Analysis of Watershed Characteristics and Spatial Soil Loss Estimation: A case Fincha Watershed, Western Ethiopia

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Abstract

Characteristics of watershed were not well investigated as global also in Fincha, Ethiopia. Fincha watershed is the most erosion prone area in the highlands of Ethiopia towards to Fincha dam. Therefore, the aim of this study was to analysis Fincha watershed characteristics based on land use/cover, soil type and slope classification and to identify soil erosion prone area using Arc-GIS and Arc-SWAT model. Accordingly, nine major land use/covers were identified. Those were:- bush land, dominantly cultivated, moderately cultivated, irrigated land, grass land, water bodies, swamp area, urban and woodland open. From these most part of the catchment was under cultivation with 67.677% of the total area. In the same way, the major soil types identified were: - chromic luvisols, chromic vertisols, dystic cambisols, eutric cambisols, eutric nitosols, eutric regosols, haplic phaeozems, humic cambisols and water. Cambisols were covered the highest percentage, 39.98% area of the catchment. Subsequently, average annual values of estimated soil loss from the catchment was 231.2 ton/ha. The identified prone erosion areas were sub-basins 1, 8, 11, 14, 17 and 20. It was very critical for environmentalists, hydrologists, agricultural experts, watershed managements and concerned decision makers for sustainable water resource projects and environmental protection system. Therefore, further detail investigation and appropriate watershed management practices should be given for these subbasins.

1. Introduction

An area that contains a common set of streams and rivers into a single water bodies is called watershed. So, characterization of watershed is a necessary and important step in planning and management of a watershed. Miller *et al*, (2003) stated that, many researchers have used DEM and GIS techniques for watershed delineation and extraction of drainage networks and various topographic characteristics of a watershed. Automatic extraction of important watershed characteristics such as watershed drainage area/boundary, field and channel slope, aspect, and drainage network using DEM 30 m were most accurately with variations less than 10% (Singh *et al*, 2005).

Arc GIS was used to extract hydrological characteristics such as flow direction, flow accumulation, flow length, stream networks, and snap pour point of various streams (Fu-quan *et al*, 2010). Gossa W, (2011), globally soil degradation is affecting 1.9 billion hectares and is increased at a rate of 5 to 7 million ha/yr. In most parts of Ethiopia the high intensity rainfall occurs when the cultivated land has low cover, which can reduce the impact of the high intensity raindrop and the high runoff which can be slowed by soil cover (White, 2005). Soil erosion and river sedimentation can cause critical environmental, ecological and economic problems worldwide (Yang *et al*, 2003). Soil erosion from the upstream area of the Blue Nile River Basin and the subsequent sedimentation in its downstream area caused a rapid loss of storage volume due to excessive sedimentation (Betrie GD *et al*, 2011).

Bezuayehu (2006) reported that Fincha watershed is a typical example of many watersheds in the country that had undergone land use change and presently undergoing environmental degradation and causing serious problems. It is one of those highland areas of the country with severe soil erosion

problem draining to the Nile River. Fincha hydropower reservoir is a highland area with a severe soil erosion problem that drains to the Blue Nile River due to increasingly mountainous and steeper slopes area cultivated, in many cases without protective measures against land erosion and degradation (Assefa, 1994).

Soil loss from watershed was increased from time to time due natural and human induce activities.Reduction in storage capacity of rivers and reservoirs become increased due to soil loss and sediment yield from the catchment (Agarwal, *et al.*, 2009). So,characterization of watershed, soil losses, sediment yields,reservoir capacity reduction, disturbance of aquatic ecosystem and watershed managements were main agendas of scientific researchers.

Since erosion and Sediment yield is one of the most complex natural processes and many factors are involved in it, the full knowledge of the factors influencing this phenomenon is very difficult (Zahabioun *et al.*, 2010).

Analysis of watershed characteristics, soil erosion, transport and deposition of sediments in reservoirs, irrigation canals and hydropower systems were very essential for land and water management, but these were not studied in-depth in the catchment.

So, watershed characterizations, spatial distributions of soil losses and prone area identification of Fincha catchment using GIS and SWAT model was pertinent for best watershed management practices, planning, implementation, decision making, giving solution for future.

2. Study Area

The study area is situated in Abay/Nile River basin which is located in the Horro Guduru Wollegga Zone, Oromia National Regional State, Ethiopia. Geographically located between 9°9'53" N to 10°1'00" N latitudes and 37°00'25" E to 37°33'17" E longitudesas shown in Fig. 1. The altitude in the catchment ranges from 902 m in the lowlands up to 3,171 m amsl in the highlands. The climate of the Fincha watershed is tropical highland monsoon with an average annual rainfall of 1763.6 mm and mean monthly temperature of the area varies from 14.6 to 17.7 °C. Most of the rain falls during the months of June to September with peaks occurring during July to August and it is virtually somewhat dry from November through to April.The total area of watershed was 2,619 km² and six districts-namely, Jimma Geneti, Horro, AbbayChomen, AbaboGuduru, Guduru, and Jimma Rare. The watershed is bordered on the north by the Blue Nile River (also called Abbay River in Ethiopia), on the east by the Guder River Basin, on the south by Awash River Basin, and on the west by Diddessa River Basin.

