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Impact of Sustainable Land Management Interventions on Soil Moisture Content and Base Flow at Geda Watershed, Central Highlands of Ethiopia

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Abstract

Soil erosion by water caused severe land degradation in the highlands of Ethiopia; due to declined soil fertility and water availability both crop and livestock productivity has been negatively affected in the area. To tackle the problem, watershed based sustainable land management interventions have been implemented at Geda watershed since 2012; however, the contribution of the interventions on soil water retention capacities and base flow improvements were not studied. Therefore, this study explored the impact of the interventions on soil moisture content and the dry period base flows by comparing untreated and treated sub watersheds found adjacent each other. Data for soil moisture was collected from crop and grazing plots at 0-20cm and 20-40cm depths during the beginning of the dry season (October) and at mid dry season (January) from both subwatersheds and landscape positions. Discharges of rivers and springs were measured using graduated bucket at the outlets of the sub watersheds and the values were weighted to the area of the respective sub watersheds. Water productivity was explored by interviewing farmers who practiced irrigation at the lower part of each subwatershed. Data were analyzed based on standard procedures and statistical soft wares.ANOVA showed highly significant differences between untreated and treated subwatersheds for soil moisture contents at the beginning of the dry season ($P \leq 0.001$) and at the most dry season ($P \leq 0.001$). Statistically higher mean values of 25.92% and 27.35% were observed at 0-20 cm and 20-40 cm soil depths respectively in the treated subwatershed compared to 21.70% and 23.82% in the untreated subwatershed during the beginning of the dry season; and higher mean value of 10.16% was recorded at the treated subwatershed compared to 9.50% in the untreated subwatershed during the dry season (January) at 0-20 cm soil depth. Soil moisture content was not affected by landscape positions and land use types at the study area. In addition soil moisture was positively correlated with plant species diversity, plant biomass production, and soil organic carbon. Furthermore, highly significant difference was observed for dry season base flow with a mean value of 1.99 Ls^{-1} at the treated subwatershed compared to the man value of 0.27 Ls^{-1} in the untreated subwatershed. Due to increased base flow, irrigable land increased and crop production shifted from less water demanding and less productive pulses to higher water demanding and higher productive vegetables at the treated subwatershed. Thus, it can be concluded that sustainable land management interventions at Geda watershed brought positive impacts on improving soil moisture content and base flows; therefore, we recommend sustaining and expanding the practices to other watersheds as well.

Keywords: Discharge, landscape position, land use, soil moisture content, subwatershed
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1. Introduction

Soil erosion by water caused severe land degradation in the highlands of Ethiopia; the problem reduced soil fertility and water availability for agricultural and none agricultural activities. In these areas, erratic and seasonal rainfall with un-even distribution and the lack of adequate water storage capacity increased water demand for agriculture, livestock and human use (Jemberu, 2018). Land use changes in these areas negatively affected soil ecosystem processes such as increased nutrient loss, soil instability, reduced water holding capacity, reduced base flows and reduced landscape productivity (Yoseph et al., 2017). Such soil degradation and water resource deterioration are the results of various sets of changes in physical, chemical and or biological characteristics of the soils (Jemberu et al, 2018).

Soil erosion changes the fertility and the physical properties of soils; it changes texture, decreases infiltration rate, water holding capacity and root depth, increases bulk density, generate surface runoff which causes even more soil erosion (Dabi et al., 2017; Jemberu et al, 2018). Consequently, decline in soil fertility, and moisture scarcity resulted in decreased average crop yields at various parts of the country, contributing to cyclic poverty (Desalegn et al., 2015).

Thus, in order to curb the increasing soil erosion and rehabilitate degraded landscapes in Ethiopia, watershed based soil and water conservation interventions had been implemented since the mid-1980s (GIZ, 2015; page 14; Gashaw, 2015; Wolka, 2018); and Sustainable Land Management (SLM) interventions since 2008 at different parts of the country. The expected outcomes of these practices were reduced soil erosion, increased water availability, reducing downstream siltation on irrigation dams, grazing and cultivable lands and inland lakes; and hence improved landscape productivity (Wolka, 2018). SLM practices include construction of soil and or stone bunds, terraces, trenches, check dams, percolating pits, planting of tree lucerne at highly degraded plots, combinations of structural and vegetative measures, and most importantly prohibition of free grazing (Ebabu et al., 2019).

Soil water retentions are important parameters in improving soil, hydrological, ecological and agricultural fields (Rajkai et al, 2004; Yang et al., 2015). The water content of soils is the amount of water contained within the pores of the soils (Fredlund and Xing, 1993); thus, changing the soil physical and chemical properties. Erosion controlling measures are designed to reduce physical soil removal; still they indirectly increase soil fertility (Dabi et al., 2017), reduce bulk density, increase total nitrogen, improve organic matter and clay contents (Amare et al., 2013; Hishe et al., 2017b) which have greater roles in improving infiltration processes and soil moisture holding capacities.

