Heliyon 8 (2022) e09536

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Assessment of soil erosion hazard and factors affecting farmers' adoption of soil and water management measure: A case study from Upper Domba Watershed, Southern Ethiopia

Teshome Yirgu *

Department of Geography and Environmental Studies, Arba Minch University, P.O. Box 21, Arba Minch, Ethiopia

ARTICLE INFO

Keywords:
Geographic information system
Multiple regression model
Adoption of soil and water conservation practices
Revised universal soil loss equation and soil erosion severity

ABSTRACT

Soil erosion is a serious and continuous environmental problem in the highlands of Ethiopia, particularly, in the study watershed. The purpose of the study was to assess potential annual soil loss and factors affecting the adoption of soil and water conservation technologies in the Domba watershed. In the study, rainfall data, satellite imageries, and digital soil map were used to determine the RUSLE factors. In addition, household data was used to assess contributing factors to erosion hazards in the area. Furthermore, Revised Universal Soil Loss Equation along with Remote Sensing Techniques, Geographical Information System, multiple regression model was used in analysing the data to find out the contributing factors for the severe soil erosion in the study area. The study result revealed that the estimated annual soil loss of the watershed was ranging between 0 to 95 t ha^{-1} y^{-1}. Degraded mountain ranges of Sule and Gana kare-Woyza ridges contributed majority (more than 82%) soil loss in the watershed. This part of the watershed was categorized under severe erosion intensity class and levelled in priority list for intervention measure. The study further showed that there exists a strong positive relationship ($r = 0.874$) between adoption of improved SWC measures and the independent variables used in the study at 0.05 significant level. Among these variables, plot area, plot distance to residence and perception of erosion problem significantly but negatively influences adoption of improved SWC practices. The study further showed that above 77.6% of the variance of adoption of SWC measures were explained by eleven variables used in the study. Therefore, to revert the severity of soil erosion, both government and non-government institutions should enhance timely and proper management measure in the study watershed.

1. Introduction

Soil is the loose material on the crust of the earth, which consists mainly mineral particles, organic material, soil water and air and it is a major natural life-supporting resource. Soil erosion specially by water is one of the main forms of land degradation, which is aggravated by human activity and related land use change. It resulted in significant environmental impact through reduction in crop production, retards vegetation growth (Hurni et al., 2010), water quality and soil nutrient decline (Pimentel et al., 1995) and reduction in soil depth and erode the top fertile soil (Hurni et al., 2010), remove large proportion of clay and humus from soil (Adugnaw et al., 2017). Land degradation, mainly erosion by water is a major global challenge that covers about 29% of global land area (Dawen et al., 2003). According to sources, in Ethiopia about 25% of the total land is degraded, and affecting nearly a third of the current Ethiopia's population (Gebre silasie, 2016). Hence, restoring degraded landscapes through water and land management practices, and establishing enclosures boosts landscape productivity and income generation activities such as livestock fattening (Mekuria et al., 2020).

Plethora of literature revealed that soil erosion causes socio-economic and environmental challenges such as reduction in crop yield, environmental degradation, decrease in household income etc. Kertez (2009), Yuan, et al. (2016), Pasqual et al. (2013). Degradation of soil, mainly in the form of erosion by water is one of the severe environmental problems that currently affect the landscape and rural livelihood in most Ethiopian highlands. Soil erosion can be caused by both natural and human induced factors. Among the natural factors: unique steep terrain, intense rainfall and soil types that are vulnerable to the forces of detachment are the top mentioned factors for heavy run off in the Ethiopian highlands (Temesgen, 2015; Tilahun et al., 2001). Human

* Corresponding author.
E-mail address: Teshome.yirgu@amu.edu.et.

https://doi.org/10.1016/j.heliyon.2022.e09536
Received 22 November 2021; Received in revised form 14 January 2022; Accepted 19 May 2022

induced factors such as hill side farming, over grazing, over population, unsustainable vegetation use are practices that most trigger erosive power of soil Belay and Eyasu (2017), Pasquale, et al. (2013). In addition, irresponsible land use policies, obsolete farming practices, steep slope farming and improper soil management practices are also leveled as the other contributing factors of soil erosion in most of the Ethiopian highlands and in most sub-Saharan countries Belay and Eyasu (2017); Kibret and Fanuel (2015); Paul et al., Studies reported that for 2001 estimated global annual average potential soil erosion amount was 35 Pg yr^{-1} for 2001, while in 2012 an overall increase of 2.5% soil erosion was registered (Dawen et al., 2003). The impact of water erosion is spatially variable across the globe, but its severity is paramount mainly in sub-Saharan Africa. In sub–Saharan African countries mainly in the White Volta basin and the Nile basin estimated overall mean soil loss of 35 t ha^{-1} yr^{-1} and 75 t ha^{-1} yr^{-1} was reported respectively (Ahmed, Ismail 2008).

Despite various soil management measures were taken to curtail severity of soil erosion in the Ethiopian highlands, but its status fall short of an improvement as the current rate is alarmingly increasing. Empirical studies conducted in the Ethiopian highlands showed that on cultivated lands mean annual soil loss varies from 42 t ha^{-1} y^{-1} at Andit Tid locality (Hurni, 1990) to 64 t ha^{-1} y^{-1} in Gununo site in Southern Ethiopia (Belay, 2002) to 70 t ha^{-1} y^{-1} (Bedadi, 2004) in Blue Nile Basin, Northern Ethiopia. This exceeds the permissible rate of annual soil loss limit estimated for the Ethiopian highlands that is less than 18 t ha^{-1} y^{-1} (Mengie et al., 2019b; Morgan, 2005). This clearly shows that the risk from soil erosion in Ethiopian highlands is paramount that it can impede not only environmental sustainability and agricultural production but also badly threaten the livelihood of the rural households.

According to reports of World Bank (2007), the minimum annual cost of soil erosion ranges between 2 and 3 per cent of the national agricultural GDP. This clearly shows the extent to which soil erosion is a contributing factor to the country's structural food insecurity problem (Bewuket, 2009). More recently, the government of Ethiopia and development partners has been dedicated with considerable resources to encourage soil and water management practices and technologies to reverse soil erosion problems and improve rural livelihoods (Teshome et al., 2021). Nevertheless, most of the techniques have not been supported with intervention prioritizing that identifies highly susceptible areas using geospatial analysis (Gashaw et al., 2017).

In Ethiopia, Geospatial based soil loss estimation and erosion risk prone areas identification researches are conducted in the Northwestern and eastern part of the country (Haregeweyn et al., 2017; Hurni et al., 2015), but such investigations are untapped in Gamo highlands, where this study was conducted. Like most Ethiopian highlands, Domba watershed of Gamo highlands have experience severe soil erosion. Due to land use change, high rainfall erosivity, rugged terrain and long history of traditional cultivation practices the watershed is critically suspectable to erosion severity. Thus, tries to quantify the status of soil erosion and there by identify erosion prone micro-watersheds in Domba watershed, which enables both the stakeholders and watershed community to undertake Soil management intervention measure.

In order to estimate annual soil loss and prioritize erosion risk areas in the study watershed, the author employed GIS-based Revised Universal Soil Loss Equation (RUSLE) model. Though, RUSLE model has a limitation that it neglects sedimentation processes in the equation and does not estimate the amount of sediment leaving the watershed, with this limitation it fairly estimates soil movement at a particular site (Bewket and Teferi 2009; Temesegen et al., 2017). In the research the following questions are answered. which part of the watershed is severely prone to erosion hazards? what the estimated amount of soil loss in the watershed? which potential factors influences SWC measures in the watershed? Therefore, this study attempts to estimate the existing soil loss amount and prioritize hotspot erosion prone sites and thereby identify the major factors that influences farmers' adoption of SWC measure in the study watershed.

2. Research methods

2.1. Study area

Upper Domba watershed is located in the Ethiopia's Southern highlands, *Gamo highlands* at about 470 kM South of Addis Ababa, Federal capital of Ethiopia. It lies between 6° 15′15″ to 6°27′30″ N latitude, and 37° 14′30″ to 37^0 27′ E longitude (Figure 1). The study watershed is best characterized by dissected mountain blocks, undulating terrains, valleys and plateau landscape. *Orthic* (95%) and *Dystric Nitisols* (5%) soil types are the major soil types of the watershed. Plateau areas of the watershed are dominated by clay-rich *Acrisols*, which dominantly acidic, low soil nutrient content and are agriculturally unproductive (see Figures. 2 and 3).

According to Dita District population offices, in 2020 population of the watershed was 92,726, of which 51 % and 49% are female and male respectively. Agriculture particularly crop farming and livestock rearing is the main source of livelihood in the watershed.

2.2. Research methodology

2.2.1. Data sources and sampling procedure

Descriptive survey design was used to validate erosion severity and livelihood challenges of potter households because it is more appropriate to describe the situation of soil erosion and factors affecting adoption soil and water conservation measures in the study area. In addition, mixed research approach, mainly quantitative and qualitative approaches were employed. Mixed research approaches have given an opportunity for researcher to assess the data and understand a research problem more completely (Creswell, 2012). The data was collected both from primary and secondary sources using household survey, interview, focus group discussions and archival sources.

