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Soil Loss and Its Impact on Crop Productivity Under Varying Land Uses in Demba-Gofa District, Southern Ethiopia

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Abstract

Soil erosion is the main cause of land degradation in Ethiopia and annually several tons of soil is removed away from the highlands. Thus, the purpose of this study is assessing soil erosion rates under various land uses and identifying the main contributing factors in Demba-Gofa woreda. A multistage random sampling approach was used to identify the research subjects. Questionnaire, key informant interview, FGDs, and field observations were used as data collection instruments to identify the major contributing factors of soil erosion in the studied woredas. Finally, the application of RUSLE model predicted that the lowest annual rate of soil loss observed at forest land is approximately 5.43 t ha-1 year, -1 whereas the highest amount of soil loss in crop land was about 36.01 t ha-1 year-1 and followed by in the grass land 22.10 t ha-1 year-1 and in the shrub land 11.29 t ha-1 year-1. The analysis of multiple linear regression model predicted that deforestation activities, educational level of farm household heads, mismanagement of cultivated lands, perception of local farmers on soil erosion, land size, farm distance, and slope of the land were found to significantly aggravates soil erosions at $p <$ 0.05 level. Land sat satellite image with Arc-GIS 10.3 analysis for the last 15 years (2000-2017) of the three rural kebeles indicated that a total of 489.4 ha (56.3%) forest land was converted into shrub and grasslands. Thus, the national and the local governments should focus on reforestation, awareness creation on soil erosion and how farmers manage farmlands.

***Keywords**: Soil erosion, natural resource degradation, RUSLE, Demba-Gofa*

Introduction

Soil erosion is one of the most serious environmental challenges faced by human society (David, 2006). It is a form of land degradation caused by both natural and human factors. Land degradation, especially soil erosion, continue to be a widespread environmental problem in the world challenging agricultural production. For instance, about 10 million hectares of cropland are lost each year in the world due to soil erosion (Pimentel & Burgess, 2013). Globally soil is being lost from agricultural areas 10 to 40 times more rapidly than the rate of its formation and is thus impacting human food security (Pimentel & Burgess, 2013).

Regarding Africa, soil erosion is one of a serious environmental challenges obstructing the efforts of poverty reduction. Faster population growth, poor resource endowment, military and political conflict, and agriculture biased macro-economic policy initiated the decline of the natural resource base on which the livelihood of the rural population depends and resulted in chronic poverty in most parts of the continent (Pender et al., 2006). The efficiency of agricultural land has declined by 50% due to soil erosion and desertification, and yield reduction due to soil erosion is estimated to range from 2 to 40 % with the mean of 8.2 % for the continent (Eswaran et al., 2001).

Assan and Beyene (2013) reported that, about 2 to 4 billion tons of fertile soils are annually removed and between 20,000 to 30,000 hectares of agricultural lands are converted into unproductive wastelands due to land degradation in the form of soil erosion in the northwestern highlands of Ethiopia. Based on field assessment of rill and inter-rill erosion, Haile and Fetene (2012) estimated that about 97.04 % of Kilie catchment, East Shoa, has 0–10 Mg ha^{1} yr^{-1} soil erosion rates. A study conducted by Abate (2011) in Borena district of south Wello estimated the rate of soil loss due to soil erosion to be between 10 Mg $ha^{-1}yr^{-1}$ and 80 Mg $ha^{-1}yr^{-1}$. Around 75% of the total area of the Gerado catchment, northeaster Ethiopia was found to have rates of soil losses which were above 25 Mg ha^{1} yr^{-1}

The estimation of soil erosion typically involves the use of empirical models; Revised Universal Soil Loss Equation (RUSLE) is one of the most commonly applied models (Erol et al., 2015). The available data on modelling soil erosion with the RUSLE have shown that the model is applicable for specified conditions (Adugna et al, 2015). This model reveals that soil erosion is greatest on cultivated land (Gimenez-Morera et al., 2010). They reported that due to soil erosion, Ethiopia losses USD 1 billion yr^{-1}. Erosion could also generate deposition of soil materials in the reservoirs, irrigation schemes, and waterways downstream (Adugna et al., 2015). Moreover Adugna et al., (2015) in their studies in northeast Wollega found that the annual rate of soil loss is in the range of 4.5 Mg $ha^{1}yr^{-1}$ in forest land and 65.9 Mg ha^{1} yr^{-1} in cropland. The rate of soil loss in the cropland, which accounts for about 69 % of the total soil loss in the study area, is very highly severe. Hence, soil erosion assessment under varying land uses and investigation of its exacerbating factors should be the most important and primary task of academicians.

Statement of the problem

Soil erosion in the form of sheet-wash, rill, and gully formation seriously destroys agricultural lands and affects rural livelihoods in many highland regions of Ethiopia. For instance, Belay and Bewket (2012a) found out that 82,692 tons of fertile soils were lost, 4.7 ha of agricultural lands were damaged, and the livelihood of more than 3 % of the people in eight villages was affected in one cropping year due to gully erosion in the northwestern highlands of Ethiopia. On average, about 1.26 mm of soil depth or 16 tons of soils per hectare were annually lost due to sheet-wash in the mentioned villages (Belay & Bewket, 2012b).

In Ethiopia, soil erosion is the most important land degradation process that affects the physical and chemical properties of soil resulting in on-site nutrient loss and off-site soil sedimentation. Previous studies by Haile and Fetene (2013) suggested that high rates of soil erosion in the country is mainly exacerbated by various factors such as extensive deforestation due to the prevalence of high demand for fuel wood collection, over grazing into steep land areas, topography (steepness slope), intensity of seasonal rain fall, and bad farming practices with deplete plant cover. Population growth and the intensification of agriculture production also results in high erosion rates (Haile & Fetene, 2013).

Unless appropriate measures are taken to prevent soil in the different landscapes, the intensive agriculture carried to meet the increasing demand for food will increase soil erosion in the country (Mekonnon et al., 2013). Thus, soil erosion assessments in the various land uses and the most contributing (exacerbating) factors of soil erosion as well as conservation measures are priority areas that need investigating (Kropfl et al., 2013). Owing to soil erosion hazards, the Government of Ethiopia and non-governmental organizations have commenced different soil conservation measures since 1970s (Mekonnen et al., 2013). However, many studies noted that the implemented structures were unsuccessful among the small holder farmers (Ndah et al., 2015).

According to Gofa-Zone Agricultural and Rural Development Department's (GZARDD, 2020) annual report, soil erosion is a severe problem in Demba-Gofa district due to lack of proper mechanism to control erosion caused by the heavy rain fall; traditional means of flowing,
structure of the slope, and poor practice of new physical and biological soil and water conservation technologies. The physical conservation structures are expensive and labor intensive for the farmers to reduce the challenges of soil erosion. Prevention of soil erosion relies on selecting a practical and inexpensive as well as effective and easily manageable soil protecting schemes. Since soil erosion is a critical problem in the area different land management measures have been implemented; particularly, since the past ten years using free farmer labor campaigns to reduce the challenge of soil erosion and improve rural livelihoods. Thus, the soil erosion assessment in the various land uses and its contributing (exacerbating) factors have not been well established in physical or economic terms, although there have been many attempts to do so in the study area. Hence, there is knowledge gap to intervene.

