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Watershed degradation and management practices in north-western highland Ethiopia

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Abstract Watershed degradation in Ethiopia has become a major environmental threat and caused significant damages both in the natural environment and the development of human society. This paper assesses an overview of the extent, causes, and effects of watershed degradation and the management actions in north-western highland Ethiopia, taking the Rib watershed as a case study site. The data were collected from field observations, interviews, and questionnaire surveys administered to 210 farmers. The results show that watershed degradation is a serious and widespread problem in the study site. The major causes of watershed degradation include population growth, uncontrolled grazing, unsustainable land use and management practices, and weak land ownership system. Watershed degradation, mainly in the form of soil erosion, has adversely reduced agricultural production and worsened food insecurity and poverty in the study area. Various watershed management practices that combine structural and biological measures have been practiced to curb the problem. However, the farmers' decisions to adopt and implement the measures have been highly influenced by a range of socioeconomic, biophysical, and institutional factors. Access to support services, size of the farmland, educational level, and plot ownership were found to influence farmers' decisions positively at a statistically significant ($P < 0.01$) level. It needs efforts to create farmer environmental awareness and develop strong watershed management standards and guidelines. The watershed could benefit from hand in hand efforts of local farmers, concerned governmental agencies, and researchers.

Keywords Binary logistic regression · Farmers' perception · Highland Ethiopia · Watershed degradation · Degradation control measures

Introduction

Watersheds are vital components of the terrestrial ecosystem. Healthy watersheds such as freshwater and land resource systems not only provide important ecosystem services to humanity (Knüppe and Meissner 2016) but also maintain the physicochemical and biological processes that occur within the watershed (Jones 2002; Zhihui Li et al. 2015). Watersheds, however, are globally degrading and the services they provide are continually deteriorating, yet demand for these services is increasing (Coxhead and Shively 2005; Darghouth et al. 2008; Gebremeskel et al. 2018; Gebretsadik 2014; Haregeweyn et al. 2012; Mengistu and Assefa 2019; Shroder 2014). Watershed degradation processes can have both natural and anthropogenic origins. Global processes such as climate change, land use/land cover

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changes, urbanization, together with rapid population growth, are among the major factors causing the long-term deterioration of watersheds worldwide (Azam 2016; Darghouth et al. 2008; Zhihui Li et al. 2015; Zhiying Li and Fang 2016; Nyssen et al. 2015; Pumo et al. 2017; Sharma et al. 2010; Tarfasa et al. 2018; Wang and Dong 2019).

Watershed degradation is of particular concern in Ethiopia where millions of poor farmers depend on subsistence agriculture. Continuing watershed degradation mainly in the form of soil erosion, deforestation, and surface and subsurface water deterioration has resulted in a long-term reduction in quality and quantity of land and water resources, and seriously threatened the agricultural productivity of the country and people's livelihoods, particularly in highland parts where croplands are very scarce resources (Bishaw 2001; Gebregziabher et al. 2016; Haregeweyn et al. 2015; Hurni et al. 2010; Nigussie et al. 2017a; Nyssen et al. 2015). Ethiopian highland watersheds had inherently fertile and productive soils (Haregeweyn et al. 2012). But most recently, these areas have faced severe degradation because of increasing stress to produce more food for the ever-growing population. Sustainable management of watersheds is, therefore, of utmost importance to recover the degraded areas and improve agricultural production and the livelihood of the society.

Although the issue of conserving watersheds in highland Ethiopia was largely neglected until the early 1970s (Adgo et al. 2013; Shiferaw and Holden 1999), over the past few decades, the government of Ethiopia in collaboration with native and international donors has made efforts to rehabilitate and conserve watersheds and improve people's livelihoods (Bishaw 2001; Haregeweyn et al. 2015; Nigussie et al. 2017a; Nyssen et al. 2009; Sonneveld and Keyzer 2003; Tesfaye et al. 2014). The largest work of the period was that carried out between 1976 and 1985 in which the farmers were extensively mobilized to participate in soil and water conservation (SWC) program, mostly mobilized by Food for Work (FFW) and Food Security Package (FSP) programs (Gebregziabher et al. 2016; Haregeweyn et al. 2012; Hurni 1988). Later, the program was developed into the Local Level Participatory Planning Approach (LLPPA), and then scaled up into the program called Managing Environmental Resources to Enable Transitions (MERET) to more sustainable livelihoods (Desta et al. 2005).

Since the early 2000s, integrated watershed management has been considered as an integral part of the agricultural extension and widely implemented to curb watershed degradation and improve the livelihood of the people. Recently, the government of Ethiopia has also launched an annual nationwide public campaign lasting for approximately 2 months (January and February) and aimed at mobilizing the community for integrated watershed management and development activities (Bekele et al. 2018; Wolancho 2015). Despite these huge and continuous efforts towards sustainable watershed management in almost all parts of the country, the achievements were far below the expectations, and watershed degradation has remained a big challenge for agricultural and economic development in highland Ethiopia (Admassu et al. 2008; Adugna and Bekele 2007; Gebreselassie et al. 2016; Gebretsadik 2014; Shiferaw and Holden 1999). The Rib watershed in the Lake Tana Basin is among the most affected areas by watershed degradation where continuous and widespread soil erosion and land degradation have significantly threatened agricultural productivity, food security, and rural livelihood (Lemma et al. 2019; Setegn et al. 2009).

Regardless of the severity and seriousness of the problem, no meaningful efforts have so far been made to properly address the issues of watershed degradation and causative agents in the Rib watershed. The factors that affect farmers' adoption of watershed management measures (WMMs) have also been not adequately addressed. Moreover, previous studies suggest that the farmers' willingness to use WMMs varies from place to place concerning the range of socioeconomic, institutional, and biophysical (Adugna and Bekele 2007; Moges and Taye 2017; Nigussie et al. 2017b; Tarfasa et al. 2018; Teshome et al. 2016). Therefore, this study focuses on (1) investigating the current status of watershed degradation and its causes, and (2) identifying major WMMs implemented to reduce watershed degradation and factors affecting the adoption and sustainable use of the measures. An insight into the existing watershed degradation and management practices would help design appropriate policies and conservation strategies, and thus facilitate the decision-making processes.

Materials and methods

The study area

The study was conducted in the Rib watershed, a highly degraded agricultural watershed located in the upper