In this case, household survey was conducted using 175 respondents in two sample Kebeles of the study watershed from December 2019 to April 2020 using field assistants. Qualitative data was gathered by an interview and group discussion with elders, women and agricultural experts. Demographic and rainfall data of the study period were collected from Dita district population office and from nearby kebeles of meteorological observatory stations. Soil map was taken from Ministry of Water, Irrigation & Energy, Ethiopia. Landsat 8 satellite image which was taken in 11, October 2020 was downloaded from USGS website (http://earthexplorer.gov). 350 reference data (ground truth data), 50 reference points per land use/cover types were collected from the field using GPS.

Furthermore, multi-state sampling techniques were employed to select the research subjects. In this case, in the first stage Domba watershed was purposefully selected due to the prevalence of soil erosion and the dominance of degraded landscape. In the second stage, two-sample *kebeles* (*Goza and Tukana Gana Woyza kebele*) were also purposefully selected due to the exposure of croplands to severe erosion effects. Finally, sample household heads were selected using the formula after Lewis (1997). As reported by Kothari (2004), the minimum sample size depends on the type of research design, the desired level of confidence in the results and the characteristics of interests of the population. Since the target population of the study was less than 10,000 (Lewis, 1997), and it was 2136, Lewis's formula was utilized to compute sample size. In this case, the sample size considered was 175. The formula was

$$n = (Z\alpha/2)\ p\ (1 - p)\ /d^2 \quad (1)$$

where, **n** is the desired sample size (when the population is less than 10,000), **Zα/2** is the standard normal deviate at the required (95%), confidence limit (1.96), **p** is 0.145 (contingency for non-response rate or Proportion of the target population to be included in the sample), **q** is 1- p (1- 0.145 = 0.855), **d** is the level of statistical accuracy (margin of error) set usually at 0.05 and **N** is the total number of the household heads. The desired sample size was calculated as.

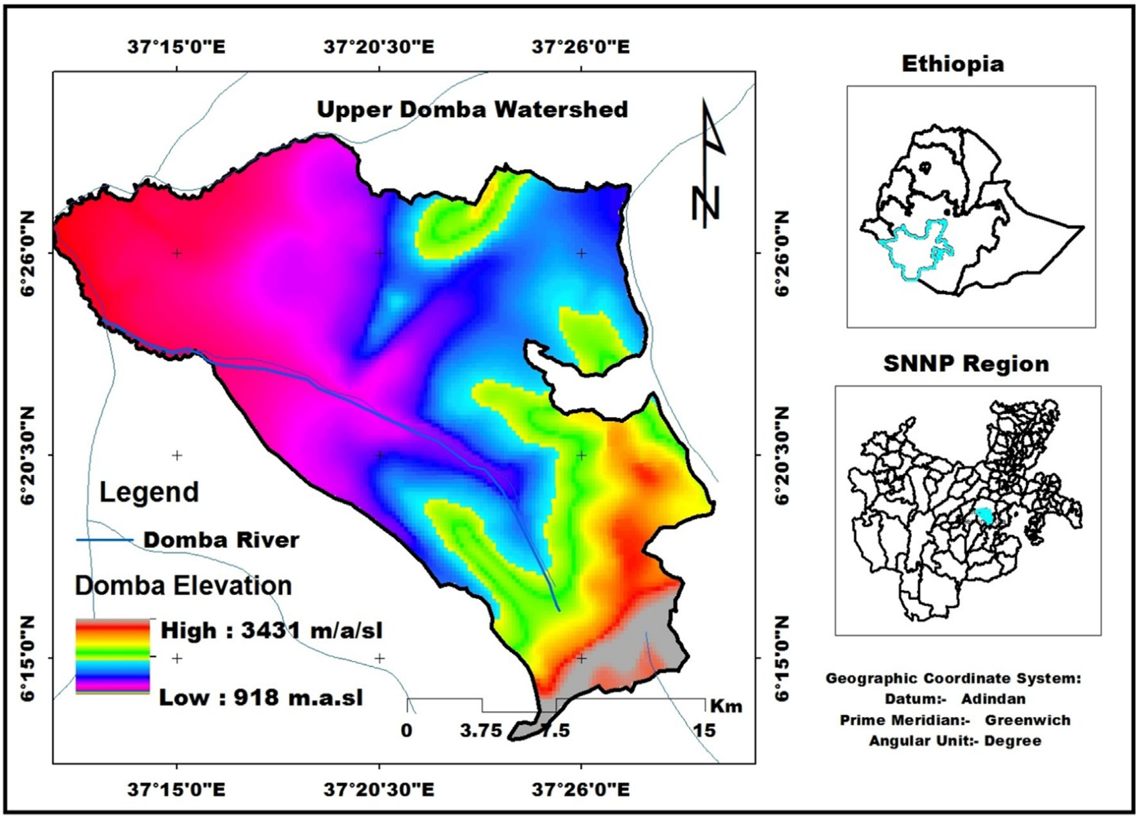

Figure 1. Map of the study area.

n = (1.96) (0.145 * 0.855)/(0.05) = 190. Substituting the value of n (190) in the second formula the *actual sample size was calculated:*

$$nf = n/1 + n/N \quad (2)$$

where, **nf** is sample size, **n** is 190 (desired sample size) and **N** is target population. Then the required sample size was proportionally selected from the target population using systematic random sampling technique. This was possible by arranging the target population into gender and slope categories. Then target population were arranged in alphabetical order using Kebele registration book, hence the first household was randomly selected and then every 10^{th} household was systematically selected as sample size using the formula after Lewis (1997).

$$K = N/n \quad (3)$$

where, K = required sample to be drawn, N = target population and n = total sample size.

2.2.2. Data analysis techniques

2.2.2.1. Analysis of soil loss. As reported by different authors, with its minor limitations RUSLE model is the most applicable & cost-effective technique to assess the rate of soil loss in slope fields and adapted to the Ethiopian highlands condition where available data was limited (Bewket and Teferi, 2009; Haile and Fetene, 2012; Hurni, 1985). In the estimation of potential mean annual soil loss of the study area five parameters are used in RUSLE model (. These are rainfall erosivity (R), soil erodibility (K), slope length and steepness factor (LS), cover management factor (C) and conservation practice factor (P). Referring to RUSLE model, the relationship is expressed as:

$$A = R * K * L S * C * P \quad (4)$$

where 'A' is the average annual rate of soil loss in t ha^{-1} y^{-1} due to water erosion, 'R' is the rainfall erosivity factor in MJ mm ha^{-1} h^{-1} yr^{-1}, 'K' is the soil erodibility factor in t h MJ^{-1} mm−1, 'LS' topographic factor, where 'L' is the slope length factor, 'S' is the slope steepness factor, 'C' is the cover and management factor, and 'P' is the conservation support factor.

2.2.2.2. Factors of Revised Universal Soil Loss Equation, RUSLE

2.2.2.2.1. Rainfall erosivity (R) factor. For the present study, a time series rainfall data of 30 years collected from five stations was used to estimate "R" value for the year 1987–2017. Weather stations used for data collection were Daramalo, Chencha, Dorze, Morka and Sawula, which are found in the neighboring localities to the study watershed (Table 1). After having the interpolated rainfall data, R-factor of the study area was assigned based on equation number two. In this study, Hurni's empirical equation (Hurni, 1985a), which estimates R-value for the Ethiopian highlands from annual total rainfall, was used. It is represented by the following equation:

$$R = -8.12 + (0.562 * P) \quad (5)$$

2.2.2.2.2. Soil erodibility (K) factor. The soil map of Domba watershed was collected from Ministry of Water, Irrigation and Energy. It was developed in 1:250,000 scale as a multipurpose digital map following food and agricultural organization (FAO) soil classification standard. Two types of soil (Table 2) have been identified. The K-value for each soil type was calculated by the help of Williams (1995) equation and FAO (2003) soil data. The following equation was used while determining K-factor for the soil in the watershed (Figure 4) (see Tables 3 and 4).

$$K = F_{csand} * F_{cl-si} * F_{orgc} * F_{hisand} \quad (6)$$

where: Fcsand is a factor that lowers the K indicator in soils with high coarse-sand content and higher for soils with little sand; Fcl-si gives low soil erodibility factors for soils with high clay-to-silt ratio; Forgc reduces K values in soils with high organic carbon content, while Fhisand lower K values for soils with extremely high sand content.