Study area and Methods

Description of the study area

The study was conducted in southern Ethiopia, in Gofa Zone at Demba-Gofa woreda. Demba-Gofa woreda is located between 6°15′ 28″ to 6° 22′ 0″ N latitude and 36° 50′ 15″ to 36° 56′ 35″ E longitude (Fig. 1). For this study, six Rural Association Kebeles (RAKs) namely Dakisho-Subo, Karicho-Mella, Yale-Dakisho, Zelele, Suka, and Tsala-tsamba were taken based on their agro-ecological variation and physiographical setup or slope condition to represent the selected woreda. They are located in the northern, north-eastern, and south-western parts of Sawla town (the centre of Gofa-zone) and located at about 558 km south-west of Addis Ababa (the capital city of Ethiopia). Demba-Gofa is bordered on south by Zala and Oyida woreda, on the east by Qucha and Zala, on the west by Geze-Gofa woreda and on the north by Geze-Gofa and Mello-Gada woreda (BoFED, 2019; Tesfaye, 2017).

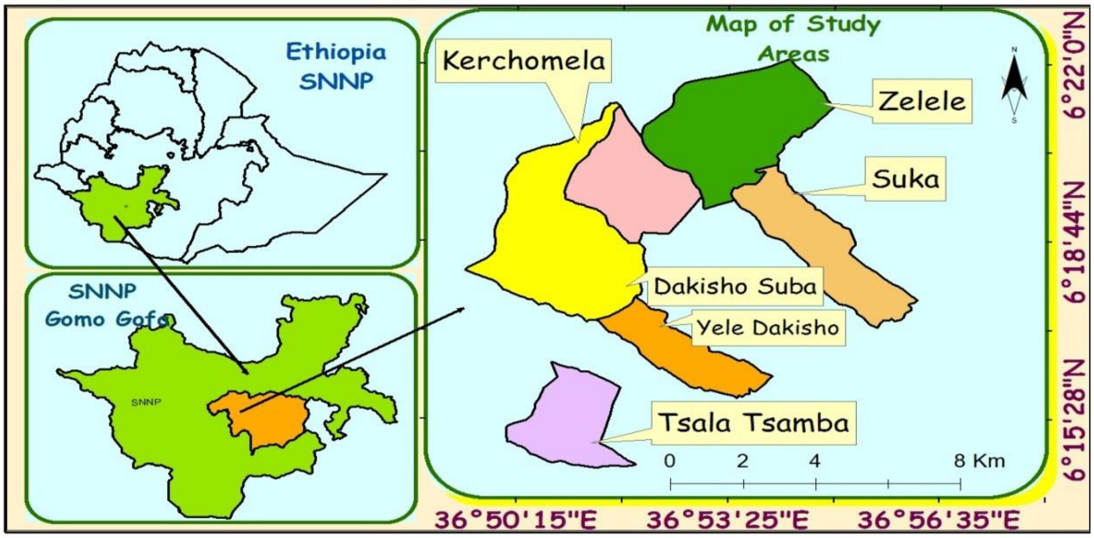

Figure 1: Location map of the study area

The typical geology of the study area is the result of the Trapp series lava flow of the Tertiary volcanic eruptions. The landscape features of the Woreda include mountains, undulating terrains, plains, and rugged surfaces accounting for 16%, 25%, 54% and 5% of the total area correspondingly. Elevation in the area ranges from 800 to 2560 meters above mean sea level (BoFED, 2019). According to BoFED (2019) report, Demba Gofa woreda is classified as highland (7.8%), midland (15.8%) and lowland (76.4%) agroecology zones. The annual rainfall ranges between 1050 mm to 2000 mm (ENMSA, 2017). The mean annual temperature ranges from 25 to 35.1 degree centigrade (°c). The average daily maximum and minimum temperatures are 30.3 ˚C and 14.8 ˚C, correspondingly (ENMSA, 2017). The relative varied geology, relief, climate, land use, and land cover of Demba-Gofa woreda favored the development of various soil types. Vertisols (black clay soils), luvisols (light brown soils), nitosols (red or reddish-brown laterite soils), cambisols (dark brown soils), leptosols (lighter shallow soils occupying steeper slopes) and cresols (grey clay soils) are the major soil groups in the woreda.

The natural vegetation of the study woreda was predominantly composed of different carissa edulis, acacia bussies, eucalyptus camaldulensis, sesbania sesban, grevillea australia, cordial Africana and dodonea which used to reduce environmental degradation. The main activity carried out in the study area is mixed farming. The major crops growing in the woreda include sorghum (Sorghum bicolor), maize (Zea mays), teff (Eragrostis teff), favabeen (Vicia faba), lentils (Lens culinaris), wheat (Triticum vulgare), chickpea (Cicer areetinum), linseed (Linumusit atssimum), and barley (Hordeum vulgare). Maize and sorghum are the main staple crops; chick-pea is grown using moisture held in clay soils after the rainy season in the middle landscapes of the woreda. Livestock husbandry is practiced through traditional practices inherited from indigenous knowledge.

Research Methodology

Research design, approaches and data sources

For the purpose of this study concurrent mixed method research approaches involving cross-sectional and longitudinal designs were employed to generate and analyze data. The mixed research approach is preferred for this study because it gives an opportunity for researchers to use both quantitative and qualitative data collection and methods of data analysis in order to address the issue under investigation (Creswell, 2012). Both primary and secondary sources of data were collected from different sources. Primary sources of data were gathered from 283 household heads using questionnaire surveys. Peter and Zuzanna (2017) reported that it is advised to have a group of about 6 to 12 people in FGDs in participatory research. A group of more than 12 participants can be difficult to facilitate and less than 6 participants may not be a reliable representation of the community. Due to this a total of 30 purposively selected FGD (10 at each kebele) were selected for this study. Additionally, 12 key informant interviews and participatory field observations were used to gather primary data.

Secondary sources of data (demographic, crop data, and other related information were collected from Demba-Gofa Agricultural Rural Development Office (DGARDO) and Gamo-Gofa Zone Agricultural Rural Development Department (GZARDD) in May, June, and October 2020. Recorded rainfall data (for 1981-2016) was taken from the Ethiopian National Meteorological Service Agency (ENMSA, 2017). To accomplish this study, the researchers employed a mixed research approach. It is a procedure for collecting and analyzing both quantitative and qualitative data side by side (Creswell, 2012).

Sampling techniques and sample size determination

In this study, multi-stage systematic random sampling technique was employed to select the research subjects. In the first stage among 6 rural woreda in Gofa Zone, Demba-Gofa was selected purposively for it is an ideal area of different land management structures adopted to reduce the prevalence of soil erosion, for its accessibility, and because it is an erosion prone area compared to the rest of the rural woredas. In the second stage 37 Rural Kebele Administrations (RKAs) (found in Demba-Gofa woreda) are clustered in to high severe (12 kebeles), severe (12 kebeles) and medium severe (13 kebeles) in terms of their land degradation risks and various land management structures they are practicing to reduce soil erosion problems. Following this six RKAs namely, Dakisho-Subo and Karcho-mella (high severe) group, Yale-Dakisho and Zelele (severe) group and Suka and Tsala-tsamba (medium severe) group were selected using simple random sampling methods.