Although there had been a number of researches on the contribution of SWC and SLM measures on sediment yield, run off and erosion reductions (Tesfaye, 1988; Gebremichael et al., 2005; Vancampenhout et al., 2006; Teshome et al., 2013; Adimassu et al., 2014; Mengistu et al., 2016), evidences on the improvement of water retention capacity, are limited. Only few researchers (e.g. Amare et al., 2013; Sultan et al., 2017; Dabi et al., 2017; Hishe et al., 2017b), reported effectiveness of soil and water conservation practices in reducing runoff, soil erosion, land degradation, and increasing base flow at various agro ecological set ups of the country.

SLM practices were introduced at Geda watershed since 2012; the practices include construction of soil and or stone bunds, terraces, trenches, check dams, percolating pits, planting of tree lucerne at highly degraded plots, combinations of structural and vegetative measures mostly with tree lucerne and phalaris, and most importantly prohibition of free grazing (Ebabu et al., 2019). Following the SLM practices, evidences were generated on erosion, runoff, and sediment suspension and crop yield (Mekonnen 2018). Thus, the impact of SLM practices on soil moisture conservation and base flow improvement was not studied so far. Therefore, this study explored the impact of SLM measures on soil moisture retention capacities and base flow situations during the dry periods at Geda watershed by comparing untreated and treated subwatersheds found adjacent each other.

2. Methodology

2.1 Description of the study area

The study was conducted in Geda watershed, north Shewa Zone of Amhara National Regional State, Ethiopia; geographically located in Blue Nile basin between $39^0$40’40’’ & $39^0$41’20’’ East longitude and $9^0$48’40’’ & $9^0$49’20’’ North latitude (Fig. 1). The watershed has a catchment area of 1,056 ha within Gudo Beret and Adisgie Kebeles (Tamene et al., 2015); it is situated in the highland agro-ecology with elevation of 2,865 to 3,105 masl. The watershed receives an annual rainfall of 950-1200 mm; rain fall in the study area is bimodal. Short rainy season falls between February and April and heavy rainy season occurs between mid-June to mid-September (Fig. 2). Daily minimum temperature of the study watershed is within a range of 0.5^{o}c to 19.5^{o}c and the maximum daily temperature ranges from 9.5 to 28.5^{o}c (Tamene, 2017).

Geologically, the site is characterized by volcanic rocks such as rhyolites, trachites, tuffs and basalts. The major soils are Andosol in the upper parts of the watershed, Fluvisol at the Valley bottoms, Regosol at eroded parts and Liptosol on steep slope areas (Ashagrie, 2009; Amare et al., 2013). The watershed is characterized by crop-livestock mixed farming system with more lands allocated for crop production and grazing while few plots, especially at the degraded and mountainous areas allocated for eucalyptus plantation. Soil erosion is the sever land degradation problem of the area especially at higher slopes.

