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Original Research

An assessment of soil erosion risk by water and conservation practices in *Dilla* watershed of Blue Nile basin

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Abstract

The main objective of the study was to assess the susceptibility of different parts of Dilla watershed to soil erosion by water and to explore the conservation interventions being practiced The Dilla watershed is part of the Dabus catchment in the Eastern Blue Nile basin located in mid-west region of Ethiopia. The soil erosion risk was assessed using the Revised Universal Soil Loss Equation (RUSLE) and the micro-watersheds were prioritized for SWC interventions accordingly. Geo-spatial datasets such as Digital Elevation Models, temporal satellite imageries, topographic maps were entered into the model for obtaining spatial erosion risk values. Conservation interventions were explored by field visits, interviews, focused group discussions and ancillary data. The model revealed that the total and mean annual soil loss in the watershed is 17,688 and 95 t/ha^{-1}/y^{-1} respectively. Based on the estimated soil erosion rates, the micro- watershed was prioritized for conservation intervention and nine micro-watersheds with severe erosion risk were identified that may be used as planning units. The results from interviews and group discussions have shown that both the farmers and the local experts considered soil erosion as a major problem constraining land productivity. The local experts in the study area were delineating micro-watersheds for soil and water conservation through field observation by examining the topography and drainage of each locality in the watershed. Prioritization for conservation measures is done based on trend analysis, visual observation, and reports from Development agents (DAs) working in the study watershed. The research concludes that under the conditions of the present situation in the study area, priority should be given to those watersheds, which have been severely affected by soil erosion, and the traditional way of delineating micro-watersheds and means of identifying erosion-prone areas should be augmented by empirical geo-spatial methods. These methods provide reliable estimation of soil erosion rates and prioritization of micro-watersheds for treatment.

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INTRODUCTION

Soil erosion by water is the most prevalent form of soil degradation and this problem is severe in the tropics and sub-tropics compared to the rest of the regions on the Globe (Eaton, 1996; Lal, 2001).

It is a dominant form of erosion in humid and sub-humid regions characterized by frequent rainstorms. It is also a problem in arid and semi-arid regions where the limited precipitation mostly occurs in the form of intense storms when the soil is bare and devoid of vegetation cover. (Blanco & Lal, 2008). In Africa, about 5Mg ha^{-1} of productive topsoil is lost to lakes and oceans each year due to soil erosion (Angima *et al.,* 2003) and hence threatening watersheds in tropical regions with intense agricultural use (Sreeja *et al.,* 2015).

Soil erosion by water has been a challenging and unceasing problem in Ethiopia for decades (Hurni 1988; Gete, 2000; Bewket &Teferi, 2009; Kebede et al. 2015; Gashaw*et al.,* 2017) and recognized to be severe threats to the national economy of the country (Hurni, 1993; Tamene, 2005). It is the most pressing environmental problem in the Highlands of Ethiopia where the topography is highly rugged, population pressure is high, steep lands are cultivated and rainfall is erosive (Bewket & Teferi (2009). The soil loss rate by water ranges from 16 to over 300 $Mgha^{-1}$ yr^{-1} in Ethiopia, mainly depending on the degree of slope gradient, type of land cover and nature of rainfall intensities (Tesfaye *et al.*, 2014). In the highlands of the country, the annual soil loss reaches 200-300 tones ha^{-1} $year^{-1}$ (FAO, 1984; Hurni, 1993).

Empirical studies indicate that soil erosion is driven by high population pressure, land shortage and critical lack of resources for conservation by subsistence smallholder-poor farmers (Blanco-Canqui and Lal, 2008), extensive deforestation due to the prevalence of high demand for fuel wood collection and grazing into steep land areas (Amsalu *et al.,* 2007; Haile and Fetene, 2013). Accelerated erosion is also triggered by anthropogenic causes such as deforestation, slash-and-burn agriculture, intensive plowing, intensive and uncontrolled grazing, and biomass burning (Blanco & Lal, 2008).

While erosion is a vital process of soil formation, accelerated erosion adversely affects soil and environmental quality. Indeed, low rates of erosion are essential to the formation of soil. In contrast, soil erosion becomes a major concern when the rate of erosion exceeds a certain threshold level and becomes rapid, known as accelerated erosion and such type of erosion adversely affects soil and environmental quality (Blanco & Lal, 2008). It has far-reaching agronomic, ecologic, environmental, economic, political, and social, effects due to both on-site and off- site damages (Thampapillai & Anderson, 1994; Grepperud, 1995; Blanco & Lal, 2008). Soil erosion not only affects agricultural land but also quality of forest, pasture, and rangeland (Blanco & Lal, 2008). In Ethiopia, despite the considerable efforts made to develop and promote different types of soil and water conservation technologies, acceptance, adoption and sustained use by the land users have not been widespread for various reasons (Amsalu and de Graaff, 2007; Bewket, 2007; Bewket &Teferi, 2009).

