. 1. Marvel EPZ Ltd.; Nairobi, Kenya.
Olaitan, S.O., (1984). Introduction to Tropical Soil Science. Department of Vocational Teacher Education, University of Nigeria, Ngukka. Macmillan Intermidate Agriculture Series.
Rehm, G. and Schmitt, M. (2002). Potassium for crop production. Regents of the University of Minnesota. WW-06794.
Reinhard, F. and Admasu Adi (1994). Honey bee flora of Ethiopia. DED-Weikersheim: Margraf, Germany.
Reubens, B. (2010). Woody Vegetation for Gully Rehabilitation in Northern Ethiopia Species Sustainability, Root Structure, and Seedling Establishment, Growth and Management.
Sertse Sebuh (2007). Study and design guidelines on watershed management with reference to forestry.Unpublished. Bureau of Agriculture and Rural Development (BoARD), Mekelle, Tigray, Ethiopia.
Shawel Betru (2006). Vegetation-environment interaction at small scale watershed, A case study in Wondo Genet watershed, Ethiopia. Master thesis, The University of Tokyo, Graduate School of Frontier Sciences Natural Environmental studies.
Tadesse, G. and Penden, D. (2002). Livestock grazing impact on vegetation, soil and hydrology in a tropical highland watershed. Proceedings of MoWR/ EARO/ IWMI/ ILRI International Workshop held at ILRI, Addis Ababa, Ethiopia 2–4 December 2002.
Tefera Mengistu, Demel Teketay, Hakan Hulten and Yonas Yemshaw (2005). The role of communities in closed area management in Ethiopia. *Mountain Research and Development* Vol 25, No 1: 44–50.
Tessema, Z.K., Boer, W.F., Baars, R.M.T. and Prins, H.T. (2011). Changes in soil nutrients, vegetation structure and herbaceous biomass in response to grazing in a semi-arid savanna of Ethiopia. Resource Ecology Group, Wageningen University, Droevendaalsesteeg 3a, Wageningen 6708PB, the Netherlands. School of Animal and Range Sciences, Haramaya University, Dire Dawa, Ethiopia. *Journal of Arid Environments* 75 (2011) 662-670.
Walkley, A. and Black, I.A. (1934). An examination of the degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method soil science 37:29-38.
Wani, S.P., Singh, H.P., Sreedevi, T.K., Pathak, P., Rego, T.J., Shiferaw, B. and Iyer, S.R. (2003). Farmer-Participatory Integrated Watershed Management: Adarsha Watershed, Kothapally India: An Innovative and Upscalable Approach. Case 7. Pages 123–147 in Research Towards Integrated Natural Resources Management.
Wassie, A., Sterck, F. J., Teketay, D. (2009). Effect of livestock exclusion on tree regeneration in church forests of Ethiopia. *Forest Ecology and Management* 257(3):765-772.
Woldeamlak Bewket (2003). Towards Integrated Watershed Management in high lands of Ethiopia: the Chemoga watershed case study. Tropical Resource Management Papers, No. 44 (2003); ISBN 90-6754-708-5.
World Bank (2008). Environmental and Natural Resources Management. Federal Democratic Republic of Ethiopia for a Sustainable Land Management Project. Report No: 42927-ET.
Yayneshet, Tesfay., Eik, L.O. and Moe, S.R. (2009). The effects of exclosures in restoring degraded semi-arid vegetation in communal grazing lands in northern Ethiopia. Department of Animal, Rangeland, and Wildlife Sciences, Mekelle University, Mekelle, Ethiopia. *Journal of Arid Environments* 73, 542–549.
Yihenew Gebre- Selassie, Suwanarit, A., Suwannarat, C. and Sarobol, E. (2003). Equations for Estimating Phosphorus Fertilizer Requirements from Soil Analysis for Maize (*Zea mays*) Grown on Alfisols of Northwestern Ethiopia. Previously Adet Agricultural Research Center, Bahir Dar, Ethiopia.

Appendix

List of tree species found in Sheka watershed

Full species name	**Local name**	**Total trees/ 0.32ha (treated)**	**Total trees/0.32ha (untreated)**	**Life form**
Acacia abyssinica	Thelim Chea	48	0	T
Rhus natalensis	Tetaelo	4	0	T
Senna singueana	Hambahambo	44	5	ST
Dodonea angustifolia	Tehases	7	25	ST
Calpurnea aurea	Hitsawts	34	0	ST
Euclea shimperi	Kuleo	2	3	T
Dichrostachys cinerea	Gonok	5	0	T
Jasminium abyssinica	Habi Tselim	2	0	T
Otostegia integrifolia	Tsiendok	1	12	ST
Croton macrostachys	Tambok	9	1	T
Grewia ferruginea	Tsinkuya	2	0	ST
Maytenus arbutifolia	Ateat	4	6	ST
Ziziphus spina-chiristi	Giba	2	1	T
Citrus medica	Trungi	2	0	ST
Euphorbia tirucalli	Kenchib	2	0	T
Euclapytus spp	Bahrzaf	3	0	T
Melia azedarach	Nim	5	0	T
Buddreja polystachya	Metere	13	1	T
Acacia saligna	Lemlem Akacha	7	0	ST
Leucaena leucocephala	Lusnia	26	0	ST
Schinus molle	Tikur Berebre	2	0	T
Olea europaea	Awlie	2	0	T
Sesbania sesban	Sasbania	28	0	ST
Cordia Africana	Awhi	8	0	T
Maytenus senegalensis	Kebkeb	0	13	ST
Faidherbia albida	Momona	1	0	T
Ximenia Americana	Mileo	2	0	ST
Euphorbia candelabrum	Kolkaul	0	3	T
Rhamnus prinoides	Gesho	2	0	ST

T_Tree, ST_Shrub or Tree

Source: Reubens (2010), Azene (2007), Reinhard and Admasu (1994)