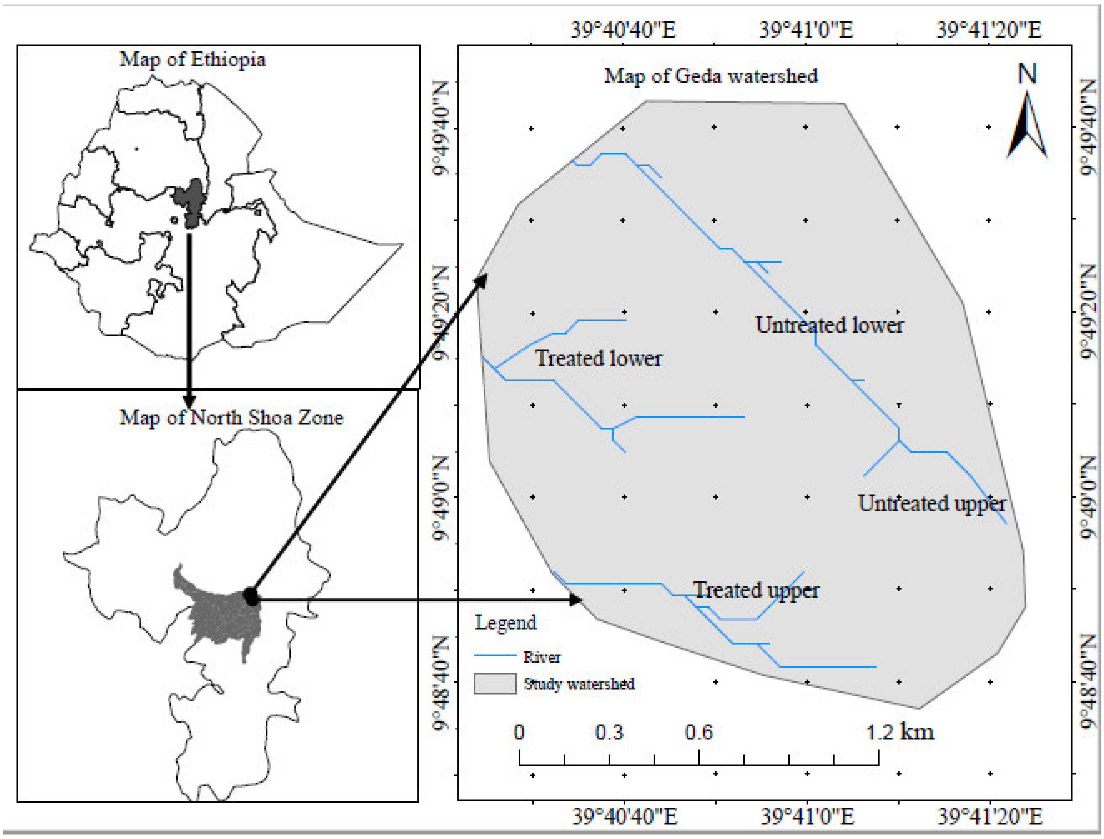

Figure 1. Map of the study area.

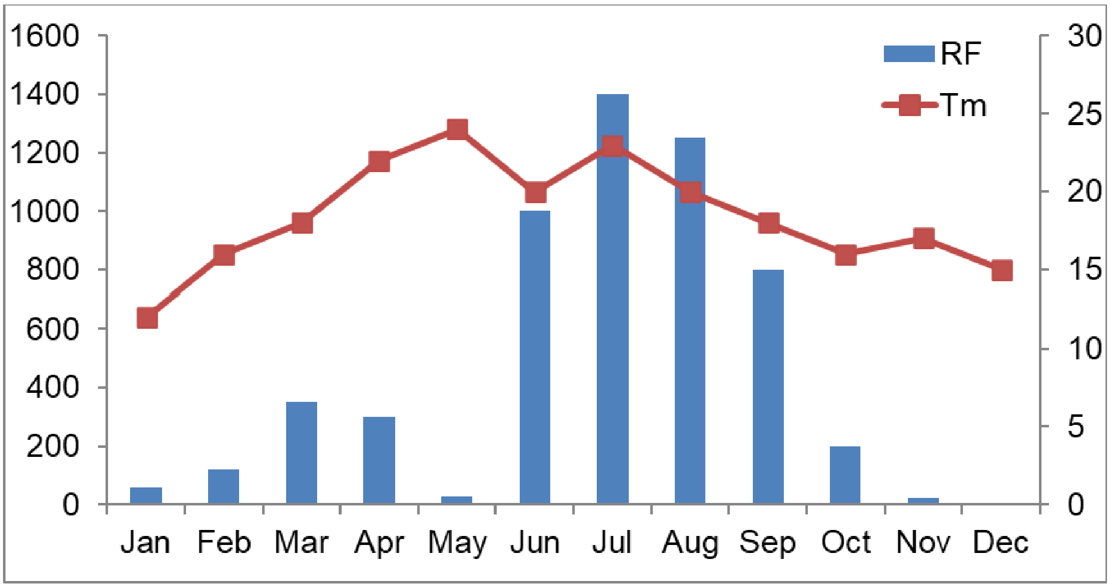

Figure 2. Mean annual rain fall and temperature at the study area (Data source DBARC).

In order to rehabilitate the degraded landscapes, different SLM options have been implemented starting from 2012 at one side of Geda watershed. Major SLM options practiced at the treated subwatershed were: soil bunds with trenches, biologically supported soil bunds mainly with tree lucerne (*Chamaecytisus palmensis)* and phalaris *(Phalaris acquatica, Phalaris arundinacea)*, percolation pits and water collecting ditches, check dams, and reduced grazing. Furthermore, highly degraded plots were treated by tree lucerne plantation. The SLM interventions covered more than 80 km soil bund with trenches, 71 m^3 of gabion check dam, 730 m^3 wood check dam, 19 percolation pits and some area closures with grass and tree lucerne vegetation on highly degraded plots (Tamene, 2017).

2.2 Data collection

2.2.1 Measuring soil moisture content

Sample collection was stratified by subwatersheds, landscape positions and land use types. Representative sampling sites were purposely selected for crop and grazing lands at both subwatersheds and landscape positions. Consequently, samples were collected from ten crop lands and ten grazing lands at both subwatersheds and landscape positions. Thus, a total of 80 soil samples were collected from 0-20cm and 80 samples from 20-40cm depths using Edelman auger for gravimetric moisture content analysis (Wilke, 2005) in October (the end of the heavy rainy season and the beginning of the dry season); this month was selected in order to exclude the saturation periods and irregular accidental rainfall that makes variation at sampling sites, so that only the soil moisture held by the soil profile can be captured as much as possible. In addition, a total of 80 samples were taken at 0-20 cm depth in January (the mid-dry season) using HD2 mobile moisture meter through directly inserting the sensor probes in to the soil profile at the field (Walt, 2016); during this period, we couldn't measure the soil moisture at 20-40 cm depth because of heavy compaction and drying. HD2 mobile moisture meter was preferred over the gravimetric method to determine the dry season moisture content for two basic reasons: 1) availability and accessibility of the apparatus, 2) to minimize moisture loss due to evaporation at the drier month (high temperature) in the process of augering, packing and sealing practices. Furthermore, it reduces labor demand for digging, sealing and transporting the soil samples to the laboratory.