Finally, from the stratified list of rural kebele association offices a total of 283 household heads (from Dakisho- subo 45, from Karcho-mella 40, from Yale-Dakisho 79, from Suka 47, from Tsala-tsamba 39 and from Zelele 33) were selected using the proportional-to-size allocation method in a systematic way from the list of 749, 687, 1340, 797, 638, and 536 total household heads of the corresponding RKAs. Household heads were systematically identified at an interval of ten from the stratified list of the households. The required sample size was determined using a simplified formula provided by Yamane (1967), as follows: -

$$n = \frac{N}{1 + (N * e^2)}$$

Where n is the sample size, N is the total household heads, and e is the level of precision (9%).

$$n = \frac{N}{1 + (N * e^2)}$$ ‘n’ is 283.

Finally, participatory field observations supported with visual photographs were undertaken during the survey time in March, April, and May 2020. The participatory field tours enabled the researchers to observe the topographic features of the study kebeles, soil erosion signs, and the main exacerbating factors of soil erosions in the study area.

Data Analysis Techniques

After collecting relevant information from primary and secondary sources, the data was analyzed and interpreted with the help of different statistical tools. Information generated using the questionnaire surveys from household heads were coded, classified, grouped, and systematically fed in to SPSS version 21. Finally, the complied data was analyzed by using descriptive and inferential statistical tools. Households' demographic and socio-economic characteristics were analyzed with the help of percent, mean, and standard deviations. In this study, multiple linear regression models was employed to analyze factors exacerbating the rate of soil erosion. Before analyzing factors that aggravated the rate of soil erosion with multiple liner regression models, VIF (Variance Infliction Factors), tolerance value, and the Condition Index (CI) of explanatory variables were evaluated to know the associations between explanatory variables. Qualitative data obtained from FGDs, key informant interviews, and participatory field observations was analyzed concurrently in narrations to triangulate empirical data. The Revised Universal Soil Loss Equation (RUSLE) model was employed to estimate the amount of annual rate of soil loss due to soil erosion factors. Land sat satellite image with Arc-GIS (10.3) was employed to analyze the bio-physical dynamics of the study area.

Model Specification

Multiple linear regressions model

It is vital for demonstrating and analyzing several variables. The multiple regression analysis extends regression analysis by describing the relationship between a dependent variable and several independent variables (Constantin, 2006). The main purpose of this analysis is to know to what extent the rate of soil erosion is influenced by various independent variables like age of household heads (x_1), sex of the household heads (x_2), educational level (x_3), family size of household heads (x_4), perception of farmers on soil erosion (x_5), slope of the farm lands (x_6), land size in hectare (x_7), contact with development agent (x_8), deforestation activities (x_9), mismanagement of cultivated lands (x_{10}), and proximity farm lands (x_{11}) and what measures should be taken. The functional form of the relationship between dependent variable (soil erosion) and explanatory variables of this study was illustrated as follows:

$Y = B_0 + B_i X_i + \ldots B_n X_n + e_i$ Where Y = dependent (response) variable

X_i = independent (explanatory) variables B_i = the parameters

e_i = Random term /disturbance term which represents all other factors that have effect on the rate of soil erosion

Spatial Image Processing

Map of the land use/cover situation of the area was mapped from Land sat Multispectral Scanner (MSS) and Land sat Thematic Mapper + (LTM) data in Arc-GIS software. Arc-GIS tool was employed to investigate the biophysical dynamics of the study areas. At first, images were transformed to a common Universal Transfers Mercator (UTM) and geo-referenced to datum that Ethiopia has already selected by World Geodetic System (WGS-84). The images were enhanced using histogram equalization to improve the image quality. The image classification was done over the last 30 years at 15 years interval. The land cover and use change of the study area analyzed four major land use types of mainly vegetation, crop land, shrub land, and grasslands. Digital Elevation Model (DEM) was also produced from this image, which is important to generate slope gradient (%).

Estimation of Annual Soil Loss

Annual rate of soil erosion loss is estimated using Revised Universal Soil Loss Equation (RUSLE) model (Adugna et al., 2015; Wall, et al., 2002; Hurni, 2005). This model is based on a well-known and extensively used erosion model and takes as input the five main factors (Rainfall erosive, soil erodibility, cover management, topography (slope length and steepness), and support practices), which are modeled using the most recently available pan-European datasets (Adugna, et al., 2015). Therefore, RUSLE model was employed by the researchers in order to estimate the amount of annual soil loss rate in the study area:

$A = R * K * L * S * C * P$

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 $t\ h\ MJ^{-1}\ mm^{-1}$, L is the slope length factor, S is the slope steepness factor, C is the cover and management factor, and P is the support practice factor.

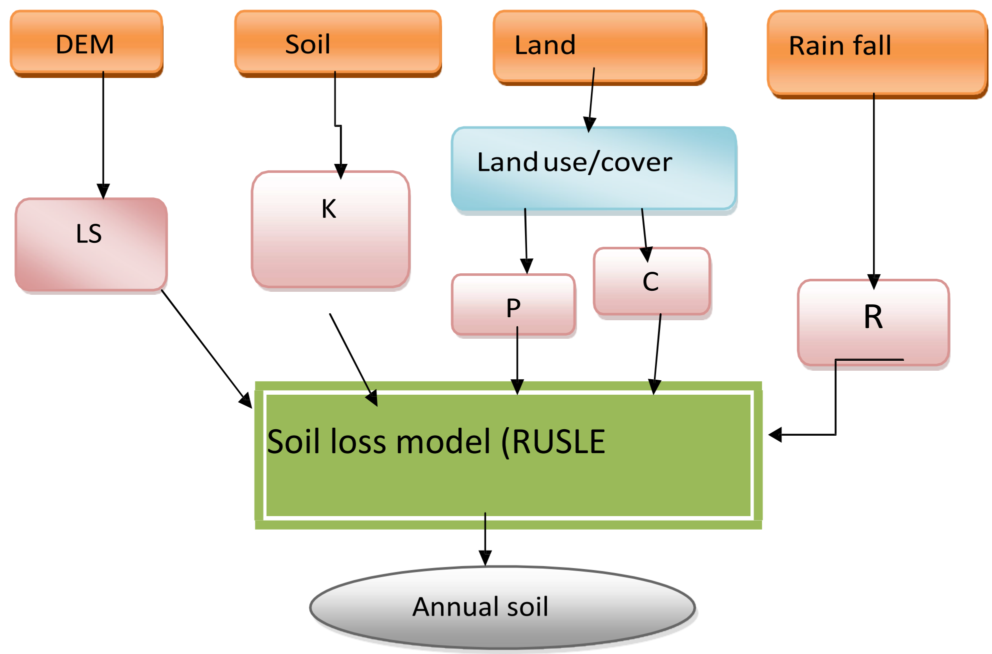

Fig. 2. Flow chart of annual soil loss based on RUSLE and GIS application

Rainfall erosivity factor (R)

For the purpose of this study monthly recorded rainfall data from the Ethiopian National Meteorological Service Agency (ENMSA, 2017) Sawla meteorological station covering the period from 1981-2016 were used to calculate the erosivity value for each storm. The erosivity factor R was calculated using the equation given in Hurni (1985a) that estimates "R" factor value from annual total rainfall based on the Ethiopian condition which has been derived from spatial regression analysis. Therefore, the R-factor is given by a regression equation as:

$R = -8.12 + 0.562\ P$

Where R is the rainfall erosivity factor and P is the mean annual rainfall (mm year−1). Similarly, research findings by Amsalu and Mengaw (2014) employed these methods to determine Rainfall erosivity (R) facto.r

Soil erodibility factor (K)

The soil erosivity factor is described as the rate of soil loss per unit of R-factor on a unit plot (Adugna et al., 2015; Wall, et al., 2002; Hurni, 1985). Soil factor "K" can be calculated using key soil parameters such as texture, organic matter, structure and permeability (Adugna et al., 2015). Review of literature by Adugna et al., (2015) and Amsalu and Mengaw (2014) noted that “K” is the resistance of soil to erosion and often represents soil loss per unit of R and given in Mg ha −1 for one unit of metric “R”. For this study, from the major land use categories of three kebeles, a total of 240 soil auger-holes from the forest (60), from the grassland (60); from crop land (60) and from shrub land (60 auger holes) at the higher, the middle, and at lower slopes of these land uses were taken. These 108 soil samples from field nested plot were sent for test to soil laboratory. The 108 soil samples collected by a grid of 5m x 5m on the top soil (0-30 cm) and soil samples for the analysis were collected from at the center and at edge-center of each grid.