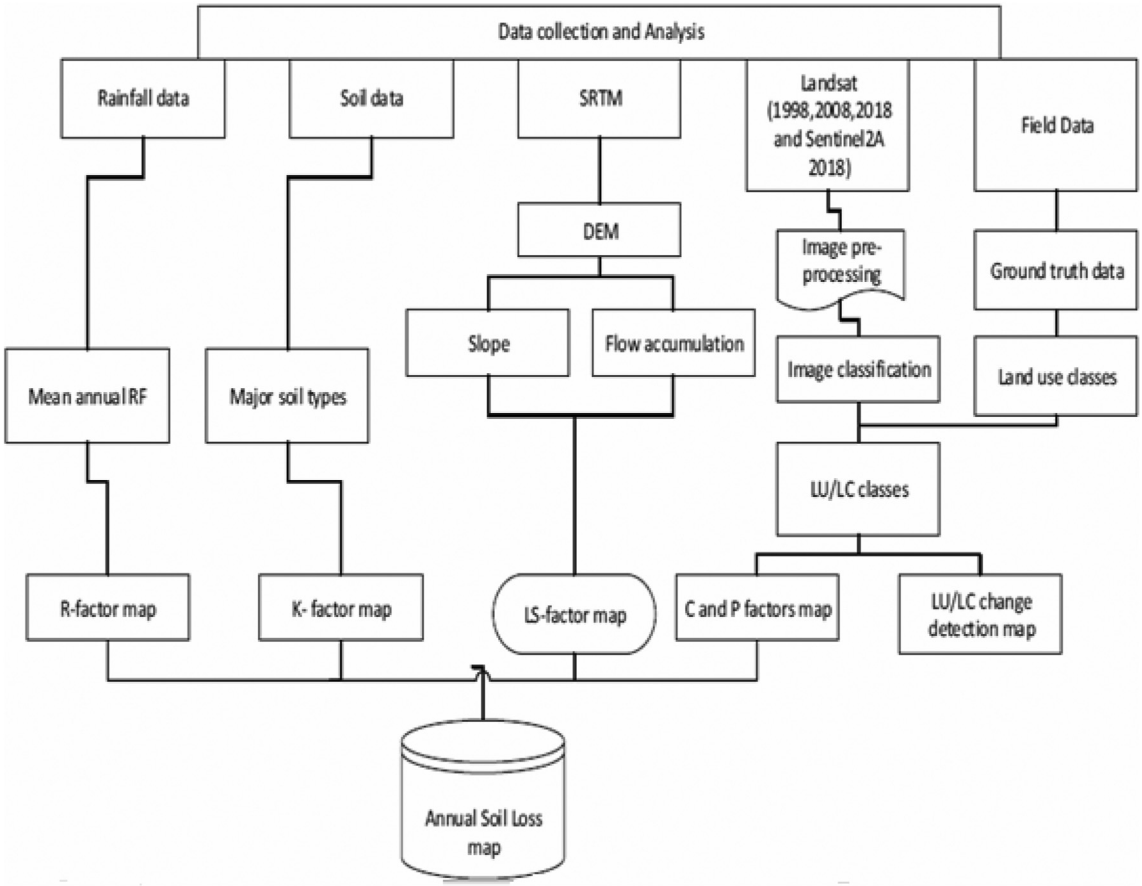

Figure 2. Flow chart of erosion risk mapping of RUSLE model.

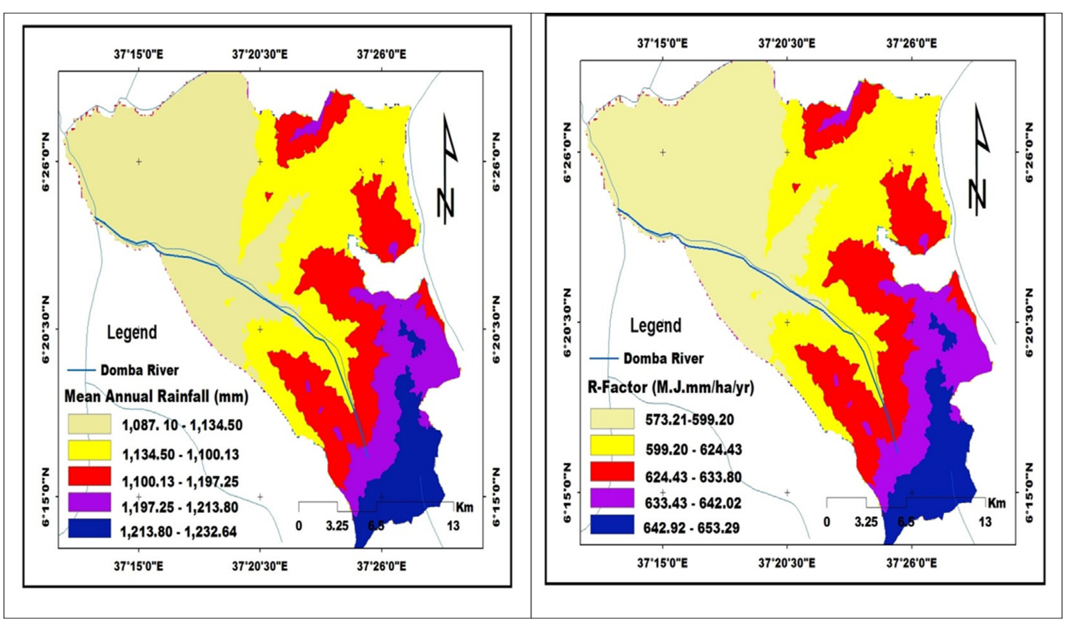

Figure 3. Mean annual rainfall and erosivity factor (M.J.mm/ha/yr) map of Upper Domba Watershed.

2.2.2.2.3. Slope length and slope steepness (LS). Digital Elevation Model dataset of 90 m resolution was clipped to encompass the zone of interest and used for generating LS factors. GIS enabled more accurate estimation of slope length and steepness. In order to derive LS-factor values, a series of DEM derived grids are produced using ArcGIS 10.3, with its extension Arc hydro 10.3. At first, any false single-cell sinks within the source DEM are filled to produce a depression less DEM. In this process, individual sink elevations were flattened to correspond with the surrounding cells. The flow directions of each DEM cell were then calculated using the flow direction toolset. From the flow direction, flow accumulation was calculated. The slope length (L) and slope steepness (S) were calculated from flow accumulation and slope in the degree of the

Table 1. Mean annual rainfall and Erosivity factors.

Name of Stations	Easting	Northing	Mean RF	R-factor
Daramalo	$37^0 36'$	$6^0 04'$	935	517.35
Chencha	$37^0 34'$	$6^0 15'$	1180	655.04
Dorze,	$37^0 32'$	$6^0 12'$	1200	666.28
Morka	$38^0 56'$	$6^0 02'$	960	531.4
Sawula	$36^0 50$	$6^0 15'$	1080	598.84

Source: Ethiopian Metrological Agency, 2018.

Table 2. Sand, silt, clay and organic carbon content of soil.

Soil unit symbol	sand %	silt %	clay %	OC %
Orthic Acrisols (AO)	53.6	15.8	30.6	2.25
Dysric Nitisols (ND)	38.9	17.6	43.6	1.57

local area (Figure 5). Finally, LS factors were derived from the following equation.

LS = (Flow Accumulation*Cell Size/22.13)0.4 *(sin slope*0.01745/0.0896) 1.3 (7)

2.2.2.2.4. Cover management (C) factor. Land use/cover map of the watershed was classified using 30*30 m cloud free Landsat 8 satellite image taken in October 11, 2020 was downloaded from USGS website (http://earthexplorer.usgs.gov). Prior to classification image rectification, layer stacking, image enhancement and extraction had been made as image pre-processing. Five main LUC types were identified based on the researchers' knowledge of the area (Table 5; Figure 6). LUC classes were forest land (area covered by dense and tall trees both natural and plantations), shrub land (land covered by short trees, shrubs, and scattered trees), cropland (a land covered by annual and perennial crops, fallow lands), bare land (stony or rocky areas and soil exposed without any cover) and settlement (urban areas, schools, and health centers and rural homesteads).

The image was classified using supervised classification in the maximum likelihood algorithm procedure. The classification was performed using 350 reference data (50 reference points per LUC type) collected from the field using global positioning system (GPS) as recommended by Congalton and Green (2009). The accuracy assessment was applied using 150 (30 per LUC type) reference data from the field using GPS. Ground control points were collected using stratified random sampling method, which is appropriate method for reference data (Congalton and Green, 2009) and accuracy assessment (Van Genderen and Lock 1977). Error (confusion) matrix and kappa coefficient were used to evaluate the overall classification accuracy of the classified image and the agreement between the classified image and the reference data respectively. Kappa coefficient is appropriate to use for accuracy assessment if stratified random sampling method has been used for collection of training points used for accuracy assessment (Senseman et al., 1995).

Thus, the overall classification accuracy was 90.56%, implying accurate classification (Congalton and Green, 2009) and kappa coefficient

Table 3. Soil erodibility (K) factor.

Soil unit symbol	F_{sand}	F_{cl_Silt}	FoC	$F_{hi\ sand}$	K−Factor
Orthic Acrisols (AO)	0.2	0.72	1.028	0.998	0.15
Dysric Nitisols (ND)	0.20	0.68	1.376	0.999	0.24

Table 4. Slope classes (modified from FAO, 2006) and area coverage in Domba watershed.

Slope Class		Area (ha)	Area ratio (%)
Description	Slope (%)		
Level slope	<1	26	0.24
Very gentle sloping	1–2	43	0.44
Gently sloping	2–5	89.3	0.86
Sloping	5–10	4,305	41.37
Strongly sloping	10–15	1420	13.65
Moderately steep	15–30	2040	19.6
Steep	30–45	1202.6	11.56
Very steep	>45	1278.1	12.28

Source: Geospatial data of the study area.