2.2.2 Measuring base flow (Water discharge)

Water discharge was measured at the lower outlets of both subwatersheds (untreated and treated), during the drier months through December 2017 to June 2018, on weakly basis. The drier months were purposely selected to measure discharge, to maximize the chance of measuring surface and subsurface water that came out of the storage capacities of the subwatersheds. Appropriate locations where all water lines (river flow and springs) join were identified at the lower most out lets of the subwatersheds; and all water sources were collected by metal board in to one directed so that it flows in to a measuring bucket without seepage. The arms of the metal sheet were inserted in to the ground and the surroundings were sealed by mud so that all water flows can be lead in to the measuring bucket (Fig. 3); yet, deep sub surface water sources and surface evaporation along rivers remain un-captured.

Figure 3. Measuring stream discharge using graduated bucket at the outlets of Geda sub watersheds. Photograph: Hailu T. 2018

Graduated bucket having twenty litters capacity was used to collect the water; and a stop watch was used to record time taken to fill the bucket. Two workers: one time keeper and one taking care of the water flow and tell the filling of the bucket were recruited. Each week, mean discharge values were taken after 10 times repeated measurements at each site. Besides, measurements were taken in the morning before people and livestock start using the water. After measuring the amount of water discharge, weighted values were recorded for comparative analysis; to compute weighted values, volumes of water discharge (Ls^{-1}) were divided by area of the subwatersheds for both subwatersheds. Furthermore, water productivity was explored by interviewing irrigation users at the lower positions of the subwatersheds. Farmers were asked on the current size of their farm land and the type of crops they grow comparing the sizes and crop types before the SLM intervention introduced; situations at the same years (2012 and 2018) to collect data from farmers in the untreated sub watershed.

2.3 Laboratory analysis

Soil samples taken in October for gravimetric moisture analysis were put in plastic bag, weighed using digital balance of 0.01g capacity immediately at the field and brought to the laboratory for drying. All samples were dried in an oven at 105^0C for 48 hours (to reach constant mass) (Craze, 1990; Wilke, 2005) and dry weight was measured using digital balance of 0.01g capacity. Then the moisture content of the soil was determined as a percentage of its oven dried weight calculated from the moist sample weight before and after drying (Fredlund and Xing, 1993). Whereas, Soil moisture content (%) measured by HD2 mobile moisture meter and water discharge (Ls^{-1}) were directly measured at the field as described above in the data collection section.

Weight of moist soil was determined by deducting the weight of the bag from the weight of the moist sample in the bag while dry weight of the soil was determined by subtracting the weight of the container (aluminum foil) from the weight of the dry soil in the container. Finally, percent moisture content of the soil was calculated as the percentage of the weight difference between the moist soil sample and dry soil sample as follows (Craze, 1990; Wilke, 2005):

$$MC\ \% = \left[\frac{W1-W2}{W1}\right] \times 100$$

Where; MC % = percent moisture content of the soil,
W1= Weight of moist soil
W2= Weight of dry soil

2.4 Data analysis

Statistical analysis was performed using General Linear Model of SAS version9.4 statistical software (SAS institute, 2016). Analysis of Variance (ANOVA) and Duncan's mean separation was performed at P = 0.05 level of significance for soil moisture analysis; whereas two samples paired t test was performed for base flows and irrigation uses.

3. Results

3.1 Soil moisture content

ANOVA revealed highly significant differences at $P \leq 0.001$ between the untreated and the treated subwatersheds for soil moisture content at the end of the heavy rainy season and beginning of the dry season (October) both at the surface 0-20 cm and sub-surface 20-40 cm soil depths; further, it showed statistically higher mean values at $P \leq 0.01$ during the dry season (January) (Table 1). The treated subwatershed exhibited 25.92% and 27.35% compared to the untreated subwatershed of 21.70% and 23.82% at 0-20 cm and 20-40 cm soil depths respectively. Furthermore, the soils in the treated subwatershed retained more moisture with mean value of 10.16% compared to the untreated subwatershed of 9.50% during the drier month (January). However, soil moisture content was not affected by the interaction of subwatersheds and landscape positions, and subwatersheds and land uses.

Table1. Effect of SLM practices, land use types and soil depth on soil moisture content.