The 108 soil samples were used to determine the physical and the chemical soil properties: mainly soil texture, organic matter content, permeability, and structure of the soil. The evaluation of the soil samples were performed based on the standard laboratory procedures. Particle size distribution was analyzed using the hydrometer method (Gee and Bauder, 1986) while soil organic matter content was predicted with the help of wet combustion method (Nelson and Sommers 1982). During our field observation, soil structure was assessed based on soil structure assessment kit information to know the soil structural class code. Following this soil structural class code was known with the help of observed shape and size of soil structures as extrapolated from the USLE nomograph (Wischmeier and Smith, 1978). But the soil permeability class code was determined from soil textural classes, which are encoded from the textural triangle based on the observed soil texture (Boorman, et al., 1995). The values were delivered regarding to K value ranges given in similar studies (Wall et al., 2002; Wischmeier and Smith, 1978).

Slope length and steepness factor (LS)

Slope length together with the steepness of the slope showed the effect of slope length and slope steepness on soil loss. Meaning that slope length (L) is the distance between the beginnings of run-off water to where soil deposition occurred. During field work (March and May, 2020), the researchers measured representative slope lengths from the major land/ use categories. These are from crop land 200 m slope length, from grass land 100 m, from shrub land140m, and forest land 230 m slope lengths respectively. Therefore, the length of slope (L) was calculated based on

Wischmeier and Smith (1978) formula as follows:

L= (X/22) 0.5; where X is the slope length collected or recorded from field measurements Whereas slope angle (S) was calculated from Digital Elevation Model (DEM) in the Arc-GIS (10.3) from flow accumulation number of cells contributing to flow in to a given cell and slope angle S in percentage was calculated by: S = 0.0138 + 0.0097s + 0.00138s2 (A.H. Kassam, 1992). S stands for the general accustomed slope angle and s is slope gradient in percent. Therefore, slope length and steepness (LS) factor is computed with the combined results of the length of the slope (L) multiplied by slope gradient S in (%).

Crop cover and management factor (C)

Crop management factor for different land use was derived from Land sat MSS (Multispectral Scanner) and Land sat Thematic Mapper (+) data and analyzed and mapped using the Arc-GIS (10.3) based on land use and land cover maps and their attribute data analysis. The (C) factor is the ratio of soil loss from land with specific vegetation to the matching soil loss from incessant flow (Wischmeier and Smith, 1978). The crop cover and management factors are used to decide the effectiveness of soil and crop management systems with respect to control of the prevalence of soil loss. For our study, four land use cover classes were identified. These land use categories are forests (vegetation), shrub lands, crop (mainly cultivation) lands, and grass lands (Fig.4). Valuation of these categories of land use cover was made separately for each land classes according to Hurni (1985) which was developed to suit the Ethiopia condition as shown in Fig. 4 and Table 5.

Support practice factor (P)

The support practice factor (P) is defined as the ratio of soil loss under a specific soil conservation practice (e.g., contouring, terracing) to that of a field with upslope and down slope tillage. Scholars in the field of this study stated that the P factor is mechanical practices such as the effects of contouring, strip cropping, or terracing and the resultant average annual soil loss rate due to water erosion (Yahya, et al., 2013). From our field observations, the dominant soil erosion control practices across the study kebeles are soil and stone bunds, crop rotation, contour farming, strip cropping, and hillside terraces. Agro- forestry and management structures like area closers are occasionally practiced across each RKA. Therefore, evaluating the P factors for our study was based on Hurni (1985) which developed to the Ethiopia condition noted that 0.9 was given for cultivated lands, contour farming, strip cropping hillside terraces and 0.8 the other land cover types as shown in Table 6.

Variables used in in the analysis

The dependent variable (soil erosion) takes the level of soil erosion with response to farm household heads on their farm lands (plot): 1= no erosion on the plot; 2 = slightly erosion; 3 = moderately soil erosion on the plot; 4 = severer soil erosion on the plot. Factors exacerbating the rate of soil erosion are influenced by age of household heads, educational level, sex of the household heads, family size, farm (plot) size, farmers' perception on soil erosion, slope of farm lands, distance (proximity) of farm lands, deforestation activities, contact with development agents, and mismanagement of cultivated lands. A total of 11 predictor factors were chosen by referring soil erosion assessment literatures (Table 1).

Table 1 Descriptions of independent variables

Explanatory variables	Level of measurement	Expected sign	Sources
Age of household head in years	Continuous		
	Positive		
Sex of the Household Head	Nominal	+ve	Tiwari et al. (2008); Fikru (2009,
Krishna et al. (2008),			
Educational level of the household heads	Ordinal	+ve	Tiwari et al. (2008); Fikru (2009) Family size of
household heads in number	Continuous	+ve	Wagayehu and Lars, 2003 Perception of the
Farmers	Nominal	-	
ve/+ve	Krishna et al. (2008),		
Slope of the Farm Land	Continuous	-	
ve/+ve	Wagayehu and Lars,		
2003			
Land size in hectares	Continuous	-	
ve/+ve	Amsalu		
	(2006);		
	Bekele	and	
Holden (2007)			
Contact with Development Agent	Ordinal		Krishna et al. (2008),
Deforestation	Ordinal	-ve	Semu (2018) Mismanagement of cultivated
lands	Ordinal		Damene et al., (2013) Proximity of Farm
Land		-	
ve/+ve	Wagayehu and Lars		
(2003)			

Results and Discussion

Rainfall erosivity factor

The rainfall erosion factor to account for the erosive power of rain is related to the amount and intensity of rainfall over the year or a factor established by blowing energy from rain drop per storm event, kinetic energy of rainfall, and maximum 30-minute rainfall intensity (Asmamaw and Mohammed, 2017; Adugna, et al., 2015; Wall, et al; 2002; Hurni, 1985). To calculate the R factors for this study, the mean annual rainfall data for 30 years (1981-2016) was collected from Ethiopian National Meteorological Services Agency (2017) of Sawla station. The mean annual rainfall is 1782.36 mm. Owing to this, the computed rainfall erosivity R factor was 993.56 MJ mm ha−1 h −1 yr−1. Due to the absence of rainfall intensity in the study area, the researchers computed the R factors according to the equation proposed by Hurni (1985). The computed R factor is higher and indicated higher erosivity of rainfall to erode the soil and high rainfall intensity in the study area. This finding is supported by Asmamaw and Mohammed (2017).