Tackling the effects of soil erosion requires an understanding of the rates of erosion processes as well as identification of the major controlling factors that enhance or retard these processes (Brhane & Mekonen, 2009). In order to opt for soil and land conservation measures in a watershed, the proper approach is to identify the high-risk areas at the micro level. For any management plan, the identification of the problematic areas is a prerequisite (Ahmed, 2013). Hence, the objectives of this study was to assess soil erosion risk in *Dilla* Watershed of *Dabu* sub-basin using the RUSLE (Revised Universal Soil Loss Equation) model within a GIS environment, explore local views and conservation practices, and prioritize micro-watersheds for initiating soil and water conservation measures. The RUSLE is an empirical soil erosion model that have been used widely all over the world including Ethiopia (Hurni, 1985; Helden, 1987) because of its simplicity and limited data requirement compared to other similar models.

Several studies have been conducted in different parts of Ethiopia to estimate the total annual soil loss per hectare (Hurni,1985); FAO, 1986); Gete, 2000); Bewket and Teferi, 2009); Gebreyesus and Kirubel, 2009); Abate, 2011); Amare *et al.*, 2014); Tadesse and Abebe, 2014); Kebede *et al.*, 2015); Gizachew, 2015); Gelagay and Minale, 2016); Molla*et al.,* 2017); Temesgen *et al.*, 2017). However, they rarely considered local views on the problem of soil erosion. Further, such kind of problems are site-specific and the result obtained in a one watershed cannot be applied for another watershed. Hence this study provides up-to-date and basic information on the status of soil erosion rate at local level which is essential for sustainable resource management and intervention strategies in the study watershed.

The study area

This study was conducted in *Dilla* watershed of *Dabus* catchment in Eastern Blue Nile basin. *Dilla* watershed lies between 9°00'N to 9°31'N latitudes and 34°57' to 35°36' E longitudes (Fig.1). It forms the Eastern sides of the Upper *Dabus* catchment, which is also part of the Abay/Blue Nile basin in Ethiopia.

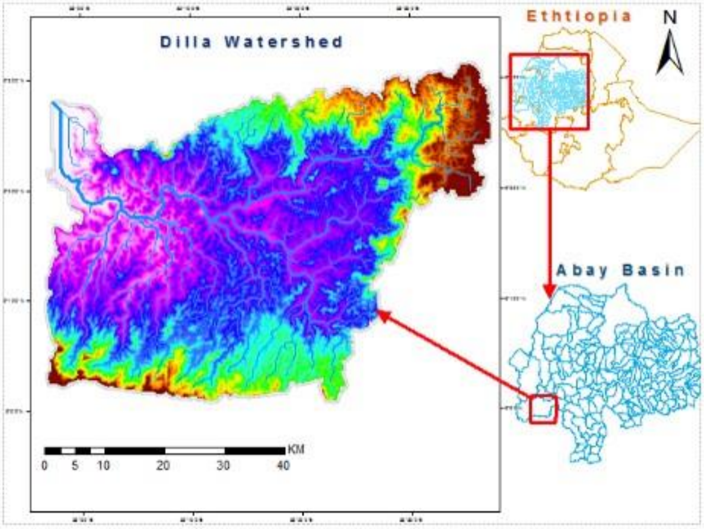


Figure 1 Location map of the study area

The *Dilla* watershed covers an area of 2,798.4km^2. As Table 1 demonstrates, seven *districts* of West Wollega zone, and three *districts* of Qelem Wollega fall in the watershed. Two districts (namely Ayira, Guliso, and Jarso) have more area share in the watershed.

Table 1: Area of districts in the watershed

ID	District Name	Zone	District Area [Km^2]	District area in the watershed [Km^2]	Share in the watershed [%]
1	Ayira	West Wollega	515.9	434.0	84.12
2	Guliso	West Wollega	579.2	442.5	76.40
3	Jarso	West Wollega	471.2	282.8	60.02
4	Boji Cheqorsa	West Wollega	344.3	159.5	46.33
5	Babo Gembel	West Wollega	901.5	360.3	39.97
6	Gawo Qebe	Qellem Wollega	1,173.2	370.3	31.56
7	Boji Dermeji	West Wollega	531.2	167.4	31.51
8	Dale Wabera	Qellem Wollega	802.8	249.4	31.07
9	Nejo	West Wollega	1,004.0	211.2	21.04
10	Dale Sedi	Qellem Wollega	579.1	113.5	19.60