	Soil moisture content (%)		
	Gv.20cm	Gv. 40cm	HD2 20cm
Sub watersheds (SW)			
Untreated Sub watershed	21.70^{b}	23.82^{b}	9.50^{b}
Treated Sub watershed	25.92^{a}	27.35^{a}	10.16^{a}
Sub watershed × land scape position (LP)			
Untreated upper	20.93^{b}	23.18^{b}	9.44^{c}
Untreated lower	22.47^{b}	24.45^{b}	9.56^{bc}
Treated upper	25.37^{a}	26.87^{a}	10.26^{a}
Treated lower	26.47^{a}	27.84^{a}	10.06^{ab}
Sub watershed × land use (LU)			
Untreated crop	20.95^{b}	22.89^{b}	9.56^{bc}
Untreated grazing	22.44^{b}	24.74^{b}	9.44^{c}
Treated crop	26.07^{a}	27.25^{a}	10.28^{a}
Treated grazing	25.77^{a}	27.46^{a}	10.03^{a}
P-SW	***	**	***
P-SW × LP	ns	ns	ns
P-SW × LU	ns	ns	ns
CV (%)	12.38	12.00	8.86

Means within columns under each topic followed by different letter(s) are significantly different from each other at $P \leq 0.05$; ** = significant at $P \leq 0.01$; *** = significant at $P \leq 0.001$; ns = none significant; Gv. Gravimetric soil moisture content; HD2 = HD2 mobile moisture meter; CV = Coefficient of variation.

Pearson correlation analysis showed positive correlation between soil moisture contents, species diversity and richness, plant biomass and soil organic carbon (Table 2). Plant species diversity and richness enriched at treated subwatershed than the untreated one; likewise, plant biomass increased as soil moisture increased for both crop and grazing lands (Fig. 4).

Table 2. Pearson Correlation Coefficients, N = 80 Prob > |r| under H0: Rho=0

	SM-20 cm	SM-40 cm	SPDV	PLBM	SOC 0-15	SOC 15-30
SM-20 cm	1					
SM-40 cm	0.89348	1				
	<.0001					
SPDV	0.19916	0.14625	1			
	0.0766	0.1955				
PLBM	0.42332	0.35652	0.16555	1		
	<.0001	0.0012	0.1422			
SOC 0-15	0.50363	0.45136	0.44371	0.39174	1	
	<.0001	<.0001	<.0001	0.0003		
SOC 15-30	0.16962	0.11545	0.39559	0.19297	0.65506	1
	0.1325	0.3078	0.0003	0.0863	<.0001	

SM-20 cm and SM-40 cm: soil moisture contents at 20 cm and 40 cm depths respectively; SPDV: species diversity (number); PLBM: Plant biomass (ton ha^{-1}); SOC 0-15 and 15-30: Soil organic carbon at 0-15 and 15-30 cm depths respectively.

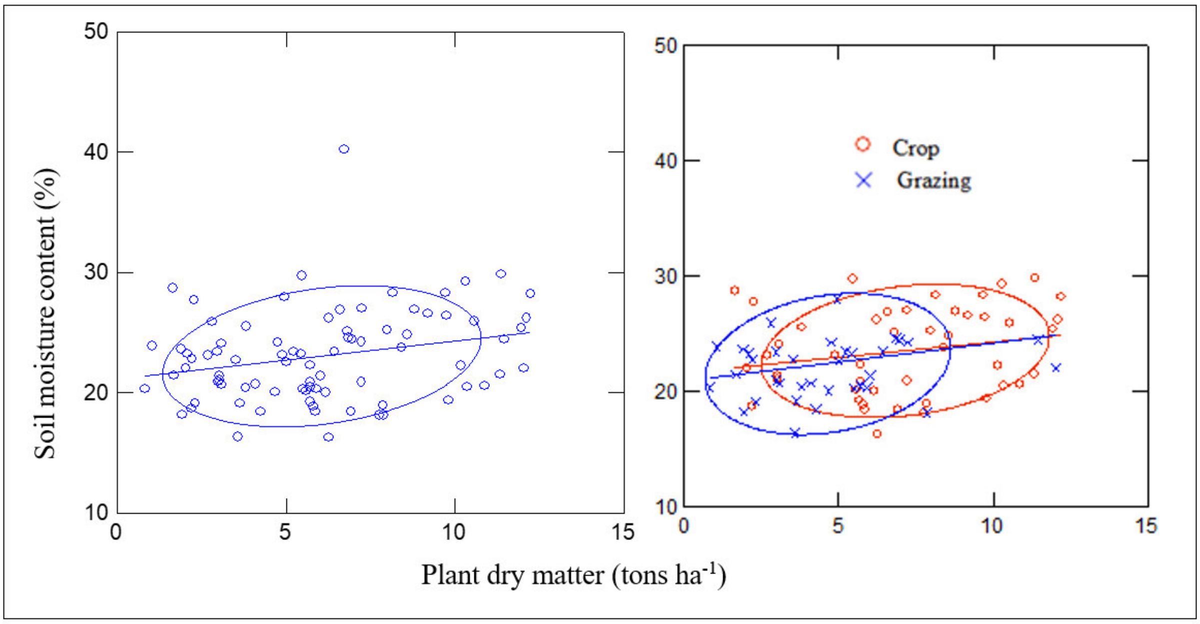

Figure 4. Relationship observed between soil moisture content and plant biomass; left: plant biomass for all land uses together; right: plant biomasses for crop and grazing lands.