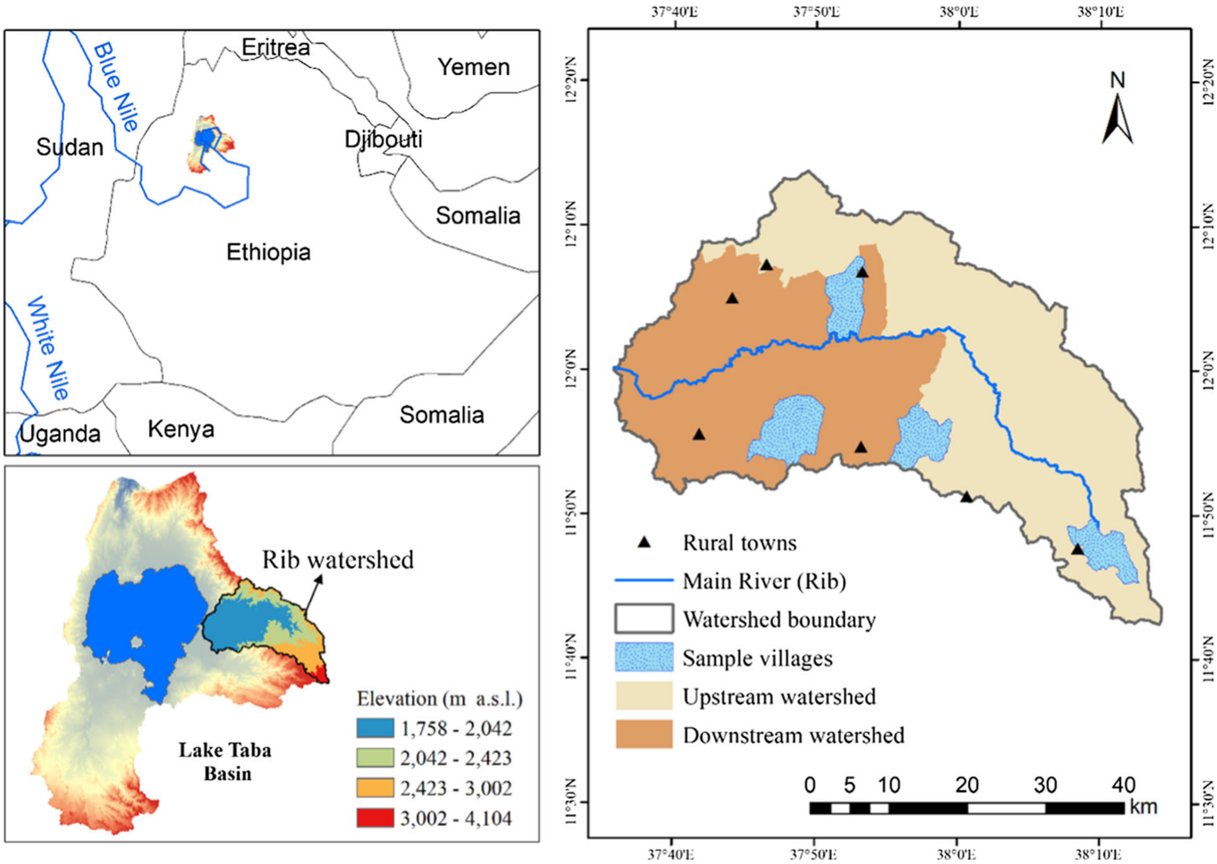

Fig. 1 Location map of the study area

part of Lake Tana Basin in north-western highland Ethiopia (Fig. 1). It is located approximately between 11° 40′ N and 12° 20′ N latitude and between 37° 30′ E and 38° 20′ E longitude. The elevation ranges from 1758 to 4104 m a.s.l., with a drainage area of 1975 km^2. The watershed is characterized by hills and peaks which are responsible for creating the drainage networks flowing towards Lake Tana, the western part of the watershed.

The watershed has a highland tropical monsoon climate which is highly affected by the seasonal migration of the intertropical convergence zone (ITCZ) and complex topography (Lemma et al. 2019). More than 70% of the rainfall comes from June to September (main rainy season) while other months receive little or no rain (Fig. 2). The mean annual rainfall (1973–2016) varies from 1040 to 2151 mm, whereas the mean annual

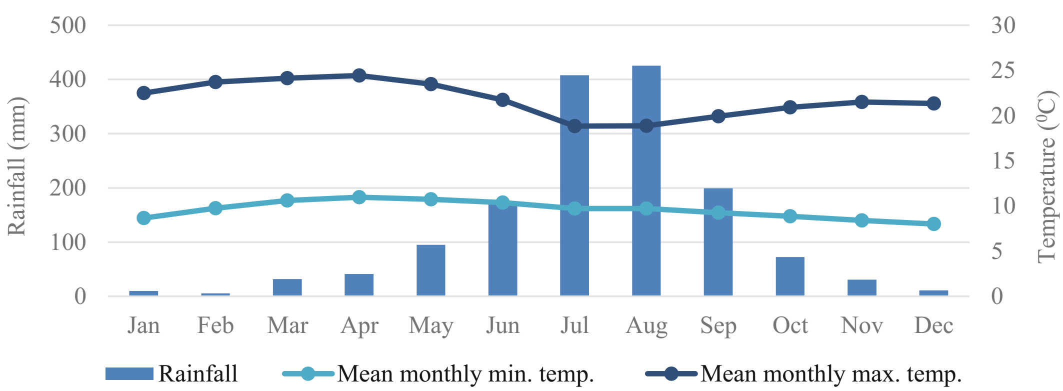

Fig. 2 Mean monthly rainfall and temperature of the watershed (1973–2017)

temperature ranges from 14.95 to 16.4 °C. The geology of the watershed is mainly dominated by Tertiary and Quaternary basalts and alluvial deposits (Beyene et al. 2018; Lemma et al. 2019), where about two-thirds of the catchment is covered by Termaber basalt (thick basaltic rock interlocked with tuffs, scoriaceous lava, and paleosols) (Moges et al. 2019). The watershed is dominated by soils derived from weathering of basaltic rocks including Luvisols, Vertisols, Leptosols, and Regosols.

The agriculture of the watershed is characterized by mixed crop-livestock systems. The major crops grown include maize, barley, tef, wheat, beans, and rice. The crop production is almost entirely dependent on rainfall, mostly occurring during the monsoon (*Kiremt*) season from June to September. The remaining months are therefore dry or receive little rain, and farming is only possible through irrigation, which is not widely practiced in the watershed. Livestock production, which largely depends on common lands, also plays a crucial role in the livelihoods of the society in the watershed. The dominant land use type in the watershed is cultivated land (covering more than 90%) followed by small remnant grass, forest, and shrublands (Moges and Bhat 2018). Like in many parts of the country, the watershed has historically lost significant forest cover, and only small leftover natural forests are currently found mainly around the Orthodox Christian churches and inaccessible hilly areas. Due to extensive deforestation combined with steep slopes, erratic and erosive rainfall, and poor land use and management practices, the watershed is also characterized by severe degraded. Basic information about biophysical and socioeconomic characteristics of the watershed is provided in Table 1.

Data and methodology

A multistage stage sampling approach incorporating purposive and random sampling techniques was used to select the respondents. In the first stage, the watershed was arbitrarily classified into upstream and downstream reaches based on elevation and suggestions by the farmers and watershed management experts. During the pilot study process, it was clear that the rate of watershed

Table 1 Biophysical and socioeconomic characteristics of the watershed

Attribute (unit)	Upstream	Downstream
Total area (km^2)	1079.54	895.46
Altitude (m a.s.l.)	2100–4103	1758–2100
Topography	Undulating	Relatively plain
Slope range	Moderate to very steep	Nearly level to moderate
Mean annual rainfall (mm)	1358.5	1194
Rate of soil erosion	Severe (runoff and topsoil removal)	High (more of sedimentation)
Agro-climatic zone	Humid, alpine	Humid, sub-humid
Dominant soil type	Cambisols, Regosols, and Leptosols	Fluvisols, Vertisols, and Luvisols
Dominant crops	Finger millet, maize, tef, barley, potato, and beans	Rice, maize, wheat, lentil, and potato
Dominant livestock	Cattle, sheep, and equine	Cattle, sheep, goats, and equine
Risk of flooding	Low	High
Irrigation practice	Poor	Better
Access to the regional capital	Low	High
Access to the zonal city	High	Low
Access to the main road	High	Medium
Number of total villages	45	31
Sample villages and households		
Name of the villages	Kolay Dengors and Atadidim	Wej and Esitifanos
Total population	16,896	15,560
Total households	3462	3493
Sample households	104	106

degradation is relatively higher in the upstream areas than the downstream, and the type of degradation also differs. In the upstream areas, watershed degradation is commonly observed in the form of runoff and removal of topsoil, whereas sedimentation is a dominant problem occurring in the downstream areas when eroded materials that are being transported by water from the upstream areas settle out of the water column onto the surface. The study by Nigussie et al. (2017a) also shows that the farmers who reside or have farmlands in the upper catchment are more likely to perceive the severity and impact of soil erosion compared with the downstream counterparts. Based on these rationalities, the watershed was classified into two clusters. In the second stage, two villages or locally known as *Kebeles* (smallest administrative unit of Ethiopia) were randomly selected from each cluster, for a total of four villages. Thirdly, a systematic random sampling technique was used to select 210 respondents (household heads). The list of household heads was obtained from local agricultural offices of respective villages.