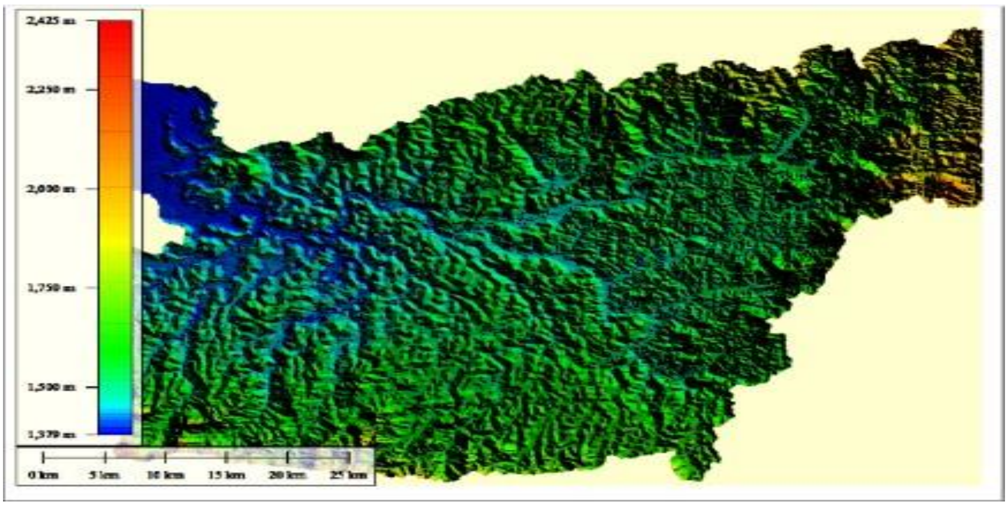


Figure 2 Digital elevation model of Dilla watershed

Figure 2: Depicts that elevation of the watershed varies between 1379m-2425m, and steep and rugged slopes along the upstream ridges and undulating and gentle slopes in the downstream part characterize the topography.

Climatologically, the majority of the watershed area falls under warm sub-humid lowlands with mean annual rainfall that ranges between 1500-2200 mm and mean temperature of 15-30ºC. Mixed crop (cereals, oil seeds, and root crops), livestock and coffee production are the main means of livelihood in the watershed.

MATERIALS AND METHODS

Data sources and usage

Digital Elevation Model (30 m resolution), Landsat satellite imageries, Topographic maps (1:50,000), GIS layers for soil and rainfall data were used for this study. These data were gathered from USGS online archives, Ethiopian Ministry of Water, Irrigation, and Electricity (Mo WIE), Ethiopian Mapping Agency (EMA). The research explored local views on soil erosion and associated problems as well. Data pertaining to observed status of soil erosion, causes and consequences, measures taken to alleviate the problem, techniques used for identifying erosion prone areas and methods used in micro-watersheds prioritization for conservation purpose were all gathered from field observation, in-depth interviews and group discussions held with agricultural and natural resource experts working at different levels in the study watershed. Such data were collected from West Wollega Zone Agriculture and Rural Development Office (Ghimbi) Dale Wabera, Guliso, and Nedjo District Agricultural and Rural Development offices.

The first step of data preparation and analysis performed in this study was delineation of the watershed (Fig.3) This was done with ArcGIS Desktop 10.4.1 version and ArcHydro Tools to quickly and effectively delineate the watershed region and streams from a digital elevation model (DEM 30m) (Tesfaye & Wondimu, 2014).

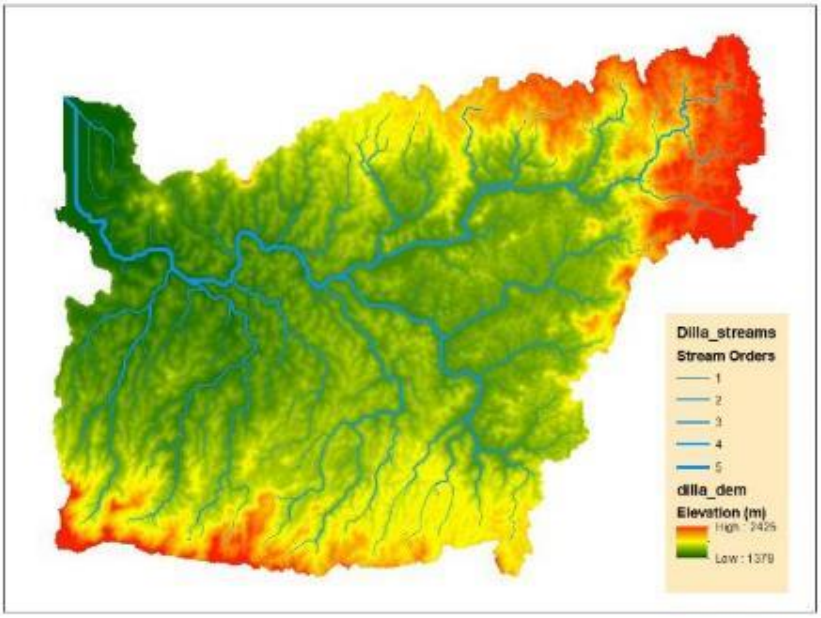


Figure 3: Elevation and Stream Network Map of Dilla Watershed

Computing RUSLE factor values

In order to model annual soil loss, the Revised Universal Soil Loss Equation (RUSLE) was used. It was developed originally to estimate soil losses on agricultural lands, and estimates erosion from rill and inter-ill processes (tons/ha/year). A revised and updated version of the model, the Revised Universal Soil Erosion Equation (RUSLE), allows for more detailed consideration of farming practices, conservation measures, and topography. RUSLE has been embedded into computer software to facilitate its use, but has also been applied using geographic information system (GIS) through raster calculator to calculate erosion rates.