3.2 Base flow

Paired t-test revealed highly significant difference (P ≤ 0.000) between the untreated and treated subwatersheds for the dry season base flow. The higher mean value of 1.99 Ls^{-1} was observed at the treated subwatershed compared to the lower man value of 0.27 Ls^{-1} in the untreated subwatershed (Table 2).

Table 2. Paired t-test for base flow showing significant differences between the untreated and treated subwatersheds.

Subwatersheds	N	Mean	Median	Mean difference	t	P-value
Untreated	25	0.2654	0.2552	1.7243	-14.676	0.000
Treated	25	1.9896	1.8123			

Furthermore, sufficient water storages and surface flows were visible in the treated subwatershed than the untreated subwatershed during the dry months (Fig. 5) so that base flow was recorded from springs and rivers at this subwatershed; whereas, only springs were the source of base flows recorded in the untreated sub watershed. Due to the cumulative effects of surface water and subsurface water sources, higher discharge volumes were recorded during the dry season continuously for 25 weeks in the treated subwatershed than the untreated subwatershed (Fig. 6).

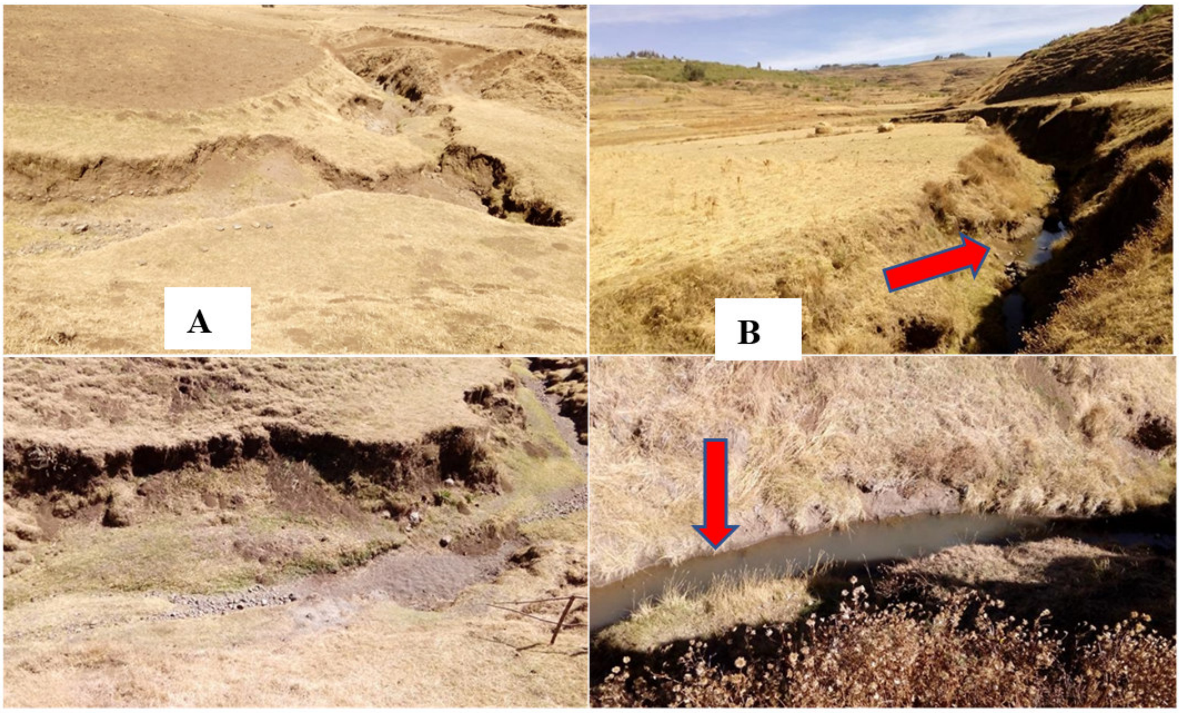

Figure 5. Partial view of riparian areas at the lower landscape position in Geda watershed during the mid-dry period (January); **A**: rivers in the untreated subwatershed having no water at all; **B**: rivers in the treated subwatershed having sufficient water storage and surface flow.

Photo graph: Hailu T. Jan. 2018.