The household survey was carried out between November 2016 and May 2017 using a semi-structured questionnaire covering detailed information about the socio-economic, biophysical, and institutional aspects of the watershed. The questionnaire interviews were carried out with the help of four enumerators who were bachelor degree holders and have good knowledge about the study area and well acquainted with local language and culture. The survey questionnaire which comprised both open-ended and close-ended questions were initially designed in English and later translated to *Amharic* (local language). A pre-survey test was conducted in each of the villages with randomly selected households to customize the questions to local conditions. Besides the household survey, personal observations, informal communications, key informant interviews (KIIs), and focused group discussions (FGDs) were conducted to gather detailed and first-hand information on the current status of watershed degradation and management practices. Four FGDs (one in each village) were held with 36 farmers (8 to10 farmers in each group), comprising different social status, age, educational level, and gender. The participants of FGDs were purposively selected with the help of development agents (agricultural extension workers) and the watershed management committee. Moreover, several in-depth KIIs were held with senior citizens, village and district administrators, development agents, and watershed management committee members.

The data were analyzed in both quantitative and qualitative methods. The data collected through open-ended questionnaires were encoded and processed using IBM SPSS statistical software (ver. 23.0, IBM, Armonk, NY, USA). A logistic regression model was employed to determine the factors controlling the farmers' decisions to implement WMMs, whereas the data collected through field observation, FGDs, and KIIs were qualitatively analyzed and used to supplement the information gathered through household surveys.

Empirical model

A binary logistic regression model was used to quantify the relationship between the dichotomous-dependent variable and a set of explanatory variables. This model has been widely used to assess the influence of various independent variables on farmers' decisions to adopt and apply WMMs (Alemayehu and Bewket 2017; Asfaw and Neka 2017; Mekuriaw et al. 2018; Teferi et al. 2013). A dichotomous farmers' willingness to adopt and practice WMMs was taken as the dependent variable and represented by dummy variable taking 1 if the farmer is willing to adopt WMMs and 0 otherwise. The farmers' decisions to adopt and apply any kind of natural resources management technologies are always controlled by a set of complex and interrelated factors (Nigussie et al. 2017b). In this study, several explanatory variables (Table 2) hypothesized to influence farmers' decisions to implement WMMs on their plots were selected based on the interview results, previous experiences, and available literature.

Results

Characteristics of the respondents

Table 3 shows a summary of the statistics of some household characteristics of the sample respondents. About 32, 38.5, and 29.5% of the respondents participated in the survey were 18–35, 35–50, and above 50 years old, respectively, with the mean age of 41.3 years. About 95.7% of the respondents were married and the men were the heads of the household in all married couples. The majority (76.2%) of the respondents were illiterate; those who did not attend any formal and/or informal education and thus cannot read and write. Out

Table 2 Description of explanatory variables included in the model

Variable name	Description (unit/coding)	Expected sign
Plot size	Size of the area managed by the household (ha)	+
Family size	Family size of the household (adult equivalent)	±
Plot distance	Plot distance to residence (walking minute)	−
Education	The educational level of the household head (1 if literate; 0 otherwise)	+
Extension services	Access to extension services measured in the number of extensions contacted per year	+
Slope	The slope of plots (%)	±
Training	Participation in any watershed management related training (1 if participated; 0 otherwise)	+
Plot ownership	Ownership of the plot managed by the household (1 if the plot is own; 0 otherwise)	+
Income level	Total income of the household per annum (ETB)	+
Position of plots	Position of plots in the watershed landscape (1 if upstream; 0 otherwise)	+

+, −, ± signs indicate a positive, negative, and indeterminate influence of the variables on farmers' decisions, respectively. ETB is Ethiopian Birr (currency)

of 23.8% literate respondents, about 1.4% were college graduates and 14.1% had attended primary and/or secondary schools, whereas the remaining 8.3% did not attend any formal education rather taught through informal education (locally called *meserete timhert*) mostly carried out around the homesteads. Most of the educated respondents were young (aged below 35 years), most likely attributed to the recent improvements in educational facilities that created good opportunities for young farmers (Tefera and Sterk 2010). Educated farmers have a better understanding of the causes and consequences of watershed degradation and the benefits of conservation measures than uneducated counterparts (Moges and Taye 2017), thus they could serve as contact persons for extension agents in disseminating information.

Table 3 The characteristics of survey respondents ($n = 210$)

Variable	Category	Responses	
		No.	Percentage
Age (years)	18–35	67	32
	35–50	81	38.5
	> 50	62	29.5
Gender	Male	204	97.14
	Female	6	2.86
Education	Illiterate	160	76.2
	Literate	50	23.8
Marital status	Single	4	2
	Married	201	95.7
	Divorced	3	1.43
	Widowed	2	0.95
Participation in social committees	Yes	26	12.38
	No	74	87.62

About 12% of the respondents were members and of different social committees in the watershed such as village cadre, watershed management, and development group, local justice committee, and so forth. The farmers who participate in such kind of social activities could easily contact the agricultural expertise and other governmental bodies therefore, have better access to information regarding watershed management and agricultural development issues. The maximum and minimum family size of the respondents was 9 and 2 persons, respectively. The overall mean family size was 6 persons (with the most common family size of 4 to 7 members), which is above the national average family size of 4.9 persons per household. The shortage of farmland is one of the critical factors hampering agricultural practice in the study area, thereby significantly affects food security and livelihood opportunities. The landholding size ranges from 0 to 5.25 ha with the mean size of 0.85 ha. The processes through which land was acquired and the size of land varied from household to household. To overcome the land shortage problems, most farmers in the watershed also use sharecropping and renting techniques in addition to their lands allocated by the government. Along with crop cultivation, livestock production also plays a crucial role in the livelihood of the watershed community. As a result, almost all farmers in the watershed raise different livestock types.

Current status of watershed degradation

The farmers were asked about the occurrence of any form of watershed degradation on their farm plots and villages. About 94% of the respondents confirmed the widespread existence of watershed degradation in the study area (Fig. 3). The majority of the respondents perceived that soil erosion is the dominant form of

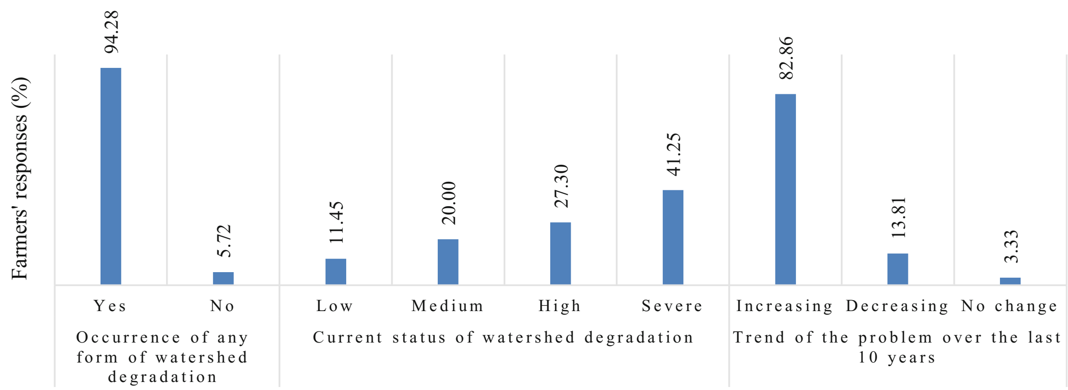

Fig. 3 Summary of farmers' perception of watershed degradation

watershed degradation which has notably challenged daily farming activities. Nutrient depletion, loss of vegetation and biodiversity, and reduction in quality and quantity of water were also the forms of watershed degradation perceived by the respondents. Extensive gullies and bare lands where the top fertile soils had been taken by erosion were also observed during the transect walks.