The RUSLE is a factor-based, which means that a series of factors, each quantifying one or more processes and their interactions, are combined to yield an overall estimate of soil loss. Five factors are incorporated to predict annual average soil loss per unit area (A): rainfall run-off erosivity (R), soil erodibility (K), land cover (C), topography – expressed as a combination of length and slope (LS), and conservation practice (P). Values for the factors have been derived from various datasets and are used to compute erosion rates as follows.

$$\boldsymbol{A = R \times K \times C \times LS \times P} \quad \textbf{Equation 1}$$

Where A is given in units of tons per hectare per year

R= Rainfall – runoff erosivity factor

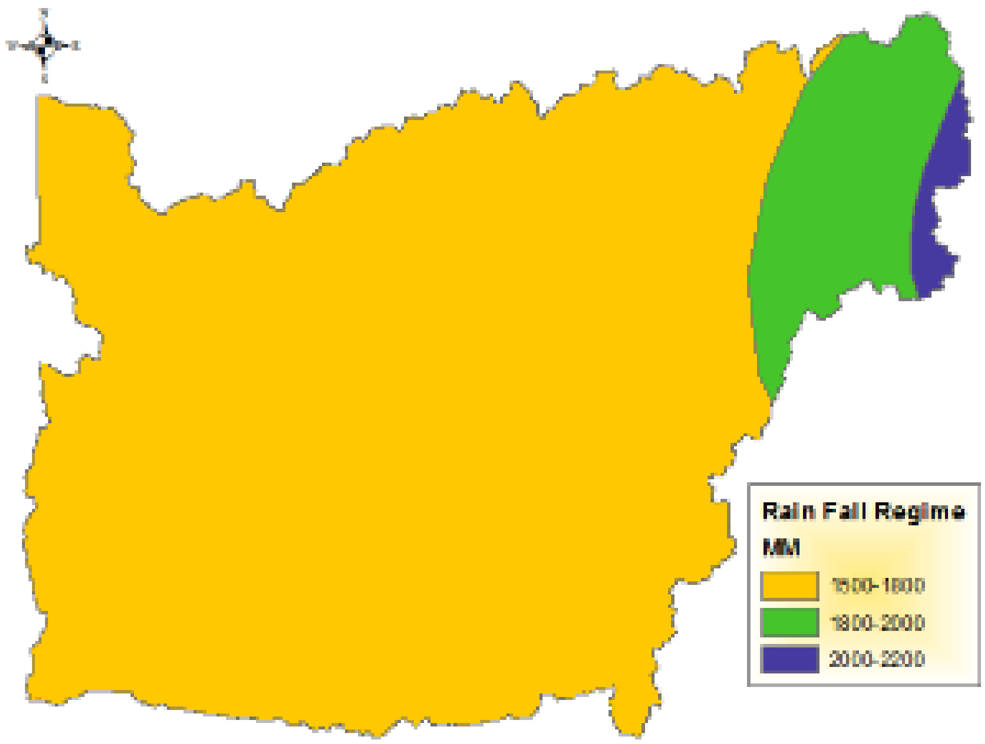
The rainfall run-off erosivity index (R) measures the erosion potential of rainfall. This factor is usually computed using the rainfall energy and the maximum 30 minutes' intensity (EI30). However, such empirical data are not available for Ethiopia and the study area. Hence, a more recent model by Kaltenrieder (2007) which estimate the R factor (Table 2) from annual rainfall amount was adopted in this study.

$$\boldsymbol{R = 0.36X + 47.6} \quad \textbf{Equation 2}$$

Where X is mean annual rainfall in mm.

Table 2 Rainfall and R value distribution in Dilla watershed

ID	MA Rainfall (MM) [X]	R Value [$R = 0.36X + 47.6$]	Area [ha]
1	1500-1800	641.6	249,446.6
2	1800-2000	731.6	266.6
3	2000-2200	803.6	37.3



As demonstrated in Figure 4, rainfall erosivity is higher in the North Eastern margin of the watershed.

K = Soil erodibility factor

The soil erodibility factor measures the resistance of the soil to detachment and transportation by raindrop impact and surface runoff. Soil erodibility is the function of the inherent soil properties, including organic matter content, particle size, permeability, etc. Because these properties vary within a given soil, erodibility (K values) also varies which ranges between 0 and 1. Since data about these parameters are not directly available, erodibility values of the major soils in Ethiopia was extracted from a GIS dataset obtained from the Ministry of Water Resources and Irrigation Development (Table 3)and the K-values are assigned based on the soil type method developed by Soil Conservation Research Project (SCRP, 1996). Hence Fig.5a and Fig. 5b depict the spatial distribution and the respective soil erodibility values of the major soil types in the study area.

Table 1 Major soil types and K values

ID	Major Soil	Area (ha)	K-Value
1	Dystric Cambisols	244,569.6	0.2
2	Pellic Vertisols	7,572.3	0.15
3	Marsh	8,042.3	0
4	Orthic Acrisols	20,398.8	0.15