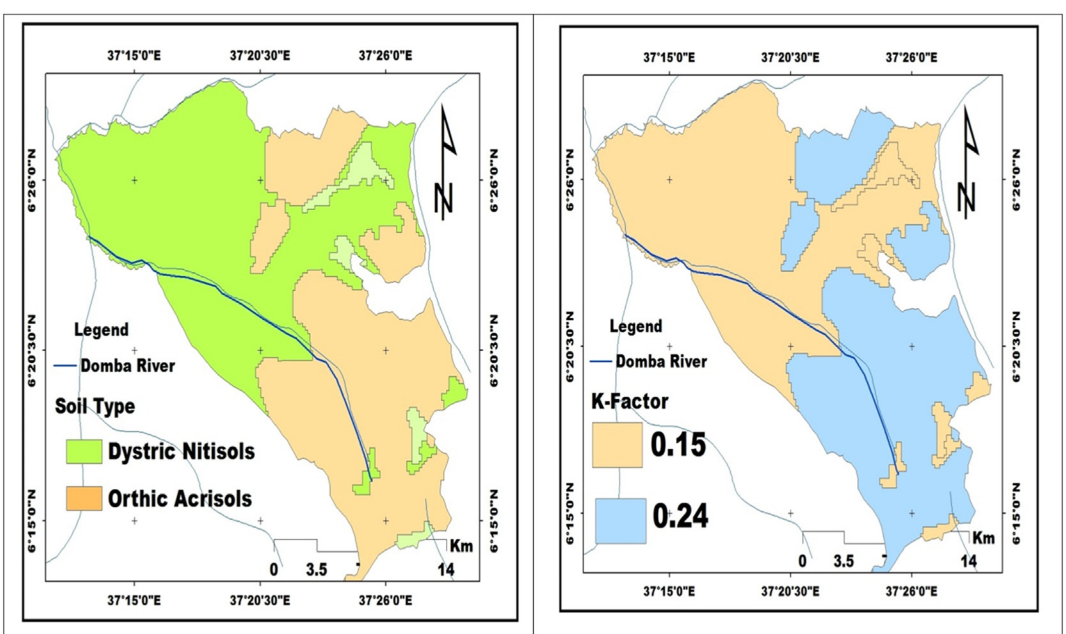

Figure 4. Soil and Soil erodibility factor Map of Upper Domba Watershed.

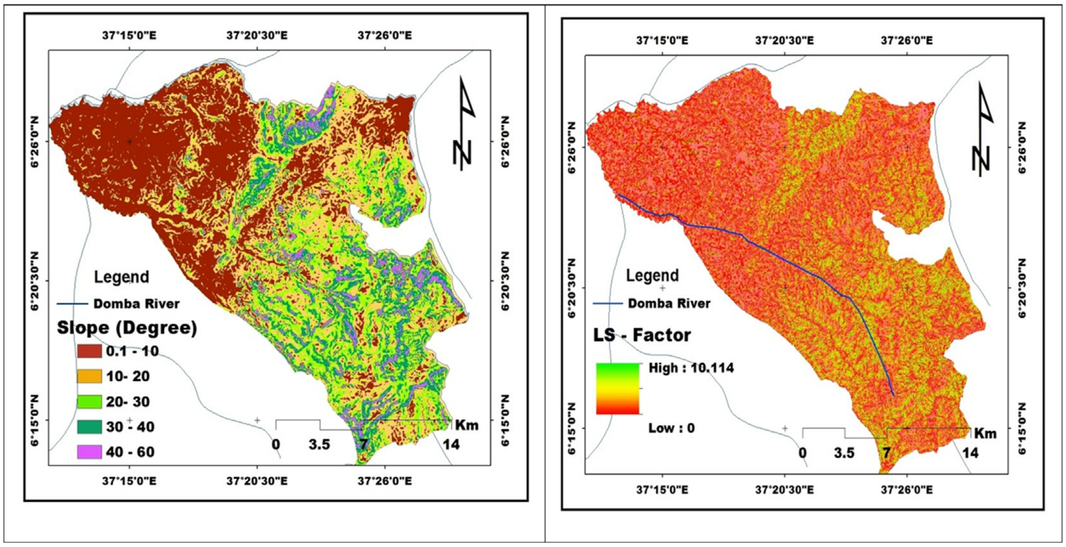

Figure 5. Slope and LS- factor map of Upper Domba Watershed.

Table 5. Land use/cover, area coverage and C- factor values.

LU/LC Type	Area in ha	C- factor	Source
Shrubland	5819	0.01	Asmamaw et al. (2012)
Forestland	30	0.01	Hurni (1985)
Bare soil	431	0.05	Wischmeier and Smith (1978)
Cropland	3261	0.24	Asmamaw et al. (2012)
Settlement	908	0.25	

result indicates (.89) showing a good agreement between the classified image and reference data. The classified land use/cover raster map was converted to vector format to assign suggested C-values for each land use/cover types using ArcGIS10.3 software. As C-values suggested by Hurni (1985).

2.2.2.2.5. Conservation practice (P) factor. The P- factor value was taken from the data gathered by household survey and an interview with district & watershed agricultural experts. From these sources, the researcher found that contour plowing is the most widely use management practice in the study area. Therefore, evaluation of the P factors was made based on Hurni's model (1985), which was developed to be appropriate to the Ethiopia condition. Accordingly, it has given 0.9 for cultivated lands, contour farming, strip cropping hillside terraces and 0.8 for the other land cover types as shown (Table 6) (see Table 7).

Finally, all the parameter layers were resampled to 30 × 30 m cell size raster map and the five RUSLE factors were multiplied in raster calculator of ArcGIS10.3 in a cell-by-cell basis to estimate the potential annual average soil loss and its spatial variability in the watershed. The schematic presentation of the soil erosion analysis has been presented in Figure 7 (see Figures. 8 and 9).

2.2.2.3. Household data analysis. In this case, multiple linear regression model enables us to describe the relationship between dependent variable and several independent variables (Constantin, 2006). To quantify the level of significance of variables used in the study, the formula after Best and James (2007) was employed.

$$Y = B_0 + B_i X_i + \ldots Bn X_n + e_i \tag{8}$$

where Y = dependent (response) variable, xi = independent (explanatory) variables, Bi = the parameters, e_i = Random term/disturbance term which represents all other factors that effects the adoption of improved SWC measures.

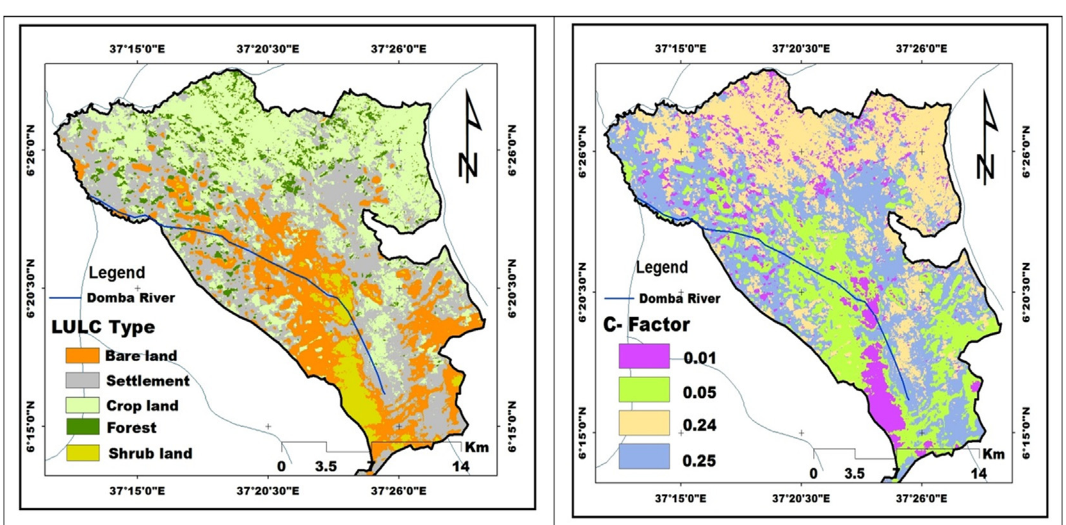

Figure 6. Land use/cover and C-factor map of the study area.

Table 6. Conservation practices factor.

Land-use/land-cover types	Slope (%)	P- factor value
Agricultural land	0–5	.1
Agricultural land	5–10	.12
Agricultural land	10–20	.14
Agricultural land	20–30	.19
Agricultural land	30–50	.25
Agricultural land	50–100	.33
Nonagricultural land	0–100	1.00

Source Wischmeier and Smith (1978).

Table 7. Spatial distribution of soil loss in the Upper Domba Watershed.

Slope category (percent)	Watershed area		Proposed range of soil loss $(t/h^{-1}/^{y-1})$	loss rate (x 10^4 t/y^{-1})	soil loss (%)
	Area (ha)	Area (%)			
0–10	4,463.3	42.9	0–10	1.9	0.45
10–20	2,829.9	27.2	10–20	6.2	1.4
20–30	1,040.4	10	20–30	17.2	3.9
30–60	1,997.6	19.2	30–50	52.3	11.7
>60	72.8	0.7	>50	368	82.6
Total	10,404	100		445.6	

Source: Remote sensing data of the study area, 2020 * Proposed range of soil loss rate was after Ganasri and Ramesh (2015).

According to Gulden and Nese (2013) in the regression model if the tolerance value is greater than 0.10 ($1-R^2$), the VIF is less than 10 and the calculated value of CI is less than 30 it shows that there were not relationships among explanatory variables.

2.2.3. Ethical consideration

In scientific research, the researchers have an obligation to respect the rights, needs and desires of the informants. In this regard, the objectives of the study were introduced to the participants of the study and they were informed that participation in the study was entirely volunteer, and assured that the information they provided would be handled confidentially and would only be used for academic purposes. Furthermore, they were informed not to include their personal identifiers in completing the survey questionnaire and their informed consent was obtained before their involvement in the study. Moreover, the research was conducted following the ethical principles set by Arba Minch University Institutional Research Ethics Board.