Although most of the respondents agreed on the existence of watershed degradation, they had varied perceptions regarding the severity of watershed degradation. To understand the farmers' view on the current status of watershed degradation, they were given the choice for four levels of degradation (low, medium, high, and severe). Among the farmers who acknowledged the occurrence of watershed degradation in the study area, about 41% perceived the problem as severe, whereas only about 11% perceived low degradation. Relatively high erosion rates were observed in the upland areas with low vegetation cover where surface runoff has caused significant transportation of top fertile soil and formation of deep gullies. Farmers were also asked to indicate the trend of watershed degradation over the last ten years. The vast majority (about 83%) of respondents confirmed that the rate of watershed degradation in their village is increasing over time. In contrast, about 14% of the respondents perceived a decreasing rate of watershed degradation which might be attributed to the integrated watershed management efforts made by the government and the local community over the last few years, basically through a public campaign. Watershed degradation is not a sudden phenomenon rather it is always the result of several interacting factors. A set of factors that were perceived by the farmers as causes of continuing and widespread degradation of the studied watershed are indicated in Fig. 4. It was clear from the survey results that because of increasing demand, the farmers in the watershed usually use crop residues and animal dung for household energy and animal feed (Fig. 5), instead of using them for soil fertility improvement and conservation.

Impacts of watershed degradation

Watershed degradation has various social, economic, and environmental impacts. It has an immediate

Fig. 4 Major causes of watershed degradation in the Rib watershed perceived by the farmers

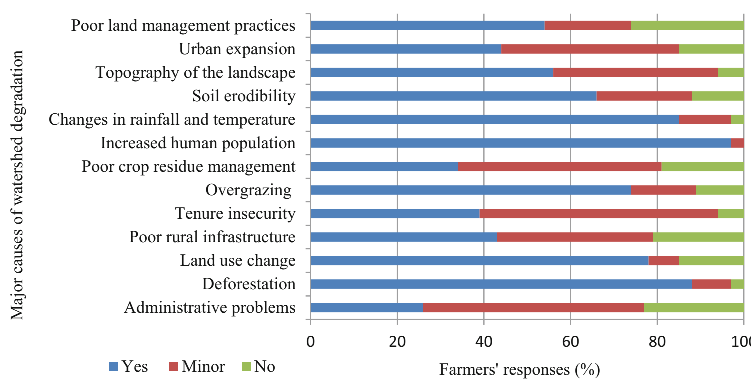

Fig. 5 Drivers of watershed degradation. Animal dung prepared for household fuel and energy (left side), and crop residues collected for animal feed and different household purposes (right side) (Adapted from photo by the corresponding author, March 2018)

negative implication on agricultural production, leading to higher food insecurity and poverty rates among the rural community who directly and largely depend on smallholder subsistence agriculture. To assess the impacts of watershed degradation in the study area, a list of possible consequences was given to the farmers and they were asked to indicate the extent to which they perceive the effects based on a 5-point Likert type scale (5 = perceived at a greater extent; 1 = perceived at very little extent). Table 4 summarizes the major effects of watershed degradation in the Rib watershed perceived by the farmers. As perceived by majority of respondents, watershed degradation in the study area has caused significant loss of fertile soil and nutrients ($\bar{x}$ = 3.73 σ = 0.81) and consequent reduction in crop yield ($\bar{x}$ = 4.38, σ = ± 0.68) and livestock production ($\bar{x}$ = 3.28, σ = 0.92). Moreover, loss of wildlife and vegetation, reduction in farm income, and flooding and sedimentation were also highly perceived as critical outcomes of watershed degradation.

Watershed management practices

The interview results confirm that the farmers in the study area were well aware of the watershed degradation problems and their impacts. As a result, several watershed degradations controlling techniques that combined structural and biological measures were commonly applied in the study area. The vast majority (87.25%) of the respondents used at least one type of WMMs. The most commonly used WMMs in the study area can be grouped into two broad categories, i.e., agronomic/biological and structural/physical measures. The summary of major WMMs implemented in the study area is indicated in Fig. 6. Most of the structural measures were implemented through a community-based campaign lasting approximately 2 months (January and February) every year and which is aimed at mobilizing the community for collective watershed practices (Fig. 7). Since the Rib watershed is located in topographically hilly and undulating areas, structural WMMs are very crucial to

Table 4 Mean score of perceived effects of watershed degradation in the study area (*n* = 210)

Effects of watershed degradation	No.	Max.	Min.	Mean ($\bar{x}$)	SD (σ)
Reduction in crop yield	210	5	3	4.38	0.68
Decline in farm income	203	5	2	3.69	0.93
Loss of fertile soil and nutrients	209	5	2	3.73	0.81
Reduction in livestock production	207	5	2	3.28	0.92
Increase in cost of production	210	5	1	3.37	1.00
Reduction in farmland size	194	5	1	2.83	0.96
Destruction of infrastructure	92	4	1	2.05	1.16
Loss of wildlife and vegetation	210	5	2	3.96	0.77
Decline in water quality/quantity	135	5	1	3.00	1.15
Flooding and sedimentation	148	5	1	3.21	1.19
Food insecurity	191	5	1	3.10	1.01
Climate change	146	5	1	3.04	1.42

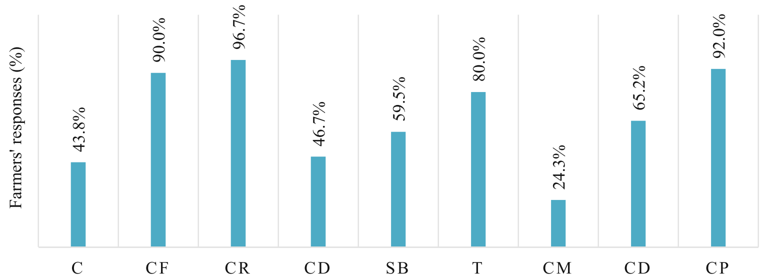

Fig. 6 Commonly practiced watershed management measures in the study area; where, C, composting; CF, chemical fertilizers; CR, crop rotation; CD, check dam; SB, stone/soil bund; T, terracing; CM, crop residue management; CD, cut-off-drain; and CP, contour plowing (Adapted from household survey 2016/2017).

reduce surface runoff and increase water infiltration, thereby prevent soil loss through erosion.

Factors controlling farmers' decisions to implement WMMs

The empirical results obtained from the binary logistic regression model are presented in Table 5. The results indicate that the farmers' decisions on adoption and continued use of WMMs are highly associated with a set of factors. Plot distance and slope were negatively correlated with the implementation of WMMs, while other variables had a positive correlation. The negative signs show that as the value of variables increases, the willingness to apply WMMs decreases.