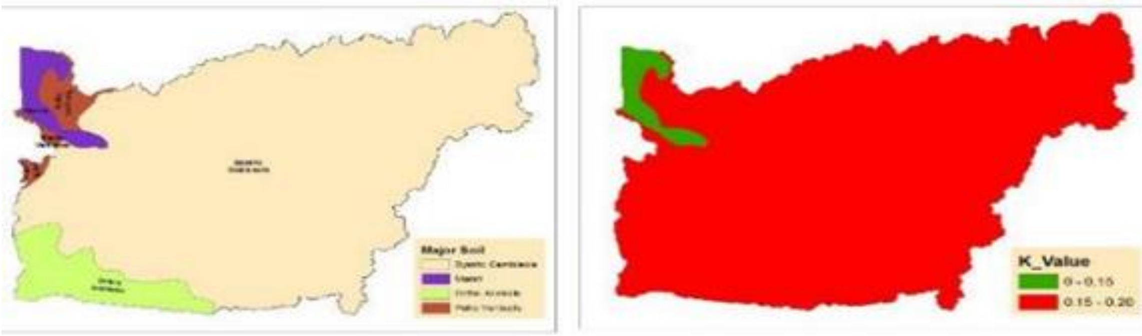


Figure 1 (a) Major Soil Types; and (b) Soil Erodibility or K-value

C = Cover management factor

The land cover factor in RUSLE incorporates the effects of varying vegetation and cover types, tillage practices and other land use types. In this study we have used the Land use/Landcover image/raster layer produced from Landsat 8, 30m resolution, [Path 171 and row 53 and 54 imagery, acquisition date 15 January 2017] downloaded from https://earthexplorer.usgs.gov and seamless mosaicked and clipped for the study area (watershed).

Using ENVI 5.3.1 Image analysis software, six general classes of land cover/land uses were identified with the supervised classification method and maximum livelihood algorithm. The C values are then estimated accordingly (Table 4), and Figure 6a and Figure 6b show the land use/cover and C-Value distribution.

ID	General LULC	Description	C Value	Area (ha)
1	Grassland	- entirely covered by grass - Wooded grassland	0.01	76,675.7
2	Cultivated	-includes all agricultural land such as: Moderate and mixed perennial and annual crops, also includes built-up areas	0.15	77,004.8
3	Woodlands	-Dense woodlands, coffee with shade trees	0.06	119,936.8
4	Bare land	-without significant vegetation cover	0.6	188.3
5	Forest	-Natural forest cover and riverine forest	0.01	217.9
6	Swamp	-Largely wetland with significant water	0.01	5,809.3

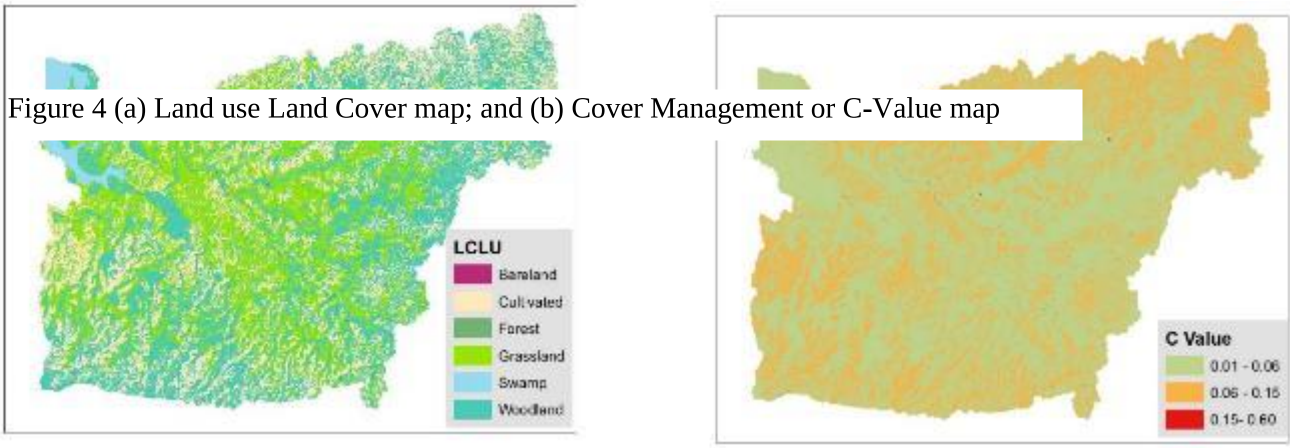


Figure 4 (a) Land use Land Cover map; and (b) Cover Management or C-Value map

LS = Topographic factor

The topographic (LS) factor adjusts erosion predictions to give greater rates for longer (L) and Steeper (S) slopes. There are a number of algorithms available for the calculation of the LS factor. In this study we applied the approach developed by Moore and Burch (1986) as cited in (Hickey, 2000). They derived an equation for estimating LS based on the slope steepness algorithm and the flow accumulation algorithm, both data layers can be derived in GIS application from a digital elevation model using raster calculator. The Moore and Burch LS factor is given by:

$$\boldsymbol{LS} = ([\boldsymbol{Accum}]) \times \boldsymbol{\alpha} \;/\; \mathbf{22.13})^{\mathbf{0.04}} \times (\boldsymbol{sin}[\boldsymbol{Slope}] \;/\; (\mathbf{0.0896})^{1.3} \qquad \textbf{Equation 3}$$

Where $[Accum]$and $[Slope]$ are the flow accumulation and slope grids, respectively, derived in GIS, and α is the length of a grid cell in the DEM. The distribution of LS values in the study area is demonstrated in Figure 7.