Table 2 Mean annual rainfall and R-factors of Sawla meteorological stations

StationMean annual rainfall (mm) (1981–2016)	1782.36
R-factor MJ mm ha^{-1} h^{-1} yr^{-1} Sawla	993.56

Soil Erodibility Factor

The K-factor accounts the influence of soil properties on soil loss during storm events on upland areas (Adugna et al., 2015; Wall et al., 2002). Different literature review indicated that there are various methods of estimating the K factors such as soil texture, permeability, soil structure, and organic matter content (Wall et al., 2002; Wischmeier and Smith 1978). To compute soil erodibility factor (K) for this study, soil parameters such as texture, organic matter, structure and permeability were used. The soil erodibility (K) of each land use/cover type is computed based on Wischmeier and Smith (1978) as follows:

$K\ (factor) = 2.77 * 10^{-7} (12 - OM) M^{1.14} + 4.28 * 10^{-3} (s - 2) + 3.29 * 10^{-3} (p - 3),$

Where: M = [(100 − C) (L + Armf)]; and C is % of clay (< 0.002 mm); L is % of silt (0.002–

0.05 mm); and Armf is % of very fine sand (0.05–0.1 mm); OM is the organic matter content (%), p is a code indicating the class of permeability and s is a code for structure size.

Table 3: Soil texture, organic matter content, permeability, soil structure, and estimated values of soil erodibility (K) factor in the study area

Land use/cover type	Top soil texture class and (%)			Organic matter (%)	K value
	Clay loan	ilt	Fine sand		
Forest (plant vegetation)	62	7	21	10.1	0.18
Shrub land	34	9	47	3,2	0.37
Crop land	15	6	49	5.5	0.22
Grass land	32	5	33	8.4	0.22

Note that: Code class of soil permeability and structure size is 4 and 1 respectively

As indicated in Table 3 above, the soil erodibility (K) factors for different land use in the study area ranges from o.22 to 0.37 t h MJ−1 mm−1. The soil erodibility (K) factor in the forest was 0.18 t h MJ−1 mm−1 while in the shrub land was found to be 0.37 t h MJ−1 mm−1. The K factors of crop land and grass land were predicted as 0.22 t h MJ−1 mm−1 in each (Table 3). The K factor in the forest land use is lower compared to the other land use categories in studied area due to this land category’s more organic content that may enable lower K-factor whereas the soil erodibility (K) factors of crop land, grass land, and shrub lands are greater compared to the forest land use (Table 3). The result of soil erodibility (K) factor of the study area is similar with the finding of El-Swaify (1992) which reported K factors from 0.06 to 0.48 t h MJ−1 mm−1 for tropical soils. According to FAO (1984) report, most of Ethiopian soils K factor ranges from

0.05 to 0.6 t h MJ−1 mm−1.

Slope length and steepness factor

During the field observation different land cover/uses were measured and documented. For example, 200 m slope length from crop land (cultivated land); 100 m from grassland, 140 m from shrub land, and 230 m slope length from the vegetation or the forest land were measured to estimate (LS) factors. Therefore, the length of slope (L) of land use category is computed with (X/22) 0.5 where X is slop length (based on Wischmeier and Smith1978) formula. Whereas the slope steepness (the gradients) in percent is computed with S = 0.0138 + 0.0097s+ 0.00138s2 and extrapolated based on Hurni (1985) to Ethiopia's condition.

Table 4: Slope length (L) and its factor and slope class, gradient (S) (%) and S factor

Factor Slope length (m) L	L factor	Class	Slope gradient (%)	S factor
100 (grass land)	2.5	Grass land	2-8	0.99
140 (shrub land)	2.5	Shrub land	8-15	1.00
200 (crop land)	2.5	Crop land	< 2	0.5
240 (forest land)	3.8	Forest land	15-30	1.00

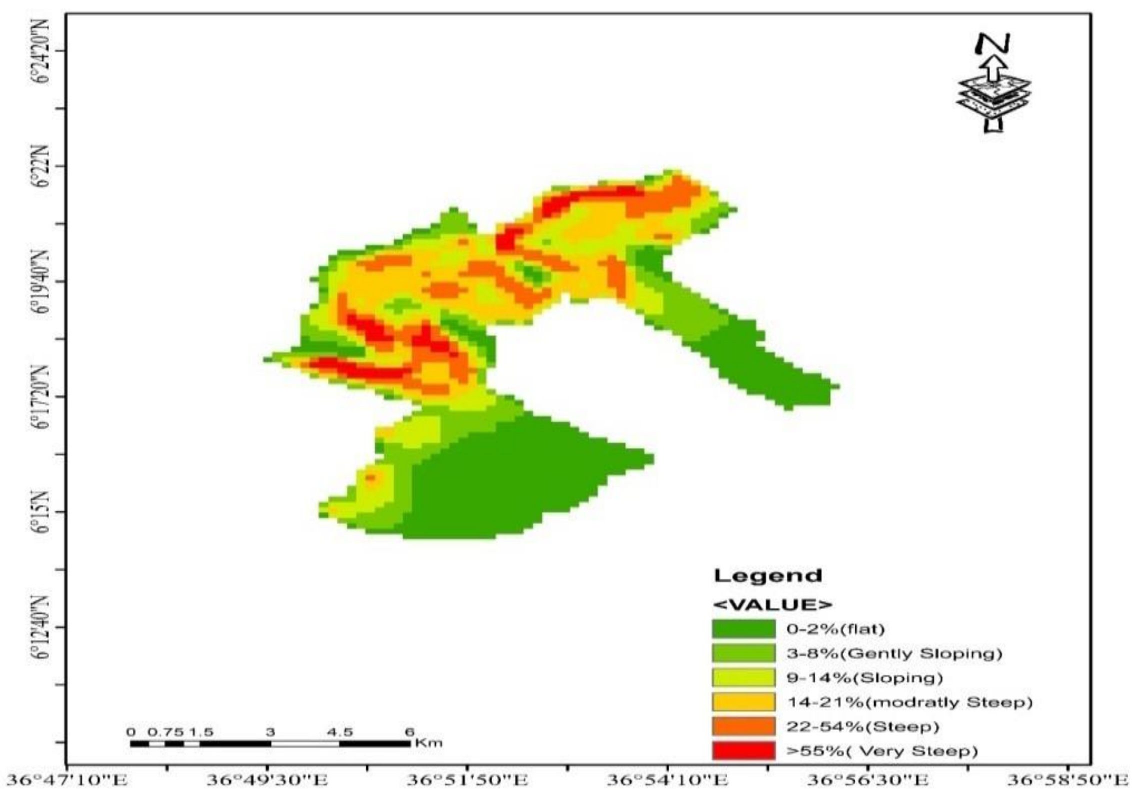

Figure 3; slope classes of the study areas

Land Cover/ use and management factors

According to the image classification result of the study area, four land use and land cover images were identified as crop land, forest, grass land, and shrub land (Fig 4). The share of land coverage showed that crop land was the largest proportion which accounts (29.3%) followed by shrub land which accounts for (28.36%) and the forest and grasslands that account for (23.85%) and (12.47%) respectively (Fig.4 and Table 5). The average value of the cover management factor (C) in the study area is 0.056. The maximum C factor was observed in crop lands and showed that the prevalence of soil erosion in this land category may be greater than the other land uses (Table 5). The cover and management factors (C) was extrapolated based on Hurni (1985); Wischmeier and Smith (1978) and Soil Conservation Research Program (SCRP, 2002) database on Ethiopian conditions.