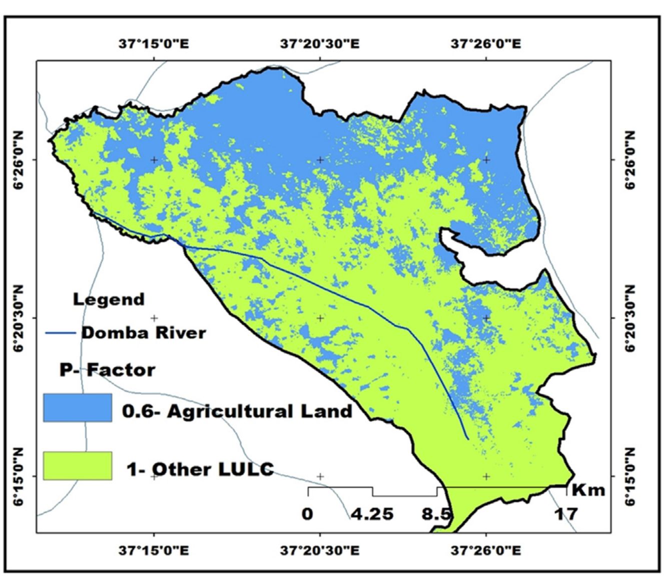

Figure 7. Map of conservation practices (P factor).

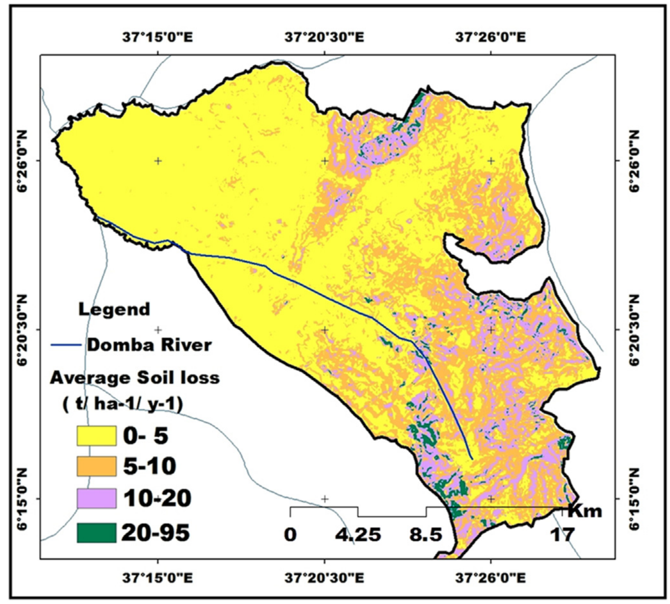

Figure 8. Mean annual soil loss map of Upper Domba Watershed.

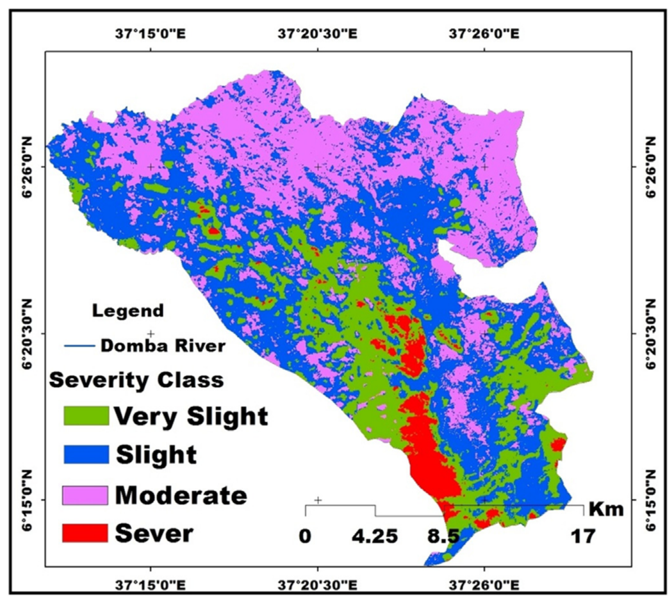

Figure 9. Soil erosion risk map of Upper Domba Watershed.

3. Results

3.1. Annual soil loss rate

The estimated annual soil loss of cultivated lands in the study watershed ranges between 0 & 95 t ha^{-1} y^{-1}. But potential mean annual soil loss was estimated to be 30.6 t ha^{-1} y^{-1}, while the minimum soil loss was observed in the cultivated lands of central low-lying area (Figure 8 and Table 7). Cultivated lands in the eastern hills showed the highest loss rate in the watershed.

Relatively high soil erosion rate of the study watershed is emanated from forestland encroachment, hillside farming practices and the use of obsolete land-use practices. Several kinds of literature reported that cultivation of mountain sides was considered as the major cause of erosion severity in other parts of the Ethiopian highlands (Abate, 2011; Gashaw et al., 2017).

3.2. Delineation of erosion severity areas

Like most Ethiopian highlands, soil erosion is the pressing environmental problem in the study area, where crops are grown on steep plots, rainfall pattern is also erosive and concentrated in few months of the year. Accordingly, more than a third (37.2%) of cultivated lands in Domba watershed is under medium to high slope categories (between 10-30 %) and should supported with viable SWC measures. In this part of the watershed erosion intensity was medium and it was leveled in 3rd priority class for conservation measure. The areas with high to very high erosion risk category is characterized by hilly and rugged landscape (between 30 and 50 % slope). It covers 19.2 % of the area and contributes about 15.6 % of annual soil loss of the study area (Figure 9). These areas are found in the Southern and South eastern edges of the watershed. This area was listed in the 2nd priority class for conservation intervention (Table 8).

In this area crop farming is practiced in limited level, except in the lower slopes of the watershed. Hence agroforestry, fruit farming and controlled grazing are the viable recommended management options to be implemented along with physical structure.

About 0.7 % of the study area has a slope greater than 60 %. This area contributed 82.6% annual soil loss amount of the watershed and the soil loss rate in the area exceeds 50 t ha^{-1} y^{-1}. As a result, this area is exposed to a very severe erosion intensity and leveled in 1st priority list for intervention measure. such area needs additional 100 years to rehabilitate and retain the original soil status (Kouli et al., 2009). As a result, much efforts are expected from the community, government and stakeholders to use the natural resource wisely and rehabilitate the degraded landscape. As recommended by MOA (2016) in such areas in Ethiopia crop cultivation cannot be practiced, except for forestry and ecotourism activities. The MOA (2016) report further recommended that such areas require application of viable management measures such as physical and agronomic SWC measures. Over 57 % area of the watershed has annual soil loss beyond the minimum threshold value (10-ton ha^{-1}) for sustainable agriculture (Morgan, 1995).

3.3. Influencing factors of farmers' adoption of SWC measure

In the study area farmers have been highly practicing both physical and vegetative SWC measures at different scope to reduce the effect of soil erosion. In this regard, there are multiple variables that influence farmers' adoption of soil management practices. The findings show that there existed strong positive relationship ($r = 0.874$) among eleven variables and farmers adoption of SWC measures in the study area (Table 9). The analysis further showed that 76.4 % ($R^2 = 0.764$) of the variance of farmers adoption of SWC measures was explained by eleven variables. The remaining 23.6 % ($1-R^2 = 0.236$) of the variance of influencing factors of adopting SWC measures were explained by other variables that were not identified in the model. The study showed that out of the eleven explanatory variables, it is only seven variables (livestock ownership, plot area, perception of erosion problem, access to training, education level, slope of the plot and plot distance to residence) that are found to have significantly influence farmers' adoption of SWC measure. While the remaining four explanatory variables (contact with extension agents, age, Gender and family size) have insignificant influence on farmers' adoption of Soil management measures. Group discussion result also suggested positive contribution of availability of training facilities related to SWC technologies. Despite their expected importance, sex, family size, age of household head and contact with extension agents had lower effect on the farmers' adoption of management measures.

Table 8. Erosion severity class of Upper Domba Watershed.

Soil loss (t ha^{-1} $year^{-1}$)	Area (ha)	Area (%)	Erosion intensity class	Priority class for conservation measure
<5	1,342.1	12.9	Very low	5th
5–10	3,121.2	30	Low	4th
10–20	2,829.9	27.2	moderate	3rd
20–50	3,038	29.2	High	2nd
>50	72.8	0.7	severe	1st
Total	10,404			

Source: Constructed from Geospatial Data (2020).

Table 9. Model summary.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.874	.764	.735	1.12991

Source: survey data, 2020, * stands for significant at 5%. HHH stands for the household head.

Livestock ownership (TLU): The study revealed that households with large livestock size (TLU) had positively and significantly (at < 0.05) affects farmers' adoption of traditional SWC measure. The model further indicates that as farmers' livestock size increase by one TLU, the rate of applying SWC measure increases by a factor of 84.2% being the other variables in the model remains constant (Table 10).

plot area: Land is the major source of economic and livelihood wellbeing for the rural households in Ethiopia and hence it is a scares resource in Domba watershed. The study found that farmers plot size has a negative but significantly ($P < 0.05$) influence on farmers' adoption of improved SWC measures (Table 10). Our finding showed that with increasing plot size, there expected a probability of reluctance of farmers to engage in improved SWC measures. Group discussion result also confirm this situation that farmer with small plots may have enough time to invest and work on SWC measures.