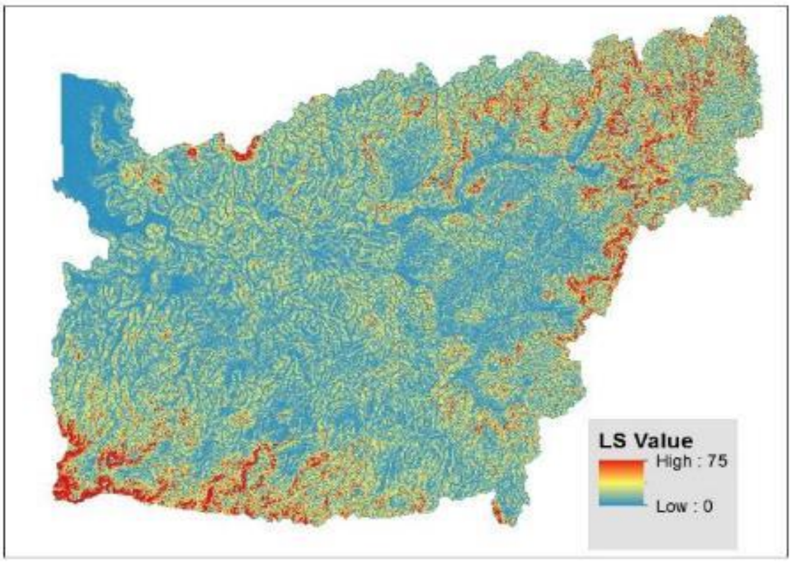


Figure 5 Slope Length and Steepness or LS Value

P = Erosion control practice (P)

Finally, the erosion control factor (P) accounts for the influence of support practices such as contouring, strip cropping, and terracing, etc. A default value of 1 is commonly used when erosion control practices are not adopted or when there is no adequate empirical data. In this study, we have used a default value of one.

Calculating soil loss

With RUSLE, soil loss for each grid cell calculated as the product of the R, K, C, LS, and P factors. Here, we have used a constant value of 1 for P.

Accordingly, the total soil loss in the study area is found to be 17,688 tones and an average of 95 t/ha/y the raster output for soil loss (in tons/ha/year) in the watershed is shown in Figure 8.

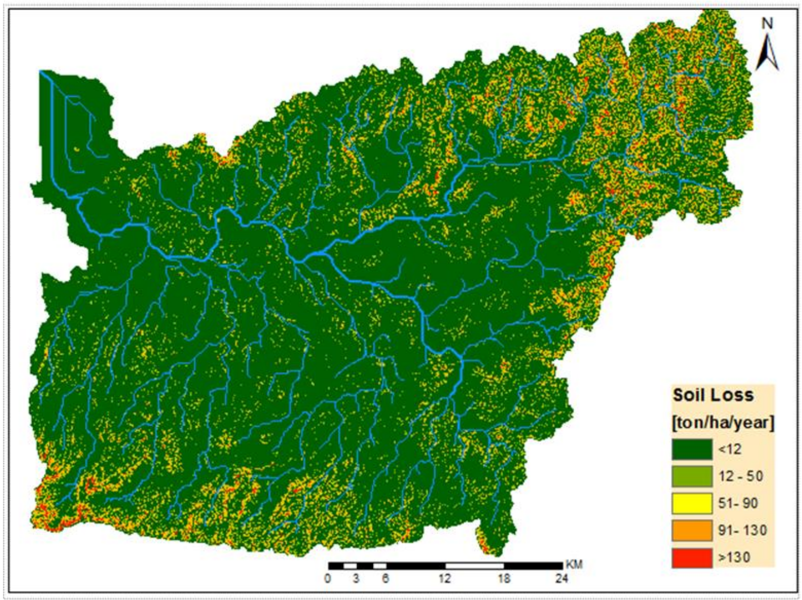


Figure 6 Total Annual Soil Loss per Hectare (t/ha/y)

RESULT AND DISCUSSION

Based on the estimated value, the total soil loss in the watershed is 17,688 tones and 95 t/ha/y on average basis [ranging between 0- 235t/ha/y] and in about 26.7% of the watershed area the annual soil loss rate exceeds the maximum tolerable soil loss threshold of 11tons/ha/year for Ethiopia (Hurni, 1985). *Dilla* watershed is then divided into five severity classes (Table 5). Accordingly, about 26.7% of the watershed is predicted to suffer from high erosion. Yet there are few areas, which are marked with very severe soil loss, and most of the high erosion areas are associated with steep slopes and crop cultivation mostly on upstream locations. Field observations revealed that in the midstream areas soil loss is mostly in the form of small gullies on cultivated lands, overgrazed and less vegetation cover mostly damaged by termites. The study indicated lower erosion rates for lower part of streams and the only observed spots of high values are associated with farmlands with less conservation practices and steep slopes.

Table 3 Distribution of Annual soil Loss and Severity Classes

Soil loss class	Loss value [t/ha/y]	Severity	Area [ha]	Percent (%)
I	Less than 12	Low	204,987	73.30
II	12-50	High	72,067	25.75
III	51-90	Very High	2,625	0.94
IV	91-130	Severe	131	0.05
V	Greater than 130	Very severe	10	0.005

Spatial distribution of soil loss

GIS dataset overlay analyses were performed and field observation, interviews and discussions were held with different stakeholders at different level in order to map and verify the spatial and geographic distribution of soil loss in the study area. Accordingly, North Eastern part of the watershed and upstream areas in the South West are found to have high soil loss rates. This result agrees with the information obtained from district ANRDs and interviews. Hence, the micro-watersheds with high value of soil loss and most of their areas affected are given in Table 6 and mapped as in Figure 9.