Table 5 Land use and cover management factor map of the study area

Land-use type	Area in ha	Area %	C factor
Forest land	1508.84	23.88	0.01
Shrub land	1790.74	28.36	0.014
Crop land	1850	29.30	0.15
Grass land	787.27	12.47	0.05

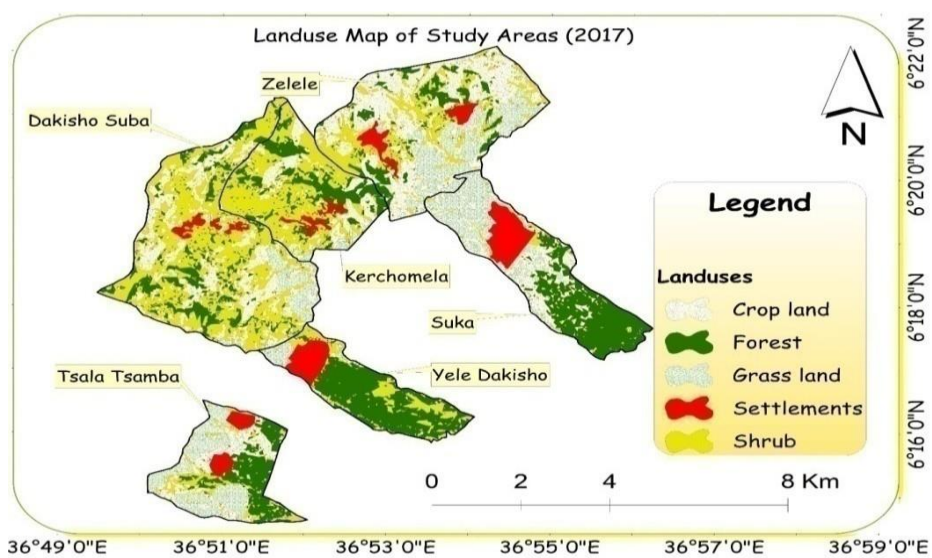

Fig 4. Land use and cover map of the study area (2017)

Support practice factor

The land use classification and the slope categories of the studied area were given in figure 4 and 3 respectively. Therefore, the P value was determined according to Hurni (1985) as Ethiopian condition (Table 6). Following this 0.9 was given for cultivated lands and 0.8 for the other land cover types as shown the table below.

Table 6: Support practices of the study area

Land-use type	P factor
Forest land	0.8
Shrub land	0.8
Crop land	0.9
Grass land	0.8

Estimation of Mean Annual Soil Loss

The average annual soil loss estimated by RUSLE model from the study area as rainfall erosivity R factor was 993.56 MJ mm ha^{-1} h^{-1} yr^{-1} and the K factors, L factors, S factors, C and P factors were computed as different land cover/use categories above. According to the model (RUSLE) the range of annual rate of soil loss in the study area was 5.43 t ha-^{1} $year^{-1}$ to 36.01 t $ha^{-1}year^{-1}$ (Table 7). As indicated in the table above, annual rate of soil loss in the forest was 5.43 t ha^{-1} $year^{-1}$; in the grass land was 22.10 t ha^{-1} $year^{-1}$; in the shrub land was 11.29 t ha^{-1} $year^{-1;}$ and in crop land was 36.01 t ha^{-1} $year^{-1}$. The RUSLE model estimated that the highest annual rate of soil loss was observed in the crop land and is followed by the grass land and shrub lands respectively (Table 7).

The lowest annual rate of soil loss observed in the forest land may be due to this land category's high amount of organic content and its ground's coverage by plant residuals that reduce the rate of soil erosion. The maximum rate of soil loss in the crop land implies that the rich top soil in cultivated land was removed by water erosion and crop productivity in the studied area was affected by soil erosion. As indicated in the above table, almost 29.3% of the total land cover/use was covered by crop lands and the maximum annual rate of soil loss was prevailing in this land category. Therefore, land management or conservation measures should be given priority this land cover/use categories.

Table 7 Mean Annual Soil Loss rate and severity classes of the study areas

LULCC	Soil loss (t ha-^{1} year^{-1}) class	Severity (ha)	Area	Coverage in (%)
Forest land	5.43	Low	1508.84	23.88
Shrub land	11.29	Moderate	1790.74	28.36
Crop land	36.01	Very High	1850	29.30
Grass land	22.10	High	787.27	12.47

The maximum annual rate of soil loss (36.01 t ha-1 year-1) in the study area was grouped under very high severity class based on (Wall et al., 2002) severity class (> 33 t ha-1 year-1). This annual rate of soil loss was totally higher than the tolerable soil loss of 18 t ha -1 year-1 estimated for Ethiopia condition by Hurni (1985). This implies that integrated land management practices with stakeholders should be done to minimize the prevalence of soil erosions. As compared to the annual rate of soil loss from cultivated fields by Hurni (1990, 1993) estimated about 42 t ha−1 year−1; the annual rate of soil loss on crop lands 65.9 t ha−1 year−1 in northeast Wollega by Adugna, et al., (2015), the annual rate of soil loss in this study finding was lower. Regarding the minimum annual rate of soil loss (5.43 t ha-1 year1) in the study area, it was more than two times the minimum soil loss tolerance value by Hurni (1985) in Ethiopian condition. Generally, the result of this study indicated that the amount of soil loss from a given unit of land is high. This could be due to high population, deforestation activities, inappropriate use of cultivated lands, lack of proper use of the newly installed agricultural land management structures and low perceptions on soil erosion.

Farmers' response on the contributing factors of soil erosion

Among the numerous factors that exacerbate the prevalence of soil erosion in the studied kebeles, the prevalence of deforestation, mismanagement of cultivated lands, educational level of household heads, and the slope of farm lands were found to be the major factors rated by (65 %,), (62 %), (58 %) and (51 %) of the sample population respectively (Table 8). Moreover, farmers' perception on soil erosion and farm size also exacerbated the occurrence of soil erosion in the studied kebeles. These were considered as the next 5th and 6th most exacerbators of soil erosion as rated by (48.4 %) and (43 %) of the sample population. Proximity (distance of the plot) rated by (41 %) sample respondents, contact with Development Agent (34 %), and family size rated by (27 %) of respondents were found to be other factors for the prevalence of soil erosion (Table 8). According to the participants of focus group discussion and key informant interviews, deforestation (mainly for fuel wood purpose), unwise use of cultivation lands, educational level of farm household heads, slope of farm lands, and farmers' perception on soil erosion are the principal drivers of soil erosion in the studied areas.

Table 8 Farmers' response on the contributing factors of soil erosion on their farm plots

Contributing factors	Frequency	
Deforestation Activities	185	
		5.4
Farm Size of Household Heads	121	
		3
Mismanagement of Cultivated Lands	175	
		2
Farmers' Perception on Soil Erosion	137	
		8.4
Proximity (Distance of the plot);	115	
		1
Contact with Development Agent	97	
		4.3
Family size	75	
		7
Age of household head	94	
		3.2
Sex of the household heads	67	
		4
Educational level of the household heads	165	
		8.3
Slope of farm land	145	
		1.2

Source: Field survey (2020)

Note: percentage adds up to more than 100 because of multiple responses.