Erosion problem: The study identifies that farmer's perception was significantly but negatively associated with adoption of soil and water conservation practices. As noted on Table 10, the coefficient of beta (β) value -0.421 implies that as perception of the household heads decreases, the likelihood of adoption conservation measures increases by the factor of -0.421. Group discussion result with selected farmers revealed that they are reluctant to adopt SWC structures, because they are looking for short term economic benefits and that they fear SWC structures reduce their plot size. The finding was in line to the reports of Bezuayehu and Sterk (2010) and Amdihun et al. (2014).

Education status: Education enhances the ability of farmers to process new information, in so doing education may encourage farmers to access new technologies and diversify their income. The empirical finding indicates educational had positively and significantly ($P < 0.05$) influenced farmers' use of improved SWC technologies at 5% probability level. The model result implies that as farmers' level of education increases, the probability of applying SWC technologies increases by 75.3%. The marginal effect in the model shows that the likelihood of those farmers with better educational background to adopt improved SWC technologies increases by 0.3%. This means that farmers with high education level are more likely to use and adopt improved management measures than those do not.

Slope of plot: Cultivated lands, particularly those on steep slope are vulnerable to soil erosion hazards. This is because steeper slope enhances the speed of runoff and thereby accelerate soil erosion. The study showed that slope of plot has significant ($p < 0,05$ level) positively effect on farmers' adoption of SWC technologies. The beta coefficient of slope in the model was 0.519, which implies that as the slope of plot increases by one-unit hectare, the chance of applying improved SWC technologies also increase by a factor of 0.519. This suggested that with increasing slope of plots there is proportional increase in the adoption of SWC measures.

Table 10. Model Result for factors Influencing the adoption of SWC practices (n = 175).

Coefficients							
Independent variable	Unstandardized Coefficients		Standardized Coefficients	t-ratio	Sig.	Co- linearity statistics	
	B	Std. Error	Beta			Tolerance	VIF
Constant	18.127	14.201		8.203	0.001		
Age (years)	-5.019	11.039	-.028	-1.397	0.620	.626	1.596
Family size (adult equivalent)	6.139	9.075	.095	1.843	0.466	.525	1.904
Sex of HHHs	.991	7.508	.148	0.079	0.282	.497	2.019
plot area (hectare)	-.176	7.054	-.285	-3.276	0.041	.700	1.428
erosion problem	-.427	1.129	-.421	-4.317	0.021	.771	1.301
Livestock ownership (TLU)	1.284	.152	.842	9.871	0.002	.989	1.011
Access to training	3.341	.533	.484	5.564	0.016	.907	1.102
Educational status(years)	4.096	.174	.753	8.309	0.003	.898	1.113
Slope of the plot (%)	2.178	.478	.519	6.294	0.013	.746	1.340
Plot distance to residence	-1.221	.921	-.419	-1.201	0.044	.693	1.443
Contact with extension Agent	1.167	8.021	.087	2.012	0.126	.472	2.115

Distance of plots: The study result revealed that plot distance was found to have negative and significant ($p < 0.05$ level) influence on farmers' willingness to adoption of soil management measures at 5% significant level. This implies that as the plot distance from the residence increases, there is a proportional decrease (by a factor of -0.419) in the level of applying improved management measures. This could be due to the fact that more time and energy is needed to reach distant plots relative to homestead fields. The lesser the plot distance from the residence area, the higher frequency farmers supervise or make regular follow up their plots and care.

Access to Training: The result revealed that training related to soil management measures had positive and significant influence on farmers' adoption of improved SWC technologies at less than 5% probability level. This means that households' participation in soil management training most likely increases the likelihood of applying soil management technologies on their plots. Training enables farmers to rehabilitate their plots and thereby improve fertility status of soil. The model finding also implies that other variable being constant, the chance of adopting improved SWC technologies increase by 48.4% as the farmers attend soil management training. This is because farmers who are participated in formal soil management training have better skill, so that they are more motivated to engage in SWC technologies than those who did not get formal training.

4. Discussion

The empirical finding indicates that estimated annual soil loss of cultivated lands in the study area ranges between 0 & 95 t ha-^{1} y-^{1}. The mean potential average annual soil loss in the cultivated lands was estimated to be 30.6 t ha-^{1} y-^{1}. This figure is very large one even to the amounts observed in other parts of Ethiopia. For instance, study by Bewket and Teferi (2009); Temesgen et al. (2017) reported that very high rates of soil erosion ranging from 20 to 237 t·ha$-^{1}$·year$-^{1}$ was observed on the cultivated lands of the Blue Nile Basin, Northern Ethiopia. while considering the mean loss rate, our result was comparable with the research reports of Belayneh et al. (2019a), Amsalu, 2006 and Haregeweyn et al. (2017), they reported 37 t ha-^{1} y-^{1}), 30.6 t ha- ^{1} year-^{1}) and 27.5 t ha-^{1} year-$_{1}$ respectively in their studies conducted in Northern Ethiopia. This does not mean that cultivated land in the Ethiopian highlands experienced high soil loss rate, but lower soil loss (23.7 t ha$-^{1}$ year$-^{1}$) was recorded for Geleda watershed, Northern Ethiopia (Gashaw et al. (2017). As noted by Hurni (1985) the tolerable amount of soil loss for Northern Ethiopia highlands was estimate to be between 2 and 18 ha$-^{1}$ year$-^{1}$. This shows that Domba watershed is suspectable to severe erosion, probably due to hillside farming and improper land use practice. About 57.1% area of the study watershed has a steep terrain (slope greater than 10%), which is vulnerable to soil erosion and not recommended for cereal cultivation if further SWC measures were not applied (MoA 2016). Furthermore, 0.7 % of study watershed (slope greater than 60%) contributed about 82.6% of annual soil erosion amount and exposed to severe erosion intensity and levelled in 1st priority list for intervention measure. This shows that severity of erosion in that part of watershed is assumed to be beyond the tolerable rate and requires reasonable intervention measure. According to sources, such area needs additional 100 years to rehabilitate and retain the original soil status (Kouli et al., 2009). As a result, much efforts are expected from the community, government and stakeholders to responsibly utilize the natural resource and rehabilitate the degraded landscape.

The empirical findings of the study show that farmers' adoption towards SWC measure is influenced by various factors. The study identifies that there existed strong positive relationship ($r = 0.874$) among eleven variables and farmers adoption of SWC measures. Among variables considered in the study, it is livestock ownership, plot area, perception of erosion problem, access to training, education level, slope of the plot and plot distance to residence explained 76.4% ($R2 = 0.764$) of variance of farmers adoption of SWC measures (Daniel & Mulugeta). The remaining 23.6 % ($1\text{-}R2 = 0.236$) of the variance were explained by unmentioned variables.

Livestock pressure (over grazing) has decreased vegetation cover and resulted in soil compaction, which finally increased runoff and thereby reduces water infiltration rate (Alemayehu et al., 2013; Taddese et al., 2002). In line to this, our study revealed that households with large livestock size (TLU) had positively and significantly (at < 0.05) affects farmers' adoption of SWC measure. Similar to the finding of this study, Abebe and Sewunet (2014) reported an increasing probability of wealthier farmer (farmers with more livestock holding) to apply more SWC measure and face lower erosion risk. But Tesfaye et al. (2014); Kassie et al. (2009) reported farmers with more livestock are less likely to introduce improved SWC technologies on their plots because physical SWC technologies compete for extra land that could otherwise be used for agriculture. Due to over grazing and compaction of soil, which is resulted from overstocking, large livestock size was highly acknowledged by group discussants that livestock in the study area is the source of organic manure for cropland and thereby improve organic matter content of soil. Similar to this finding Kassie et al. (2009), confirmed that farmers have strong belief on livestock contribution in improving soil quality rather than degrading the landscape.

The regression analysis revealed that farmers farm size had a negative but significantly ($P < 0.05$) influence on farmers' adoption of improved SWC measures. Garcia (2001), Habtamu (2006) and Budry et al. (2006) reported negative and significant relationship between farm size and farmers' adoption of SWC measure. Our finding showed that with increasing plot size, there expected a probability of reluctance of farmers to engage in improved SWC measures. Group discussion result also confirm this situation that farmer with small plots may have enough time to invest and work on SWC measures. But our findings are contrary to the common expectation that adoption of improved SWC measures is high on households with large plot size. It is evident that construction of improved SWC technologies needs additional space, which is meant for construction purpose. Such farmers did not have land shortage to implement improved SWC technologies on their plots, as the result they have positive incentive than farmers with small plot area (Mengistu and Siegfried, 2012; Tesfaye et al., 2014b; Teshome et al., 2016). This is presumably true in subsistence agriculture, that farmers consider SWC technologies compete for space on small plots, which finally reduces productivity.

The study identifies that farmer's perception regarding erosion problem was significantly but negatively associated with adoption of soil and water conservation practices. The result was contrary to our expectation that with increasing farmers' perception, there expected an increase in adoption of SWC measures. This is because aware farmer has better access to modern innovations and apply on his farm. A similar study reported that farmers' implementation (or rejection) of SWC measures is significantly affected by their perception of soil erosion (Alufah et al. (2012). Implementation of SWC measure has a significant contribution for farmers in reducing soil erosion, improving soil fertility and crop yield of the field. Similarly, Amsalu (2006), in the study conducted in Beressa watershed of Ethiopia, reported positive contribution of farmers' perceptions towards adoption of Soil and Water Conservation measures.