Table 4 Micro-watershed and their respective districts

ID	Watershed/s	District
1	Itis-Kela-Burka	Boji Dermeji
2	Jarso-Raba-Ala	Nejo
3	Bocholo-Kea	Boji Chekorsa, Nejo, Boji Dermeji
4	Into-Fincha-Gawa	Boji Dermeji
5	Kersa-Seo-Yatu	Jarso, Nejo
6	Bikir-Chekorsa	Guliso, Boji Chekorsa
7	Chancho-Doke-Utalcho	Gao Qebe
8	Gomi-Debisa	Guliso
9	Kerub-Kuchi	Dale Sadi

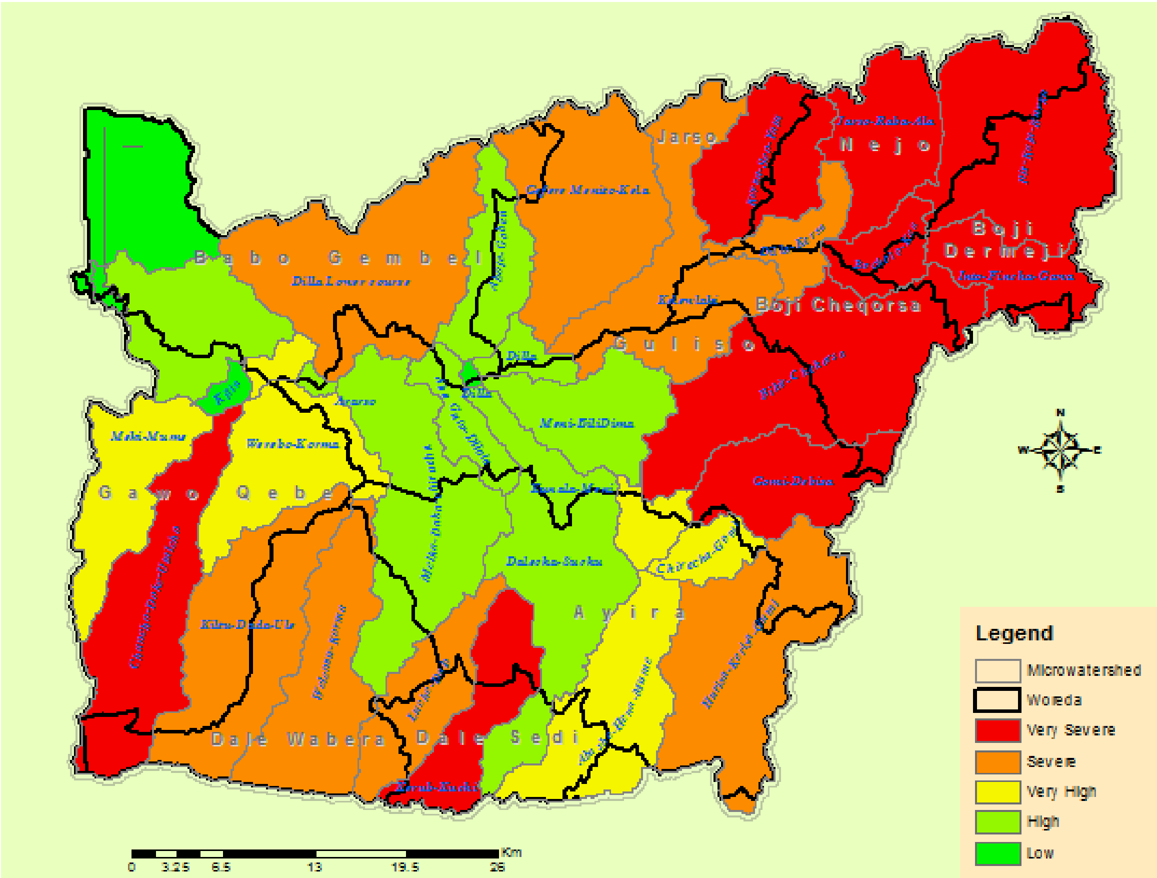


Figure 7 Soil erosion Severity by District and micro-watersheds

Watershed prioritization for conservation measures

According to Figure 10, out of 35 micro-watersheds in the study area, nine (9) micro-watersheds geographically located in four (4) *districts* estimated to have very severe annual loss, and require mitigation and implementation of soil conservation methods