The logistic regression analysis results indicate that among the ten explanatory variables included in the model, four variables, namely, plot size, education, plot ownership, and extension were found to have statistically significant ($P < 0.01$) association with farmers' willingness to apply WMMs in their plots. Similarly, family size, access to training, and position of plots in the watershed were identified as factors that affect the likelihood of the farmers' decision to implement WMMs at a 5% significance level (Table 5). However, the influences of plot distance from residence, income level, and slope of plots on farmers' decisions were found to be insignificant at 5% and 1% level of significance.

Discussion

Degradation of watersheds in Ethiopia has become one of the major environmental problems which highly affects agricultural productivity and the livelihoods of the rural community. The Rib watershed is among the highly degraded watersheds in north-western highland Ethiopia. It has been clear from the interview and filed observation results that several interacting factors are responsible for the prevalence of watershed degradation in the studied watershed. Population pressure, land use change, poor land management practices, and climate variability and change were among the highly perceived causes of watershed degradation in the study area. The Rib watershed is one of the densely populated watersheds in highland Ethiopia, which has increased competition on limited arable land and forced the farmers to intensively cultivate their plots to increase the short-term productivity of land with minimum care given to management practices. Increased population also

Fig. 7 Community participation in watershed management in the Rib watershed. Construction of cut-off-drains for diversion of runoff coming from upstream areas and to trap sediments (left side) and discussions after the campaign (right side) (Adapted from photo by the corresponding author, January 2017)

Table 5 Estimated coefficient of the binary logistic regression model ($n = 210$)

Variable name	Coef.[a]	Std. Err.[b]	Sig.[c]	Odds ratio
Plot size	1.9335	0.1969	0.0035***	2.391
Family size	0.0518	0.0154	0.0213**	0.935
Plot distance	− 0.1071	0.6052	0.5118	1.421
Education	0.6498	0.0961	0.0031***	1.662
Extension services	0.0587	0.0496	0.0079***	2.201
Slope	− 0.9213	0.0235	0.0946*	3.226
Training	0.5245	0.0244	0.0431**	1.855
Plot ownership	0.1672	0.0086	0.0084***	0.853
Income level	0.7355	0.1461	0.6252	5.166
Position of plots	0.0926	0.0527	0.0466**	0.665

***, **, * indicate significance at 1, 5, and 10% level, respectively

a, b, and c denote coefficient, standard error, and significance level, respectively

intensifies other causes of watershed degradation such as land use change, overgrazing, deforestation, and misuse of crop residues and animal dung in various ways. Livestock production is an integral part of the farming system in the watershed because livestock provides various benefits to households including food, labor, income, manure, and transportation. The source of feed for livestock in the study area is usually natural grazing. The large livestock size and a shortage of grazing land have caused overstocking and overgrazing, which constituted the major cause of watershed degradation. It was also clear from key informant interviews and field observations that huge gullies and bare lands were located in grazing lands, particularly in areas with high slope and unmanaged lands, due to overstocking and overgrazing. Overgrazing in the watershed has also destroyed structural soil conservation structures and supportive vegetative measures. Tefera and Sterk (2010) and Mekuriaw et al. (2018) have also reported the negative influence of free-gazing on the sustainability of structural soil conservation measures in other parts of Ethiopia.

Inappropriate land use and farming practices were perceived by the vast majority of respondents as the drivers of watershed degradation. Farming practices such as soil compaction, fine tilth seedbed, plowing up and down, and intensive cultivation of steep slopes were recognized as the major contributors to widespread watershed degradation. According to Taddese (2001), the cultivation of steep slopes without effective conservation measures directly leads to severe watershed degradation. Some cereal crops (e.g., tef and wheat) require plowing several times to prepare the fine tilth seedbed, which results in breaking up of soil aggregates and facilitate soil loss, especially under erratic and intensive rainfall conditions. Traditionally, the farmers in the watershed use soil compaction by letting cattle walk on the fields before planting tef (*Eragrostis tef*) and finger millet (*Eleusine coracana*) crops. Soil compaction is believed to increase the rate of germination and suppress the growth of weeds (Tefera and Sterk 2010). However, this practice significantly causes the removal of topsoils and nutrient losses on smooth and bare land through sheet erosion, especially before the growth of seeds takes place. The farmers also prepare downslope final drainage channels, locally called *feses*, to facilitate drainage in relatively flat fields where waterlogging is high. Field observation results show that these drainage channels have notably caused highly facilitated the development of surface runoff and resulted in sedimentation of downslope fields.

High altitude and rugged landscapes characterize major areas of the Rib watershed. In areas under such morphological characteristics, soil erosion is generally severe due to the high surface runoff rate. The slope of the study area ranges from 0% (downstream area) to more than 100% around Mount Guna (upstream area). In principle, slopes more than 30% should not be used for agricultural purposes rather should be allocated to natural vegetation (Gebreselassie et al. 2016). However, the field survey results show that there is no slope limit for crop production in the study area; all parts of the watershed were intensively cultivated with limited management practices. Similar to our findings, the studies by Gebreselassie et al. (2016), Laekemariam et al. (2016), and Taddese (2001) indicate the influence of intensive cultivation of high slope and marginal lands on severe watershed degradation in many places of Ethiopia. The interviewed farmers confirmed that shortage of cropland, lack of land use policy, and decline in soil fertility and crop yield were the major drivers for the cultivation of steep slopes. Watershed degradation, particularly in the form of soil erosion, poses a serious threat to the farming systems and livelihoods of the watershed community. Since agriculture is the chief source of economic activity in the watershed, the impact of soil erosion on the agricultural productivity of the watershed would imperatively influence the entire socioeconomic conditions of the watershed such as food security, livelihood opportunities, and the social well-being of individuals and society.

The watershed degradation problem in the study area often goes beyond soil loss and a decline in agricultural yields. It has significantly affected the habitats and biodiversity of the watershed through deforestation and land use changes. The entire ecosystem in the watershed is being destroyed rapidly through watershed degradation, and the plant and animal species are becoming extinct at an alarming rate. It was significantly perceived ($\bar{x}$ = 3.96) that watershed degradation has caused worth mentioning losses of wildlife and vegetation in the study area. The vast majority of farmers also acknowledged flooding and sedimentation as the major outcomes of watershed degradation that significantly impacted the availability and quality of surface and groundwater and influenced a huge portion of the watershed community who largely depends on the rivers and ponds for drinking and various household purposes, particularly in the downstream landscape.

To curb watershed degradation and ensure ecological and economic sustainability, the farmers in the watershed have implemented various conservation actions that combined structural and biological measures. Several studies (Gebrernichael et al. 2005; Jemberu et al. 2017; Klik et al. 2018; Kosmowski 2018; Meheretu et al. 2014; Monsieurs et al. 2015; Nyssen et al. 2007; Taye et al. 2018; Vancampenhout et al. 2006) show that structural watershed conservation measures such as terraces and stone-faced bunds are highly effective in reducing runoff rates and trapping the sediments, and thus sustainably manage watersheds in mountainous areas like Rib watershed. According to Nyssen et al. (2007), soil/stone bunds are highly effective in reducing the slope gradient of the land between the bunds and in the reclamation of steep lands. However, results show that structural WMMs are rarely implemented in the study area and lack proper construction and maintenance. During the field observation, it was clear that most of the stone bunds constructed in the study area were filled with sediments due to lack of proper maintenance. The check dams and vegetative treatments implemented for the rehabilitation of widespread gullies, particularly in grazing and intensively cultivated plots, were also poorly constructed and lack regular maintenance.