Regression Model Results

To predict the major factors contributing to soil erosion (dependent variable), it was analyzed with 11 explanatory variables (namely deforestation activities, mismanagement of farm/cultivated lands, perception of local farmers on soil erosion, farm land size, farmers level of education, age of household heads, slope of farm lands, distance of farm land (plot), family size, sex, and contact with development agent) by using multiple linear regression model. Before analyzing factors aggravating soil erosions with multiple liner regression model, VIF (Variance Inflations Factors), tolerance value, and the Condition Index (CI) of explanatory variables were evaluated. According to Gulden and Nese (2013) and Morgan et al. (2004) report in regression model, if the tolerance value greater than ($1-R^2$) or the tolerance value is higher than 0.10, the VIF is less than 10, and the calculated value of CI is less than 30, it indicates that there were no relationships among explanatory variables. Owing to these assumptions, the tolerance value of all variables in the model were greater than ($1-R^2 = 0.459$) and their VIF were less than 10 (Table 9). Finally based on this assumption the results were analyzed.

Using the SPSS program kit in the case of multiple linear regression model, out of 11 possible contributing explanatory variables analyzed, the coefficients of seven variables (deforestation activities, mismanagement farm cultivated lands, educational level of household heads, slope of farm lands, perception of local farmers on soil erosion, farm land size and farm (plot) distance) were found to be significantly associated with soil erosions in the studied kebeles while the rest four explanatory variables (households contact with Development Agents, age of household heads, sex, and family size) were found to have insignificant influence on soil erosions in studied areas (Table 9). The model showed that deforestation activities are the highest positive determining factors (Table 9).

Table 9: Regression Result of variables

Coefficients							
Model	Un standardized Coefficients		Standardized Coefficients	T	Sig.	Co-linearity statistics	
	B	Std. Error	Beta			Tolerance	VIF
Constant	18.127	14.201		8.203	0.001		
Age of household heads	5.019	11.039	-.028	-1.397	.620	.626	1.596
Family size households	6.139	9.075	.095	1.843	.466	.525	1.904 2.019
Sex of household heads	.991	7.508	.148	0.079	.282	.497	
Farm/land size	-.176	7.054	.285	-3.276	.041	.700	1.428
Farmers perception on soil erosion	-.427	1.129	-.421	-4.317	.021	.771	1.301
Deforestation activities	1.284	.152	.842	9.871	.002	.989	1.011
Mismanagement lands	3.341	.533	.484	5.564	.016	.907	1.102
Educational level	4.096	.174	.753	8.309	.003	.898	1.113
Slope of farm lands	2.178	.478	.519	6.294	.013	.746	1.340
Distance of the farm land	-1.221	.921	-.419	-1.201	.044	.693	1.443
Contact with experts	1.167	8.021	. o87	2.012	.126	.472	2.115

As indicated on Table 10, the goodness to fit (coefficient of determination or the R-squared) which is (0.776) indicates that (77.6%) of the explanatory variables jointly explained the outcome or dependent variable (soil erosion). The rest (12.4 %) is not explained by the explanatory variables.

Table 10 Model Summary

Model	R	R Square[b]	Adjusted R Square	Std. Error of the Estimate
1	.874	.776	.735	1.12991

Model result revealed that deforestation activity performed by household heads had significantly aggravated the rate of soil erosion at ($p < 0.05$) significance level in the study areas.

Deforestation activities are positively associated with the rate of soil erosion in this study. The evaluation of linear multiple regression model parametric indicated that as farmers' involvement in deforestation activities increase by one-unit hectare, the rate of soil erosion increases by a factor of (0.842) keeping the rest independent variables in the model constant (Table 9). As indicated in Fig. 5, the overall land cover classification for 2002 Land sat TM image and Arc GIS 10.3 proved that the share of the forest was almost 1149.3 ha (18.2%), but after 15 years (2017) its coverage was found to be 1508.84 ha (23.88%) (Fig 6). However, though the overall coverage of the forest was increasing, across in Dakisho-subo, Zelele and Karcho-mella kebeles the share of the forest from 2002 to 2017 is alarmingly declining (Fig. 6). For example, in 2002 the coverage of the forest in Dakisho-subo was 483.48 ha (27.8%), Zelele was 314 ha (21.3%), and the share of Karcho-mella was 322 ha (36.5%), but after 15 years (2017), its coverage alarmingly declined and found to be 256.41 ha (14.7%) for Dakisho-subo, 162.99 ha (11.1%) for Zelele, and 210.88 ha (23.87%) for Karcho-mella (Fig.6). The figure indicated that in 15 years across in the mentioned three kebeles, a total of 489.4 ha (56.3%) forest land was converted in to the other land uses.

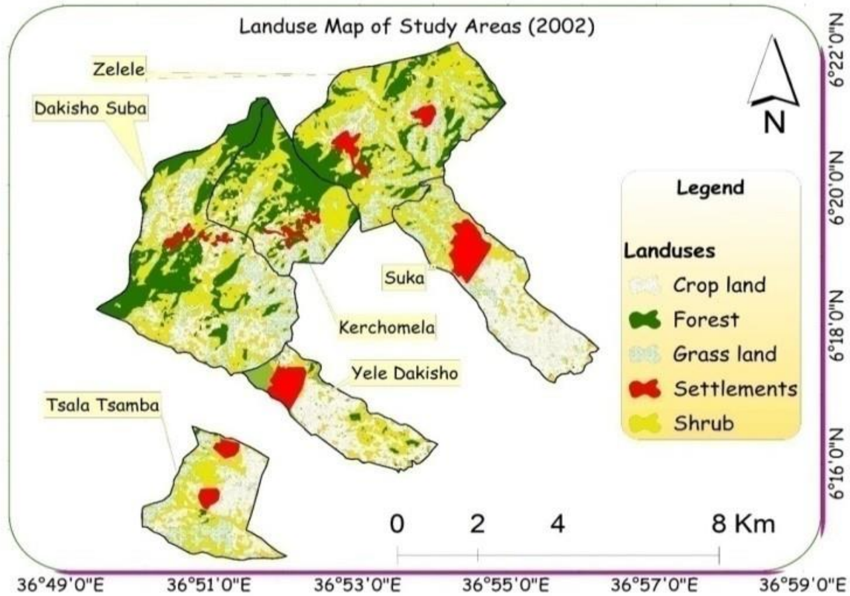

Figure 5 Forest coverage of the study area (2002)