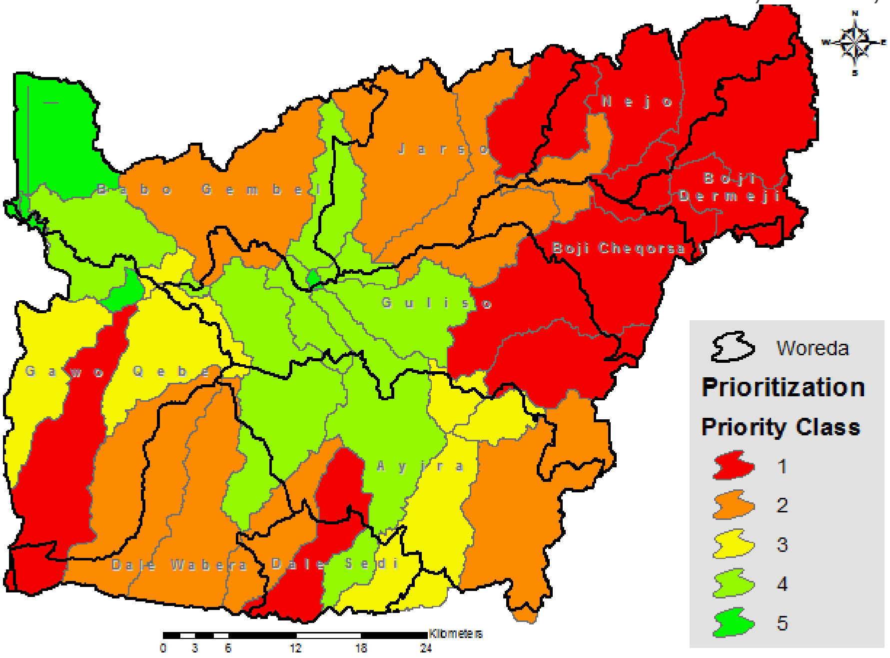


Figure 8 Prioritization map of micro-watersheds

Field observations, interviews and discussions revealed that erosion in the form of sheet and rills was the dominant form of erosion identified. Gully erosion and landslides were also reported in the North-eastern part of the watershed where traditional gold mining is practiced.

Most severe erosion was observed during the first rain showers when the soil is loose due to tillage. During that time the constructed soil bunds are filled by sediments and stop functioning until the bund is maintained. The local experts were also aware of erosion problems and the group discussions revealed that they realized the occurrence of soil erosion when visible signs appear on agricultural fields.

The major drivers of accelerated soil erosion mentioned by Agriculture and natural Resource experts at zonal and District level included; termite infestation, livestock density, inappropriate farming practices, lack of vegetation cover, steep slope, soil type (Clay soil), the duration and intensity of rainfall, overgrazing, traditional gold mining practices (particularly in the North eastern part of the watershed) were identified as driving factors contributing to accelerated soil erosion in the watershed.

Soil fertility decline and consequent yield or productivity fall, soil acidity, shortage of fodder, siltation, and human displacement (out migration) are among the effects of soil erosion felt by the respondents. During summer season (from June to Aug), the sown crop seeds (for e.g. sorghum) are eroded from crop fields due to severe erosion caused by intense rainfall.

As mentioned by the interviewed experts the soil conservation measures undertaken in the study area to arrest soil erosion included; planation of *vetiver* grass, elephant grass, *chomo* grass(Fig 11a) (*Brachiaria Humid cola*) (which also protect termite infestation), soil or stone bund (Fig 11b) (where stone is available), afforestation (on eroded areas), and check dams. Despite all these efforts, the experts mentioned some challenges encountered on the implementation of watershed management strategies. For instance, the reluctance of farmers on planting trees. Because of the assumption that it reduces their grazing land, most of the time farmers do not want to apply such conservation measures. This indicated the low level of awareness on adoption of SWC measures. Farmers also lack interest in laborious conservation activities. Dependency on funded SWC projects was also another challenge.

Figure 9 Some of the SWC measures practiced in the watershed (Field photo, 2017)

The experts working at zonal and district level reported that their experience of watershed delineation is done by examining the topography and drainage of each locality in the watershed and then named after local names. This is done through personal observation, transect walk, and interview with farm households. From their experience, prioritization for conservation measures is done based on trend analysis, visual observation, and reports from Development agents (DAs) working in the study watershed. From this, we can infer that if this local approach is supplemented by the scientific method it yields better output in identifying erosion prone areas and prioritizing micro-watersheds for treatment.

Conclusion and Recommendations

This study revealed that the RUSLE model in the GIS framework together with satellite images provide fairly reliable estimation of soil erosion rate and delineation of erosion prone areas within the watershed for conservation intervention. The computed sum total soil loss, of 17,688 tones which reaches up to 235 on a single hectare reveals that soil erosion is a serious environmental problem in the study area particularly around the upstream steeper slope areas of the watershed which requires alternate management practices to sustain long-term productivity. The local knowledge on the status of soil loss in the study watershed also revealed that soil erosion is a major problem constraining land productivity.

Besides, it is uncovered that the highest soil losses are estimated on steep and dissected slopes, in areas of high rainfall, on cultivated soils, and on areas devoid of vegetation particularly due to damage caused by termites that made the soil fragile. Field observations and interviews also shown that the prevailing soil management and erosion control practices are not proactive and the conservation structures built are non-permanent as they are continuously damaged by animals. Most of the erosion management structures that are either existing or under construction are on already worn out areas that are meant to recover the land at least for grazing.

It is thus reasonable to recommend that local knowledge when aided by empirical methods such RUSLE model and geospatial techniques will produce reliable information on which appropriate decisions are based for the attainment of environmental sustainability. The conservation efforts initiated in some parts of the watershed should be enhanced to reduce the amount of soil loss and increase land productivity. Areas characterized by high to severe soil loss should be given high priority to minimize the rate of soil loss by implementing soil and water conservation practices.

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