The factors that hinder the farmers from implementing structural WMMs were examined using the binary logistic regression model. The results of the model revealed that the farmers' willingness to implement the structures was influenced by several socioeconomic, biophysical, and institutional variables. Access to support services is one of the important determinants of farmers' decision to apply any type of management structure on their plots. Access to information is a key factor that determines farmers willing to invest in land management projects (Nyanga et al. 2016), where a lack of technical support negatively influences the farmers' cooperation in adopting land management measures (Tefera and Sterk 2010). Our result shows a significant ($P < 0.01$) positive relationship between the frequency of extension contacts and farmers' willingness to implement WMMs. The implication is that the farmers who had frequent contacts with extension agents were more aware of the effects of watershed degradation and the benefits of WMMs, and thus more motivated to manage their farmlands compared with those who had fewer or no contacts. Similar to our findings, access to support services also influenced farmers' decisions on investing in natural resources management in Ethiopia (Asfaw and Neka 2017; Moges and Taye 2017; Nigussie et al. 2017b).

Farmland is an important source of livelihood in the watershed. Thus, the size of the plot remarkably influences the decision of farmers to apply any type of WMMs. The interviewed farmers confirmed that the construction of structural WMMs such as terraces, stone/soil bunds, and cut-off-drains highly compete for space of farmlands, thereby reduce their preparedness to apply WMMs. In this study, the significant positive ($P <$ 0.01) correlation between plot size and watershed management investment suggests that farmers who hold large farm sizes were more likely to implement in WMMs compared with the farmers holding small farm sizes. This finding contradicts the study conducted in Tanzania which indicates that farmers holding more plots are less likely to carry out WMMs on all fields due to lack of enough finance, time, labor, and other inputs (Nyanga et al. 2016). However, our finding is supported by Tesfaye et al. (2014), Nigussie et al. (2017b), and Teshome et al. (2016) who reported that large plot size may create a positive incentive for small-scale farmers to implement and maintain WMMs. Education shows a significant positive ($P < 0.01$) correlation with watershed management investments. This is because education provides a better understanding of watershed degradation and management benefits, and thus positively influences farmers' decision towards management actions. This result is in agreement with that of Alemayehu and Bewket (2017) which indicates a positive influence of education on farmers' perception of watershed degradation and management.

Another key factor that highly influences the farmers' decision to implement WMMs is tenure security. Lack of plot ownership undermines farmers from investing in WMMs (Akinnagbe and Umukoro 2011; Tefera and Sterk 2010), whereas the farmers would be willing to implement long-term WMMs when they feel secure about their lands (Alemayehu and Bewket 2017). In Ethiopia, the land is owned by the state government and the farmers have only the right to use. To make farmers feel secure about their lands and ensure sustainable land management, the government of Ethiopia has stopped land redistribution since 2005 (Mekuriaw et al. 2018). Interview and FGD results indicated that although most of the farmers feel secured about their land use rights because of the land certification, the majority of them still feel unsecured due to previous frequent redistributions. As explained elsewhere in this paper, most of the croplands operated in the study area were either rented or sharecropped for a short period, usually arranged for 1 year. It was clear from filed observation and interviews that own plots are more managed than sharecropped and rented plots. The farmers less likely to invest long-term watershed management practices on sharecropped and/or rented plots rather they would give more emphasis to increase short-term yields through maximum exploitation of all available resources. As a result, plot ownership was found to influence farmers' decisions to apply WMMs positively at a 1% level of significance.

The position of plots in the watershed was found to influence farmers' decisions positively at a 5% significance level. The possible explanation is that the farmers who reside or have farm plots in the upstream areas of the watershed are more aware of the severity of watershed degradation and likely to invest in WMMs than those who reside and/or cultivate lands in the downstream areas. Interview results also confirmed that farmers who reside and/or cultivate lands in the upstream areas of the watershed better perceive surface runoff and soil erosion problems compared with downstream counterparts. Family size (adult), access to training programs, and position of plot in the watershed were also found to influence farmers' decisions positively at a 5% level of significance. The shortage of labor is one of the most important factors hindering the implementation of WMMs in Ethiopia (Haregeweyn et al. 2015). Thus, the positive correlation between adult size and willingness to invest indicates that farmers with more working force have a better capacity to implement WMMs, compared with those who have less labor force. Similarly, the significant positive relationship between access to training and implementation of WMMs implies that the farmers who participated in any sort of watershed management, and development-related training had better knowledge about the benefits of WMMs compared with those who had no training access.

Conclusions

This study used the survey data of smallholder farmers in the Rib watershed of north-western highland Ethiopia to assess the extent, causes, trends, and impacts of watershed degradation and the factors influencing the successful use of management measures. The results revealed that the study area is severely affected by various forms of watershed degradation such as soil erosion and loss of biodiversity resulted from the clearing of vegetation, expanded croplands, overgrazing, and land use/cover changes. The relatively high degradation rates were observed in the upstream fields with low vegetation cover and poor conservation practices where high runoff has caused the significant transportation of uppermost fertile soil. Watershed degradation in the study area has affected ecological, social, and economic sustainability in one way or another. A wide range of structural and biological watershed management practices have evolved in the studied watershed to conserve and rehabilitate the degradation problem. However, the quality and continuity of watershed management practices were not up to the required standard, highly constrained by various and complex factors. Farmland size, educational levels, access to support services, and plot ownership were found to have positive and statistically significant ($P < 0.01$) influence on the farmers' willingness to implement WMMs on their fields. Family size, access to training related to watershed management, and position of plots had also a positive significant ($P < 0.05$) relationship with the implementation of WMMs. In general, the current status of watershed degradation needs better watershed management plans, policies, and practices to control the adverse and multiple effects of degradation and ensure food security and livelihood sustainability of smallholder rural farmers. The effective and efficient watershed management goals could be achieved by improving environmental awareness of the local community and by considering their priority needs while designing and implementing the watershed management projects.

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References

Adgo, E., Teshome, A., & Mati, B. (2013). Impacts of long-term soil and water conservation on agricultural productivity: the case of Anjenie watershed, Ethiopia. *Agricultural Water Management, 117*, 55–61. https://doi.org/10.1016/j.agwat.2012.10.026.

Admassu, Z., Mekonnen, K., & Gojjam, Y. (2008). *Working with communities on integrated natural resources management. Ethiopian Institute of Agricultural Research*. Ethiopia: Addis Ababa.

Adugna, G., & Bekele, W. (2007). Determinants of land degradation in the lake tana basin and its implications for sustainable land management: the case of Angereb and Gish-Abbay watersheds. *Ethiopian Journal of Agricultural Economic, 6*(2), 70–101. https://doi.org/10.13140/rg.2.1.3120.7527.

Akinnagbe, O. M., & Umukoro, E. (2011). Farmers' perception of the effects of land degradation on agricultural activities in Ethiope east local government area of Delta State. *Nigeria, 76*(2), 8.

Alemayehu, A., & Bewket, W. (2017). Determinants of smallholder farmers' choice of coping and adaptation strategies to climate change and variability in the central highlands of Ethiopia. *Environment and Development, 24*, 77–85. https://doi.org/10.1016/j.envdev.2017.06.006.

Asfaw, D., & Neka, M. (2017). Factors affecting adoption of soil and water conservation practices: the case of Wereillu Woreda (District), South Wollo Zone, Amhara Region, Ethiopia. *International Soil and Water Conservation Research, 5*(4), 273–279. https://doi.org/10.1016/j.iswcr.2017.10.002.

Azam, M. (2016). Does environmental degradation shackle economic growth? A panel data investigation on 11 Asian countries. *Renewable and Sustainable Energy Reviews, 65*, 175–182. https://doi.org/10.1016/j.rser.2016.06.087.