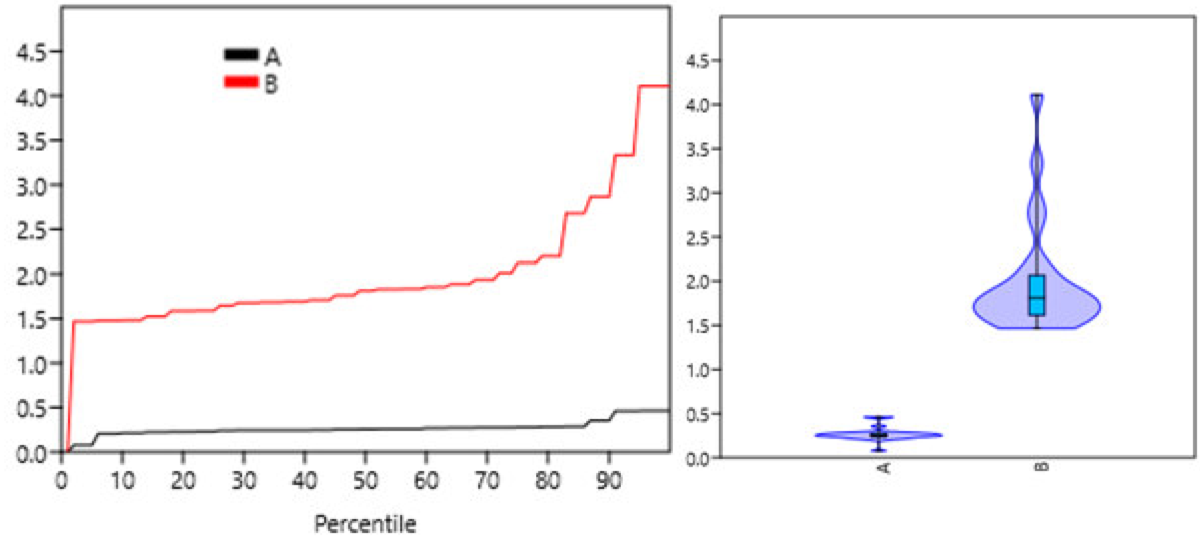

Figure 6. Status and amount of base flow; **A:** untreated subwatershed, **B:** treated subwatershed; **left:** percentile of the base flow on weekly basis, and **right:** discharge mean values (Ls^{-1}).

3.3 Water productivity

The higher moisture content and water availability in the treated subwatershed also increased irrigable lands and beneficiaries at *Ashal-wuha* irrigation site (the lower part of the treated subwatershed); irrigable land expanded from 22.5 ha to 26 ha and beneficiaries farmers increased from 25 to 29. Furthermore, farmers shifted their crop types from less water demanding and low productive pulses such as lentil and chick pea before the introduction of SLM practices to high water demanding and productive vegetables such as carrot, cabbage, garlic etc. after SLM measures (Table 3). Before SLM, land covered by pulses and vegetables were 19.5 and 3 hectares respectively; however, after SLM introduction, the land use shifted to vegetables; thus, land covered by pulses and vegetables became 1.75 and 24.25 hectares respectively.

At the lower part of the untreated subwatershed, the size of irrigation land also increased from 0.25 ha to 3 ha (Table 4); but land use couldn't shift from low water demanding pulses to high water demanding and productive vegetables.

Table 3. Comparison of irrigable land and water productivity at the treated subwatershed; before (2012) and after the introduction of SLM (2018) showing significant differences in land size and crop types with time span

Land size and land use	Year	ha	Mean	Median	Mean difference	t	P-value
Irrigated land	2012	22.5	0.7759	0.5	0.1207	-2.6357	0.0156
	2018	26	0.8966	1			
Lentil, Chickpea	2012	19.5	0.6724	0.5	0.6121	6.5579	0.000
	2018	1.75	0.0603	0			
Vegetables crops	2012	3	0.1035	0	0.7323	-9.0136	0.000
	2018	24.25	0.8362	1			

Table 4. Irrigable land size at the untreated subwatershed before five years that SLM measures were introduced at the treated subwatershed and after five years (2018) situation, showing significant differences between the two years for irrigable land size

Years	ha	Mean	Median	Mean difference	t	P-value
2012	0.25	0.05	0	0.55	-.5	0.000
2018	3	0.06	0.5			

4. Discussions

4.1 Soil moisture content

The soil moisture was significantly higher at the treated subwatershed compared to the untreated subwatershed; this could be due to the contribution of SLM technologies. The introduced SLM options has SWC structures such as soil bunds, trenches, percolation pits, terraces and multipurpose plants like tree lucerne and phalaris that were used as a biological support to the physical structures on one hand and for livestock feed and fire wood on the other hand. Although the time span is very short (five years), SLM interventions significantly contributed to the improvements of the soil moisture content. The current finding is in line with various researchers (e.g. Nyssen et al., 2008; Nynssen et al., 2010; Wubet et al., 2013; Masebo et al., 2014; Dessalegn et al., 2015; Sultan et al., 2017; Hishe et al., 2017a; Dabi et al., 2017; Keesstra et al., 2018) who assessed the contribution of SWC measures on hydrological processes at different parts of Ethiopia.