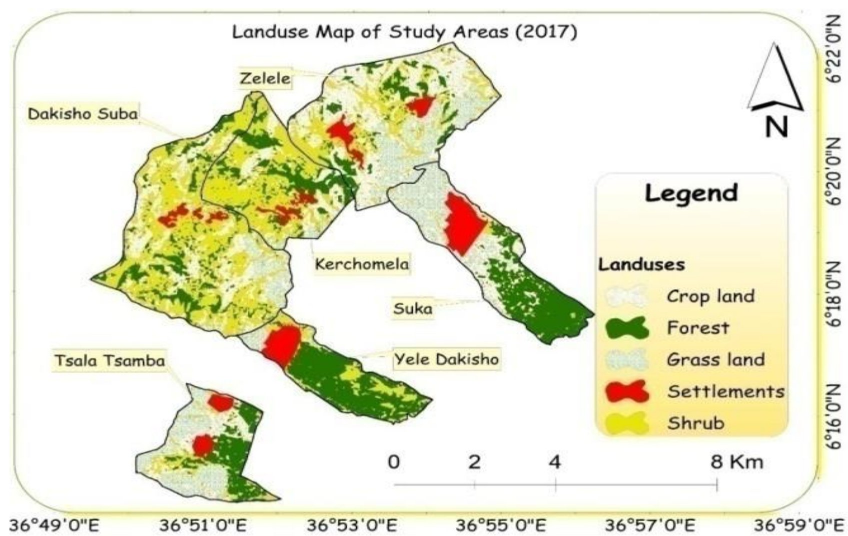

Figure 6 Forest coverage of the study area (2017)

Similarly, studies such as ELD Initiative (2019), Semu (2018), Damene et al. (2013), Lestrelin et al. (2012), Alebachew (2006), and Hurni et al. (2005) reported that withdrawal of the forest (vegetation) cover from soil are the principal drivers that increase natural rates of soil erosion.

Farm size of household heads: the estimations of linear multiple regression models show that farmers land holding negatively influenced the rate of soil erosion. This variable is significant at

($P < 0.05$) probability level inferring that as the size of land holding of the household heads decrease by one hectare, the probability of soil erosion will increase by the factor of (-.285) considering other explanatory variables in the model constant in the study area. Land is the most potential natural resource for crop production, and therefore household heads who have small farm size may involve in cultivating the margin of their lands and this exacerbates the rate of soil erosion. Research finding in the related studies of Bekele and Holden (2007) and Amsalu (2006) noted that household heads having small size (farm land) may allow risk of the marginal lands because farmers tilled this land resulting in the aggravation of soil erosion. On the other hand, these authors reported that farmers having large farm size can't bear risking loss of cultivation land to conservation structures and are hence expected to influence adoption of structures negatively which in turn aggravates the rate of soil erosions.

Mismanagement of cultivated lands: as indicated in the regression model output of mismanagement of cultivated land (harmful agricultural management practices) positively and significantly aggravates the prevalence of soil erosion. The variables significant at ($P < 0.05$) probability level indicated that as the number of household heads involved in inappropriate agricultural management practices increase, the likelihood of soil erosion will increase by the factor of (.484) keeping other variables in the model constant. The works of Damene et al. (2013), Lestrelin.et al, (2012), Powlson et al., (2011), and Hurni., et al. (2005) also support this. They concluded that inappropriate tillage, repeated cultivation, cultivation on steep slopes, and short fallow periods were some of the exacerbating activities of soil erosion.

Farmers' perception on soil erosion: farmers perception was significantly but negatively influencing the prevalence of soil erosion in the study area. The coefficient of beta (β) shows that as the number of household heads awareness on soil erosion decreases, the likelihood of soil erosion increases by the factor of (-.421). A study conducted in Beressa watershed of Ethiopia by Amsalu (2006) identified farmers' perceptions on SWCP makes it difficult to implement the technologies on their farmlands to minimize the rate of soil erosions.

Educational level of household heads: it is one of the contributing factors of soil removal in different parts of the country. For instance, different literature reviews concluded that as education level of the household heads increases, their understanding on the causes of soil erosion will increase (Abebe, 2015; Fikru, 2009; Tiwari et al., 2008). The model result proved that farmers level of education is positively and significantly related to the rate of soil erosion at ($P< 0.05$) probability level. The beta coefficients for education implies that as the level of farmers education increase in grade, the probability of practicing land management practices to reduce soil erosion increases by (.753) units.

Slope of Lands: - the coefficient of this variable showed that the slope of the land is significant at 5 % level of significance. The linear multiple regression model beta coefficients of this variable (.519) implies that as the slope of farm lands (plot) increase by one-unit hectare, the chance of soil erosion rate increases by a factor of (.519). Similar findings were observed by Belete (2017), Wagayehu and Lars (2003) and Hurni (1988) which proved that increase in the slope of the plots increases land degradation by increasing the speed of soil erosion. The slope of the land increases the constructions of land management structures like terraces, stone and soil bunds gets difficult, and creates the rate of soil erosion to increase.

Distance of farm lands (plot): distance of farm lands (plot) is the distance between the residences of household heads and their farm lands. If the farm land is nearer to his/her home, household head may protect and follow up his/her farm land from erosion risks regularly and vice versa. The beta coefficient of this variable in the model was found negative (-.419) and showed that as the distance of household heads farm increases from their residence, the regular protection of farm lands from soil erosion may decrease by a factor of (-.419). This indicated that farmers may not adopt different land management practices on a faraway plot so as to reduce the rate of soil erosions due to distance. This is consistent with the finding of Simneh (2015) and Amsalu (2006) which noted this is because the time and energy farmers spend to reach farm plots is lesser for nearer farm plots than distant farm plots and also because the closer the plot is to the residence area the closer the supervision and attention.

Conclusion

Soil degradation in the form of soil erosion is a serious and continuous environmental problem in Ethiopia particularly in the highland areas. Therefore, this study assessed the annual rate of soil loss and the fundamental contributing factors of soil erosion in Demba-Gofa woreda, Gofa zone, southwest Ethiopia. For this purpose, valuable data was collected from structured survey of 283 farm household heads, participatory field observation, and key informant interviews, and from FGDs. Meteorological data for 30 years (1981–2016) of the study areas were collected from Ethiopian National Meteorological Services Agency in Addis- Ababa. Revised Universal Soil Loss Equation model was employed to estimate the annual rate of soil loss in the different landscapes of the study area. While multiple linear regression model was employed to estimate the main contributing factors of soil erosion. The land use/cover situation of the area was mapped from Land sat Multispectral Scanner (MSS) and Land sat Thematic Mapper + (LTM) data in Arc-GIS (10.3) software. In the final result, the model indicated that annual rate of soil loss ranges from 5.43 t ha^{-1} $year^{-1}$ in the forest land and 36.01t ha^{-1} $year^{-1}$ in the crop land. The minimum and maximum annual rates of soil loss are experienced on forest cover and cropland, respectively. The maximum annual rate of soil loss on cropland revealed that the most productive top soils that contained organic minerals and related substances were removed annually by soil erosion. The maximum rate of soil loss on cropland is higher than the maximum tolerance of soil loss in Ethiopia by Hurni 1985. The annual rate of soil loss in the cropland which accounts 29.3% of the total soil loss in the study area is grouped under very high sever classes. Thus, this proved that this land use categories should be given priority to implement land management activities at initial stage compared to the others land categories.

Results from multiple linear regression analysis proved that deforestation activities, educational level of farmers, mismanagement of farm/cultivated lands by farmers, and the slope of the farm (plot) significantly and positively contributed the rate of soil erosion. Whereas distance of farm lands, farm size, and farmers perception on soil erosion significantly but negatively exacerbated the rate of soil erosion in this study. During the participatory field observation and responses of household heads, a number of land management structures such as contour farming, crop rotation, stone and soil bunds, hillside terraces, afforestation, and area closure were being implemented to reduce soil erosion. But soil erosion is a severe problem in the study area. Therefore, there due attention should be given to the problems by the concerned bodies so as to reduce the problems and rehabilitate the degraded physical landscapes.

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