Bekele, A., Aticho, A., & Kissi, E. (2018). Assessment of community-based watershed management practices: emphasis on technical fitness of physical structures and its effect on soil properties in Lemo district, Southern Ethiopia. *Environmental Systems Research, 7*(1), 20. https://doi.org/10.1186/s40068-018-0124-y.

Beyene, A., Cornelis, W., Verhoest, N. E. C., Tilahun, S., Alamirew, T., Adgo, E., de Pue, J., & Nyssen, J. (2018). Estimating the actual evapotranspiration and deep percolation in irrigated soils of a tropical floodplain, northwest Ethiopia. *Agricultural Water Management, 202*, 42–56. https://doi.org/10.1016/j.agwat.2018.01.022.

Bishaw, B. (2001). Deforestation and land degradation on the Ethiopian Highlands: a strategy for physical recovery (p. 17). Presented at the International Conference on African Development Archives, Western Michigan University.

Coxhead, I., & Shively, G. (2005). Economic development and watershed degradation. In *In Land use changes in tropical watersheds: evidence, causes and remedies* (p. 18). Cambridge: CABI International.

Darghouth, S., Ward, C., Gambarelli, G., Styger, E., & Roux, J. (2008). Watershed management approaches, policies, and operations: lessons for scaling up (No. 11) (p. 164). Washington.

Desta, L., Carucci, V., Wendem-Ageňehu, A., & Abebe, Y. (2005). *Community based participatory watershed development: a guideline* (1st ed.). Addis Ababa: Ministry of Agriculture and Rural Development.

Gebregziabher, G., Abera, D. A., Gebresamuel, G., Giordano, M., & Langan, S. (2016). An assessment of integrated watershed management in Ethiopia. *International Water Management Institute (IWMI).* https://doi.org/10.5337/2016.214.

Gebremeskel, G., Gebremicael, T. G., & Girmay, A. (2018). Economic and environmental rehabilitation through soil and water conservation, the case of Tigray in northern Ethiopia. *Journal of Arid Environments, 151*, 113–124. https://doi.org/10.1016/j.jaridenv.2017.12.002.

Gebremichael, D., Nyssen, J., Poesen, J., Deckers, J., Haile, M., Govers, G., & Moeyersons, J. (2005). Effectiveness of stone bunds in controlling soil erosion on cropland in the Tigray Highlands, northern Ethiopia. *Soil Use and Management, 21*(3), 287–297. https://doi.org/10.1111/j.1475-2743.2005.tb00401.x.

Gebreselassie, S., Kirui, O. K., & Mirzabaev, A. (2016). Economics of land degradation and improvement in ethiopia. In E. Nkonya, A. Mirzabaev, & J. von Braun (Eds.), *Economics of land degradation and improvement – a global assessment for sustainable development* (pp. 401–430). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-19168-3_14.

Gebretsadik, Z. M. (2014). Watershed degradation and the growing risk of erosion in Hawassa-Zuria District, Southern Ethiopia: watershed degradation and erosion in Hawassa-Zuria District. *Journal of Flood Risk Management, 7*(2), 118–127. https://doi.org/10.1111/jfr3.12033.

Haregeweyn, N., Berhe, A., Tsunekawa, A., Tsubo, M., & Meshesha, D. T. (2012). Integrated watershed management as an effective approach to curb land degradation: a case study of the enabered watershed in northern Ethiopia. *Environmental Management, 50*(6), 1219–1233. https://doi.org/10.1007/s00267-012-9952-0.

Haregeweyn, N., Tsunekawa, A., Nyssen, J., Poesen, J., Tsubo, M., Tsegaye Meshesha, D., Schütt, B., Adgo, E., & Tegegne, F. (2015). Soil erosion and conservation in Ethiopia: a review. *Progress in Physical Geography: Earth and*

Environment, 39(6), 750–774. https://doi.org/10.1177/0309133315598725.

Hurni, H. (1988). Degradation and conservation of the resources in the Ethiopian Highlands. *Mountain Research and Development, 8*(2/3), 123. https://doi.org/10.2307/3673438.

Hurni, H., Abate, S., Amare Bantider, Berhanu Debele, Ludi, E., Portner, B., et al. (2010). Land degradation and sustainable land management in the highlands of Ethiopia. Unpublished. https://doi.org/10.13140/2.1.3976.5449

Jemberu, W., Baartman, J. E. M., Fleskens, L., Selassie, Y. G., & Ritsema, C. J. (2017). Assessing the variation in bund structure dimensions and its impact on soil physical properties and hydrology in Koga catchment, Highlands of Ethiopia. *CATENA, 157*, 195–204. https://doi.org/10.1016/j.catena.2017.05.020.

Jones, C. (Ed.). (2002). *Watershed health monitoring: emerging technologies*. Boca Raton: Lewis.

Klik, A., Schürz, C., Strohmeier, S., Demelash Melaku, N., Ziadat, F., Schwen, A., & Zucca, C. (2018). Impact of stone bunds on temporal and spatial variability of soil physical properties: A field study from northern Ethiopia. *Land Degradation & Development, 29*(3), 585–595. https://doi.org/10.1002/ldr.2893.

Knüppe, K., & Meissner, R. (2016). Drivers and barriers towards sustainable water and land management in the Olifants-Doorn Water Management Area, South Africa. *Environment and Development, 20*, 3–14. https://doi.org/10.1016/j.envdev.2016.09.002.

Kosmowski, F. (2018). Soil water management practices (terraces) helped to mitigate the 2015 drought in Ethiopia. *Agricultural Water Management, 204*, 11–16. https://doi.org/10.1016/j.agwat.2018.02.025.

Laekemariam, F., Kibret, K., Mamo, T., Karltun, E., & Gebrekidan, H. (2016). Physiographic characteristics of agricultural lands and farmers' soil fertility management practices in Wolaita zone, Southern Ethiopia. *Environmental Systems Research, 5*(1). https://doi.org/10.1186/s40068-016-0076-z.

Lemma, H., Frankl, A., Griensven, A., Poesen, J., Adgo, E., & Nyssen, J. (2019). Identifying erosion hotspots in Lake Tana Basin from a multisite Soil and Water Assessment Tool validation: opportunity for land managers. *Land Degradation & Development, 30*(12), 1449–1467. https://doi.org/10.1002/ldr.3332.

Li, Z., Deng, X., Yin, F., & Yang, C. (2015). Analysis of climate and land use changes impacts on land degradation in the North China Plain. *Advances in Meteorology, 2015*, 1–11. https://doi.org/10.1155/2015/976370.

Li, Z., & Fang, H. (2016). Impacts of climate change on water erosion: a review. *Earth-Science Reviews, 163*, 94–117. https://doi.org/10.1016/j.earscirev.2016.10.004.

Meheretu, Y., Sluydts, V., Welegerima, K., Bauer, H., Teferi, M., Yirga, G., Mulungu, L., Haile, M., Nyssen, J., Deckers, J., Makundi, R., & Leirs, H. (2014). Rodent abundance, stone bund density and its effects on crop damage in the Tigray highlands, Ethiopia. *Crop Protection, 55*, 61–67. https://doi.org/10.1016/j.cropro.2013.10.016.

Mekuriaw, A., Heinimann, A., Zeleke, G., & Hurni, H. (2018). Factors influencing the adoption of physical soil and water conservation practices in the Ethiopian highlands. *International Soil and Water Conservation Research, 6*(1), 23–30. https://doi.org/10.1016/j.iswcr.2017.12.006.