Nynssen et al. (2010) studied the impact of SWC on catchment hydrological responses in northern Ethiopia; and found that catchment management has resulted in higher infiltration rate and a reduction of direct run off volume by 81%; this had positive influence on the catchment water balance. Between 2002-2003 and 2006, the yearly rise in water table after the onset of the rains relative to the water surplus increased by 3.4 and 11.1 respectively. Dabi et al (2017) also reported the positive impact of SWC structures in reducing run off and increasing infiltration at various times and locations in Ethiopia. According to Sultan et al. (2017), combination of soil bunds with vegetation in cultivated lands reduced runoff by 49%, while the use of trenches across slope gradient on non-cultivated plots reduced runoff by 65%. Since reducing surface run off allows the water to stay at spot and gives time for infiltration, conservation measures greatly contribute to soil moisture improvement.

Catchment management in semi-arid areas decreases direct runoff during the rainy season and improve water availability in the dry season (Nyssen et al., 2010). The average annual run off reduction due to soil bunds at Galessa Watershed, central highlands of Ethiopia was 28% (Adimasu et al., 2014) and at Enabered watershed, northern Ethiopia was 27 % (Haregeweyn et al., 2012). Likewise, stone bunds with trenches were also effective SWC measures to reduce run off in Tigray (Taye, et al., 2013). Furthermore, increased vegetation cover significantly reduced run off while it increased infiltration rate (Nyssen et al., 2008; Wubet et al., 2013; Hishe et al., 2017a). Additionally, soil and stone bunds were generally effective in reducing runoff and increasing base flow (Sultan et al., 2017; Adimassu et al., 2017); so that plots with SWC had higher moisture content compared to the non-conserved plots (Masebo et al., 2014).

Water is the most limiting factor in arid to semi-arid areas; soil moisture enhances various soil physicochemical reactions and improves various soil activities; these intern influence crop growth, nutrient availability, nutrient transformations and soil biological activities (Brady and Weil, 2002). Thus, the higher moisture content of the treated subwatershed in the current study improved plant species diversity and richness, plant biomass production as well as soil organic carbon concentration (Table 6).

4.2 Base flow

The positive impacts of SLM interventions on soil moisture content at the treated sub watershed also observed by increased base flow and enhanced water productivity. At *Ashal-wuha* irrigation site, downstream of the treated sub watershed, water availability not only increased the number of irrigation beneficiary farmers but also enhanced land productivity by shifting their farm lands from lentil and chick pea to high value and productive vegetable crops (Table 3). The reason for persisting on pulse growing at the irrigation site of untreated subwatershed irrespective of an increase in irrigable land in 2018 compared to 2012, could be due to limited water availability for high water demanding vegetables. The relatively increased land size at this subwatershed may be due to increased awareness about the benefit of irrigation works during the off seasons to improve household income; thus few farmers able to utilize the available small water from spring to irrigate and grow few pulse crops. This study is in agreement with the findings of Descheemaeker et al. (2006) and Dessalegn et al. (2015). According to Descheemaeker et al. (2006), area exclosure reduced runoff, increased soil moisture availability, promote the development of new springs and more water flows in rivers during longer periods and enhances hydrology system. Likewise, Dessalegn et al. (2015) also reported increased base flow as a response of terraces and infiltration furrows on hillsides that reduced run offs and increased infiltration of rain water. Watershed consists of natural forces such as climate, parent material and management. Thus, managing land and water also manages the whole process such as sediment and nutrients, soil functions, water flow and the ecosystems in the landscape (Keesstra et al., 2018).

5. Conclusion and recommendation

Soil moisture was significantly higher at the treated subwatershed compared to the untreated subwatershed; which further positively correlated with species diversity, plant biomass production and soil organic carbon. Yet, soil moisture contents were not significantly affected by landscape position and land uses types which might be due to the age of the interventions, and the relatively small size of the subwatersheds. Nevertheless, base flow and water productivity were enriched at the treated subwatershed than the untreated one; explaining the significant role of the SLM interventions on improving the water storage capacity of the landscape and improving the base flow. Thus, it can be concluded that SLM measures introduced at Geda watershed contributed positively towards reducing land degradation by soil erosion and improved soil moisture content as well as base flows. Based on the general positive impacts observed, we strongly recommend watershed based SLM measures to curb land degradation and enhance ecosystem resilience in the highlands of Ethiopian.

Authors' contributions

All authors have contributed at different stages of this study. MA, LT and KM involved on the design of the study, supervised the progress and provide comments on the manuscript. HT designed the study, collected and analyzed samples and interpreted the data as well as wrote the draft manuscript, GA mapped the study area.

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Competing interests

The authors declare that they have no competing interests.

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