Our finding indicates educational had positively and significantly ($P < 0.05$) influenced farmers' use of improved SWC technologies at 5% probability level. This was inline to our expectation that educated farmers have better exposure to engage in environmental management measure than their uneducated counterpart. Abebe (2015), Fikru (2009), Garcia (2001) and Habtamu (2006) confirmed that household heads with better education status have positive relationship with adoption of improved management measures. As noted by Asrat et al. (2004) educated farmers have better understand about the impacts of soil erosion and the resultant benefits of improved soil and water conservation technologies to rehabilitate the environment than their uneducated counterparts. Some sources also acknowledged the importance of literate farmers, as contact agent for natural resource experts in dissemination SWC technologies in remote localities (Assefa et al., 2016). Hence, it is presumed that the presence of more educated households, the study watershed benefits the community to sustainably manage their environment.

The analysis showed that slope of plot has significant ($p < 0{,}05$ level) positively effect on farmers' adoption of SWC technologies, Earlier studies in different parts of Ethiopia reported a positive and significant effect of plot slope on the decision of farmers to apply soil conservation structures (Abebaw et al., 2011; Beleta, 2017; Mengistu and Siegfried, 2012). Key informant interview results also confirmed similar report. They replied that farmers cultivating on the steep fields are more likely to apply soil management structures than that of gentle field cultivators.

The study result revealed that plot distance was found to have negative and significant ($p < 0.05$ level) influence on farmers' willingness to apply improved SWC measures. Habtamu (2006) identified that distance of farmland has a strong association with the adoption of introduced SWC practice. Furthermore, Simeneh et al. (2015); Tefera & Sterk (2010); Teshome et al. (2016) reported the likelihood occurrence of severe soil erosion at distant plots due to less attention was given to those farms and hence there is a need for improved erosion control measures. Farmer with distant fields are more likely to became discouraged in the adoption options, do not get much attention and received less care for its farmlands (Fikru (2009) and Simeneh et al., 2015).

The result revealed that training related to soil management measures had positive and significant influence on farmers' adoption of improved SWC technologies. The probability of utilizing & implementation skill increased as farmers are more involved in training facility. In line to this Assefa et al. (2016); Tegene et al. (2004) noted that farmers that got training on soil management methods preferably utilize modern management techniques than untrained household heads. Furthermore, better training & knowledge of farmers on the problem of soil erosion can properly & timely manage his farm and increase crop yield Firku (2009).

5. Conclusions

Soil erosion is a serious and persistent environmental challenge in the study watershed. As compared to varying empirical findings from previous scientific studies in Ethiopia, the rate of annual soil loss in Upper Domba Watershed was comparable to the national estimate and even the highest in southern Ethiopia. As noted before the study watershed is among the most degraded parts in Gamo highlands, due to slopy plots farming practice and obsolete soil and water management measures practiced for decades. To rehabilitate soil degradation, mainly soil erosion there is a need to adopt improved soil and water conservation measures and using sustainable watershed management approaches was important practices as reported in the findings. Moreover, educational level, perception of erosion problem, slope of the plot, plot distance to residence, access to training, livestock ownership and plot area significantly and positively influences the likelihood of farmers to adopt improved SWC measures. Despite their expected importance, contact with extension agent, family size, sex and age of household heads were not found to be significant indicators in farmers' adoption of improved SWC practices. Despite the number of traditional land management structures such as contour farming, crop rotation, and hillside terraces employed by study farmers for decades, still, soil erosion remains a severe challenge in the study area. This situation could be addressed by introducing environmental issues in the earlier years of the school curriculum as well as by sustainable land management-oriented adult education. Furthermore, concerned government organs are recommended to work on institutional and environmental dynamics and policy reforms to mitigate and rehabilitate the degraded physical landscapes.

Declarations

Author contribution statement

Teshome Yirgu: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgement

The author would like to thank and appreciate the financial support of Arba Minch University, without their keen support this study cannot be finalized in the present quality.