Mengistu, F., & Assefa, E. (2019). Farmers' decision to adopt watershed management practices in Gibe basin, southwest Ethiopia. *International Soil and Water Conservation Research, 7*(4), 376–387. https://doi.org/10.1016/j.iswcr.2019.08.006.

Moges, D. M., & Bhat, H. G. (2018). An insight into land use and land cover changes and their impacts in Rib watershed, north-western highland Ethiopia. *Land Degradation & Development, 29*(10), 3317–3330. https://doi.org/10.1002/ldr.3091.

Moges, D. M., Bhat, H. G., & Thrivikramji, K. P. (2019). Investigation of groundwater resources in highland Ethiopia using a geospatial technology. *Modeling Earth Systems and Environment, 5*(4), 1333–1345. https://doi.org/10.1007/s40808-019-00603-0.

Moges, D. M., & Taye, A. A. (2017). Determinants of farmers' perception to invest in soil and water conservation technologies in the North-Western Highlands of Ethiopia. *International Soil and Water Conservation Research, 5*(1), 56–61. https://doi.org/10.1016/j.iswcr.2017.02.003.

Monsieurs, E., Poesen, J., Dessie, M., Adgo, E., Verhoest, N. E. C., 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. https://doi.org/10.1016/j.geomorph.2015.01.011.

Nigussie, Z., Tsunekawa, A., Haregeweyn, N., Adgo, E., Nohmi, M., Tsubo, M., Aklog, D., Meshesha, D. T., & Abele, S. (2017a). Farmers' perception about soil erosion in Ethiopia. *Land Degradation & Development, 28*(2), 401–411. https://doi.org/10.1002/ldr.2647.

Nigussie, Z., Tsunekawa, A., Haregeweyn, N., Adgo, E., Nohmi, M., Tsubo, M., Aklog, D., Meshesha, D. T., & Abele, S. (2017b). Factors influencing small-scale farmers' adoption of sustainable land management technologies in north-western Ethiopia. *Land Use Policy, 67*, 57–64. https://doi.org/10.1016/j.landusepol.2017.05.024.

Nyanga, A., Kessler, A., & Tenge, A. (2016). Key socio-economic factors influencing sustainable land management investments in the West Usambara Highlands, Tanzania. *Land Use Policy, 51*, 260–266. https://doi.org/10.1016/j.landusepol.2015.11.020.

Nyssen, J., Poesen, J., & Deckers, J. (2009). Land degradation and soil and water conservation in tropical highlands. *Soil and Tillage Research, 103*(2), 197–202. https://doi.org/10.1016/j.still.2008.08.002.

Nyssen, J., Poesen, J., Gebremichael, D., Vancampenhout, K., D'aes, M., Yihdego, G., Govers, G., Leirs, H., Moeyersons, J., Naudts, J., Haregeweyn, N., Haile, M., & Deckers, J. (2007). Interdisciplinary on-site evaluation of stone bunds to control soil erosion on cropland in Northern Ethiopia. *Soil and Tillage Research, 94*(1), 151–163. https://doi.org/10.1016/j.still.2006.07.011.

Nyssen, J., Poesen, J., Lanckriet, S., Jacob, M., Moeyersons, J., Haile, M., Haregeweyn, N., Munro, R. N., Descheemaeker, K., Adgo, E., Frankl, A., & Deckers, J. (2015). Land degradation in the Ethiopian Highlands. In P. Billi (Ed.), *Landscapes and Landforms of Ethiopia* (pp. 369–385). Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-017-8026-1_21.

Pumo, D., Arnone, E., Francipane, A., Caracciolo, D., & Noto, L. V. (2017). Potential implications of climate change and urbanization on watershed hydrology. *Journal of Hydrology, 554*, 80–99. https://doi.org/10.1016/j.jhydrol.2017.09.002.

Setegn, S. G., Srinivasan, R., Dargahi, B., & Melesse, A. M. (2009). Spatial delineation of soil erosion vulnerability in the Lake Tana Basin, Ethiopia. *Hydrological Processes*, n/a-n/a. https://doi.org/10.1002/hyp.7476.

Sharma, R. K., Sankhayan, P. L., & Singh, R. (2010). Land use changes and forest degradation in a Himalayan watershed: analysis and policy alternatives [1]. *Journal of Natural Resource Policy Research, 2*(3), 263–280. https://doi.org/10.1080/19390459.2010.486150.

Shiferaw, B., & Holden, S. (1999). Soil erosion and smallholders' conservation decisions in the Highlands of Ethiopia. *World Development, 27*(4), 739–752. https://doi.org/10.1016/S0305-750X(98)00159-4.

Shroder, J. F. (2014). Afghanistan environmental degradation. In *Natural resources in Afghanistan* (pp. 466–491). Elsevier. https://doi.org/10.1016/B978-0-12-800135-6.00017-9

Sonneveld, B. G. J. S., & Keyzer, M. A. (2003). Land under pressure: soil conservation concerns and opportunities for Ethiopia. *Land Degradation & Development, 14*(1), 5–23. https://doi.org/10.1002/ldr.503.

Taddese, G. (2001). Land degradation: a challenge to Ethiopia. *Environmental Management, 27*(6), 815–824. https://doi.org/10.1007/s002670010190.

Tarfasa, S., Balana, B. B., Tefera, T., Woldeamanuel, T., Moges, A., Dinato, M., & Black, H. (2018). Modeling smallholder farmers' preferences for soil management measures: a case study from South Ethiopia. *Ecological Economics, 145*, 410–419. https://doi.org/10.1016/j.ecolecon.2017.11.027.

Taye, G., Vanmaercke, M., Poesen, J., Van Wesemael, B., Tesfaye, S., Teka, D., et al. (2018). Determining RUSLE P- and C-factors for stone bunds and trenches in rangeland and cropland, North Ethiopia. *Land Degradation & Development, 29*(3), 812–824. https://doi.org/10.1002/ldr.2814.

Tefera, B., & Sterk, G. (2010). Land management, erosion problems and soil and water conservation in Fincha'a watershed, western Ethiopia. *Land Use Policy, 27*(4), 1027–1037. https://doi.org/10.1016/j.landusepol.2010.01.005.

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. https://doi.org/10.1016/j.agee.2012.11.007.

Tesfaye, A., Deneke, T. T., & Gebresilassie, Y. (2014). Determinants of maintenance decision of introduced soil and water conservation practices in Fagita Lekoma District, North West Highlands of Ethiopia, 18.

Teshome, A., de Graaff, J., & Kassie, M. (2016). Household-level determinants of soil and water conservation adoption phases: evidence from North-Western Ethiopian Highlands. *Environmental Management, 57*(3), 620–636. https://doi.org/10.1007/s00267-015-0635-5.

Vancampenhout, K., Nyssen, J., Gebremichael, D., Deckers, J., Poesen, J., Haile, M., & Moeyersons, J. (2006). Stone bunds for soil conservation in the northern Ethiopian highlands: Impacts on soil fertility and crop yield. *Soil and Tillage Research, 90*(1–2), 1–15. https://doi.org/10.1016/j.still.2005.08.004.

Wang, J., & Dong, K. (2019). What drives environmental degradation? Evidence from 14 Sub-Saharan African countries. *Science of the Total Environment, 656*, 165–173. https://doi.org/10.1016/j.scitotenv.2018.11.354.

Wolancho, K. W. (2015). Evaluating watershed management activities of campaign work in Southern nations, nationalities and peoples' regional state of Ethiopia. *Environmental Systems Research, 4*(1). https://doi.org/10.1186/s40068-015-0029-y.