References

Abate, S., 2011. Estimating soil loss rate for soil conservation planning in Borena woreda of south Wello highlands: Ethiopia. J. Sustain. Dev. Afri 13 (3), 87–106.
Abebaw, S., Penporn, J., Vute, W., 2011. Analysis of factors affecing adoption of soil conservation measures among rural households of gursum district, Ethiopia. Kasetsart J./Nat. Sci. 32, 503–515.
Abebe, G., 2015. Contr. Soil Water Conserv. Prac. 1 (1), 44–58.
Abebe, Z., Sewnet, M., 2014. Adoption of soil conservation practices in North Achefer district, Northwest Ethiopia. Chin. J. Popul. Res. Environ. 12, 261–268.
Adugnaw, T., Dessalegn, D., Mulugeta, A., Seifu, T., 2017. Impact of soil depth and topography on the effectiveness of conservation practices on discharge and soil loss in the Ethiopian highlands. Land 1–18. Retrieved from. https://www.researchgate.net/publication/320845143.
Ahmed, A.A., Ismail, U.H.A., 2008. Sediment in the Nile River System. UNESCO International Hydrological Programme International Sediment Initiative, UNESCO Chair in Water Resources, Khartoum.
Alemayehu, M., Amede, T., Böhme, M.,, Peters, K., 2013. Collective management on communal grazing lands: its impact on vegetation attributesnand soil erosion in the upper Blue Nile basin, northwestern Ethiopia. Livest. Sci. 157, 271–279.
Alufah, S., Shisanya, C., Obando, J., 2012. Analysis of factors influencing adoption of soil and water conservation technologies in Ngaciuma sub-catchement, Kenya. Afr. J. Basic Appl. Sci. 4 (5), 172–185.
Amdihun, A., Gebremariam, E., Rebelo, L., Zelek, G., 2014. Suitability and scenario modeling to support soil and water conservation interventions in the Blue Nile Basin, Ethiopia. Environ. Syst. Res. 3 (2014), 1–13.
Amsalu, A., 2006. Farmers' views of soil erosion problems and their conservation knowledge at Beresa watershed. Central highlands of Ethiopia. Agric. Hum. Values 23, 99–108.
Asmamaw, B., Mohammed, A., Lulseged, D., 2012. Land use/ cover dynamics and their effects in the Gerado watershed, North Eastern Ethiopia. Int. J. Environ. Stud. 68 (6), 883–900.
Asrat, P., Belay, K., Hamito, D., 2004. Determinants of farmers' willingness to pay for soil conservation practices in the southeastern highlands of Ethiopia. Land Degrad. Dev. 15, 423–438.
Assefa, E., Hans-Rudolf, B., 2016. Farmers' perception of land degradation and traditional knowledge in Southern Ethiopia—resilience and stability. Land Degrad. Dev. 27, 1552–1561.
Bedadi, B., 2004. Evaluation of Soil Erosion in the Harerghe Region of Ethiopia Using Soil Loss Models, Rainfall Simulation and Field Trials, Research Report. University of Pretoria, Pretoria.
Belay, A., Eyasu, E., 2017. Challenges and extents of soil and water conservation. J. Agri. Res. Develop. 7 (2), 1–8.
Belay, T., 2002. Land use/ land cover changes in the Derkoli watershed of south Wello zone of Amhara region, Ethiopia. EASSRR 18 (1), 1–20.
Belayneh, M., Teshome, Y., Dereje, T., 2019a. Effects of soil and water conservation practices on soil physiochemical properties in Gumara watershed, Blue Nile Basin, Ethiopia. Ecol. ¦Proc. 2019 (8), 36.
Mengie, B., Teshome, Y., Dereje, T., 2019b. Current extent, temporal trends, and rates of gully erosion in the Gumara watershed, Northern Ethiopia. Global Ecol. Conserv. 24. https://www.Elsevier.com/locate/gecko.
Belete, L.K., 2017. Factors affecting adoption of soil and water conservation practices in the case of damota watershed, Wolaita zone, Southern, Ethiopia. Int. J. Agric. Sci. Res. 7 (1), 1–9.
Best, J., Jame, V., 2007. Research in Education, ninth ed. Dorling Kindersley prv. Ltd, India.
Bewket, W., Teferi, E., 2009. Assessment of soil erosion hazard and prioritization for treatment at the watershed level: case study in the Chemoga watershed, Blue Nile basin, Ethiopia. Land Degrad. Dev. 20 (6), 609–622.
Bezuayehu, T., Sterk, G., 2010. Land management, erosion problems and soil and water conservation in Fincha'a watershed, western Ethiopia. Land Use Pol. 27 (2010), 1027–1037.
Budry, B., Curtis, M.J., Dennis, A.S., 2006. The adoption and management of soil conservation practices in Haiti: the case of rock walls. Agric. Econ. Rev. 7 (2).
Congalton, R., Green, K., 2009. Assessing the accuracy of Remotely sensed data. In: Principles and practices, 3rd edition. Toylar & Francis group. LLC, London.
Constantin, C., 2006. Statistical Principles in Experimental Design. McGraw-Hill, New York.
Creswell, J., 2012. Educational Research: Planning, Conducting, and Evaluating Quantitative and Qualitative Research.
Dawen, Y., Shinjiro, K., Taikan, O., Toshio, K., Katumi, M., 2003. Global potential soil erosion with reference to land use and climate changes. Hydrol. Process. 17, 2913–2928. Wiley-Interscience. www.interscience.wiley.com.
Fikru, A., 2009. Assessment of Adoption of Soil and Water Conservation Practice in Koga Watershed, Highlands of Ethiopia. Unpublished Master Thesis. Cornell University, Faculty of Graduate School.
Food & Agricultural Organization, F.A.O., 2006. Food & Agricultural Organization of United Nations. 'Explaining success in reducing under nourishment numbers in Ghana. FAO, Rome, Italy.
Food and Agriculture Organization, FAO, 2003. Digital Soil Map of the World. Land and Water. Food and Agricultural Organization, Rome.
Ganasri, B., Ramesh, H., 2015. Assessment of soil erosion by RUSLE model using remote sensing and GIS. A case study of Nethravath basin. Geo. Sci. Front 7 (6), 953–961.
Garcia, Y.T., 2001. Analysis of farmer decision to adopt soil conservation technology in Argao. In: Cramb, R.A. (Ed.), Soil Conservation Technologies Fo Rsmall- Holder Farming System in the Philippine Uplands: Asocio-Economicevaluation. ACIAR, Canberra, Australia.
Gashaw, T., Tulu, T., Argaw, M., 2017. Erosion risk assessment for prioritization of conservation measures in Geleda watershed, Blue Nile basin, Ethiopia. Environ. Syst. Res. 6 (1), 1–14.
Gebre silasie, S., 2016. Land: Land policy and small holder agriculture in Ethiopia. Policy Brief, 001/Feb. 2005.
Gulden, K.U., Nesser, G., 2013. A study on multiple linear regression analysis. J. Soc. Behav. Sci. 106 (2013), 234–240.
Habtamu, E., 2006. Adoption of Physical Soil and Water Conservation Structure in Anna Watershed, Hadiya Zone, Ethiopia. Addis Ababa University, Addis Ababa, Ethiopia.
Haile, G.W., Fetene, M., 2012. Assessment of soil erosion hazard in Kilie catchment, East Shoa, Ethiopia. Land Degrad. Dev. 23, 293–306.
Haregeweyn, N., Tsunekawa, A., Posen, J., Tsubo, M., Meshesha, D.T., Fenta, A.A., Nyssen, J., Adgo, E., 2017. Comprehensive assessment of soil erosion risk for better land use planning in river basins: case study of Upper Blue Nile River. Sci. Total Environ. 574, 95–108.
Hurni, H., 1985a. Soil Formation Rates in Ethiopia, Soil Conservation Project, Working Paper 2. Ministry of Agriculture, Addis Ababa, Ethiopia.
Hurni, H., 1985. Erosion productivity conservation systems in Ethiopia. In: Proceedings of the 4th International Conference on Soil Conservation, November 3-9, 1985. Maracay, Venezuela, pp. 654–674.
Hurni, H., 1990. Degradation and conservation of soil resources in the Ethiopian highlands. In: Messerli, B., Hurni, H. (Eds.), African Mountains and Highlands: Problems and Prospective. Walsworth Press, USA, pp. 51–63.
Hurni, H., Abate, S., Bantider, A., Debele, B., Ludi, E., Portner, B., Yitaferu, B., Zeleke, G., 2010. Land degradation and sustainable land management in the Highlands of Ethiopia. In: Hurni, H., Wiesmann, U. (Eds.), With an International Group of Coeditors: Global Change and Sustainable Development: a Synthesis of Regional Experiences from Research Partnerships, Vol 5. Perspectives of the Swiss National Centre of Competence in Research (NCCR) North South. University of Bern, Bern, pp. 187–207.
Hurni, H., Zeleke, G., Debebe, B., 2015. Saving Ethiopian soil. In: Ehrenspergerott, A.C., wiesmann, U. (Eds.), Eastern and South Africa partnership programme. center for Development and Environment, University of Bern, Switzerland, pp. 27–30.
Kassie, M., Zikhali, P., Manju, r K., Edwards, S., 2009. Adoption of sustainable agriculture practices: evidence from a semi-arid region of Ethiopia. Nat. Resour. Forum 33, 189–198.
Kertez, A., 2009. The global land degradation and desertification. Hangar. Geogr. Bulet. 58 (1), 19–31.
Kibret, K., Fanuel, L.A., 2015. Soil Spatial Variability Analysis, Fertility Mapping and Soil Plant Nutrient Relations in Wolaita Zone, Southern Ethiopia. Doctoral Dissertation. Haramaya University.
Kothari, C.R., 2004. Research Methodology: Methods & Techniques. New Age International, New Delhi.
Kouli, M., Soupios, P., Vallianatos, F., 2009. Soil erosion prediction using the revised universal soil loss equation in a GIS framework, chania, Northe western Crete, Greece. Envion. Geol. 57, 483–497.
Lewis, B., 1997. Doing Your Research Project, A Guide for First-Time Researchers in Education and Social Science, third ed. Open university press maidenhead Philadelphia, USA.
Mekuria, A., Hienimann, A., Zeleke, G., Wurno, H., 2020. Factors influencing the adoption of physical soil and water conservation practices in the Ethiopian highlands. Int. Soil Water Conserve. Res. 6 (1), 22–30.
Mengistu, K., Siegfried, B., 2012. Determinants of adoption and labor intensity of stone-terraces in Eastern highlands of Ethiopia. J. Econ. Sustain. Dev. 3 (5). ISSN 2222-1700.
Ministry of Agriculture, MOA, 2016. Guideline for Development Agents on Soil and Water Conservation in Ethiopia. Center for Development and Environment, CDE. University of Bern, Switzerland. www.cde.unibe.ch.
Morgan, R.P., 1995. Soil Erosion and Conservation, second ed. Longman, Essex.
Morgan, R.P.C., 2005. Soil Erosion and Conservation, third ed. Blackwell publishing, Oxford.
Pasquale, B., David, A., Larissa, F., 2013. An assessment of the global impact of 21st century land use change on soil erosion. Nat. Commun. 8, 1–13.
Paul, V., Quang, B., Lulseged, T., 2010. Assessment of Land Degradation, its possible causes and threats to food security in Sub-Saharan Africa. In: Rattan, L., Stewart, B. (Eds.), Food Secur. Soil Qual., vol. 3. Taylor and Francis Group, New York, pp. 58–86.
Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R., Blair, R., 1995. Environmental and economic costs of soil erosion and conservation benefits. Science 267, 1117–2112.
Senseman, G.M., Bagley, C.F., Tweddale, S.A., 1995. Accuracy Assessment of the Discrete Classification of Remotely-Sensed Digital Data for Land Cover Mapping. Construction engineering research lab (army) champaign IL.
Simeneh, D., Getachew, F., 2015. Perception of farmers towards physical soil and water conservation structures in Wyebla watershed, Northwest Ethiopia. Acad. J. Plant Sci. 12 (1), 57–63.
Taddese, G., Saleem, M.M., Astatke, A., Ayaleneh, W., 2002. Effect of grazing on plant attributes and hydrological properties in the sloping lands of the East African highlands. Environ. Manag. 30, 406–417.

Tefera, B., Sterk, G., 2010. Land management, erosion problems and soil and water conservation in Fincha watershed, western Ethiopia. Land Use Pol. 27, 1027–1037.

Tenge, A., De-Graaff, J., Hella, 2004. Factors influencing adoption and continued use of long-term soil and water conservation measures in West Usam- bara high lands, Tanzania. J. Land Degradat. Dev. 15, 99–114.

Temesgen, G., 2015. Soil erosion in Ethiopia- extent, conservation efforts and issues of sustainability. PJ palgo J. Agri. 38–48.

Temesegen, G., Taffa, T., Mekuria, A., 2017. Erosion risk assessment for prioritization of conservation measures in Geleda watershed, Blue Nile Basin, Ethiopia. Environ. Syst. Res. 6 (1).

Tesfaye, A., Negatu, W., Brouwer, R., Zaag, P., 2014. Understanding soil conservation decision of farmers in the Gedeb watershed, Ethiopia. Land Degrad. Dev. 25, 71–79.

Teshome, A., de Graaff, J., Ritsema, C., Kassie, M., 2016. Farmers' perceptions about the influence of land quality, land fragmentation and tenure systems on sustainable land management in the north western Ethiopian highlands. Land Degrad. Dev. 27, 884–898.

Teshome, Y., Govindu, V., Yibeltal, Y., 2021. Land Use/Cover Dynamics and its Impact on the Rural Livelihood of Potter Households, Gamo Highlands, Ethiopia. Environment, Development and Sustainability. Springer Nature.

Tilahun, A., Takele, B., Endrias, G., 2001. Reversing the degradation of arable land in the Ethiopian Highlands. Manag. Africa's Soil. 23, 1–29.

Van Genderen, J.L., Lock, B.F., 1977. Testing land-use map accuracy. Photogramm. Eng. Rem. Sens. 43 (9), 1135–1137.

Williams, J., 1995. The EPIC model. In: J, W. (Ed.), Watershed Hydrology, vol. 4. University of Texas, Texas.

Wischmeier, W.H., Smith, D.D., 1978. Predicting rainfall erosion losses, a guide to conservation planning. In: Agric. Hand B. No. 537. US Department of Agriculture, Washington, DC.

World Bank, 2007. The population and agriculture and environment nexus in sub–Saharan Africa. World Bank, Washington, DC.

Yuan, L., Yang, G., Zhang, Q., Li, H., 2016. Soil erosion assessment of the Poyang lake basin, China: using USLE, GIS and remote sensing. J. Remote Sens. GIS 5 (3).