3. Materials And Methods

Majority of data used were secondary data that includes meteorological, spatial and hydrological data in general. Those, data were collected from different organizations like Ethiopia National Metrological Agency and from Ministry of Water, Irrigation and Electricity. Also field observation was done for locating

the outlet and visualizing the catchment. The main tools that have been used in this study for data collection, preparation and analysis were: Arc VIEW GIS10.4, Arc SWAT2012, different maps, and Microsoft excel. ArcGIS10.4 was used for creating maps, managing geographic information in a database and execution of GIS processing tools (such as clipping, overlay, and spatial analysis). SWAT2012 model was used for setting up the study project, delineating the study area, analysing HRU, writing all input tables, editing inputs and simulating all inputs.

3.1. Model inputs and their compatibility for the model

Three main input data were 1) metrological data 2) spatial data

Table 1
Metrological data and their format

Input data	Compatibility format
Daily precipitation	Txt
Daily temp (max and min)	Txt
Solar radiation	Txt
Relative humidity	Txt
Wind speed	Txt

Table 2
Spatial data and their format

Input	Format
DEM	Grid
LULC map	Grid/Shape file
Soil map	Grid/Shape file
Stream network layers	Shape file

In SWAT model watershed can be automatically delineated by importing the digital elevation model (DEM) and adjusting the threshold area or provide predefined sub watersheds. The land area in a sub watershed was divided into several hydrologic response units (HRUs). HRUs are portions of a sub watershed and possess unique land use, slope range, and soil attributes (Neitsch *et al.*, 2005).

4. Results And Discussion

4.1 Topography of the study

The topography of the Fincha watershed signifies two distinct features: the highlands, ragged mountainous area in the upper and western part of the watershed and the lowland valley area with flat topography in the lower part of the watershed. The altitude in the watershed ranges from 902 m to 3,171 m amsl. Elevation of the study area was classified into four classes. Majority of the watershed area was situated in ranges of 2,005.4 to 2,388 m amsl as shown in Fig. 3.

4.2 Watershed Delineation process

The Arc SWAT requires model setup and parameterization of the model. Watershed was automatically delineated using 30 m x 30 m DEM.

Automatically delineated the watershed was classified into several hydrologically connected sub-watersheds. After the DEM grid loaded and the stream networks superimposed, the DEM map grid was prepared to remove the non-draining zones. The initial stream network and sub-basin outlets also defined based on drainage area threshold approach. Sub-basin parameters were calculated in order to estimate the basic watershed characteristics from the DEM and 21 sub-basins with different HRU were identified. General procedure of watershed delineation was presented as Fig. 4 below.

4.3 HRUs analysis

It includes requires land use/cover, soil and slope layers and their threshold inputs. HRU is defined as a lumped land area comprised of a uniform land use land cover, soil type and uniform slope of the watershed. Land use/cover, soil type, runoff, soil loss and sediment yield could be predicted separately from each HRU. It increases the accuracy in prediction that provides a much better physical description of the water balance rather than prediction from the whole catchment at once.

4.3.1 Land use/land cover analysis

The LULC is one of the most important watershed characteristics and factors that affect soil erosion, runoff, sediment and evapo-transpiration in a watershed during simulation (Neitsch *et al.*, 2005). For LULC analysis of the catchment, the land use map Ethiopia and Fincha basin were overlaid and clipped. There were nine major land use land cover classes were identified in Fincha watershed. Those were:- bush land, dominantly cultivated, moderately cultivated, irrigated land, grass land, water bodies, swampy area, urban and woodland that presented in Table 3 and Fig. 5 respectively. Bush land occupies about 2.13% of total area. These were type of vegetation which is either a remainder of natural vegetation of the land or, if altered, was still representative of the structure and floristic of natural vegetation. Part of the watershed covered by grasslands was 10.64%. Are types of vegetation dominated by grasses rather than large shrubs or trees. As degradation of grassland increase, soil erosion also increased. Water bodies occupied 11.42% of total area. Due to poor watershed management, quality of these water bodies decreased and aquatic ecosystems was disturbed. Similarly, swamp area, urban and woodland open covered 2.533%, 1.54% and 4.06% respectively. About 67.677% of the total catchment was under human induces,

cultivation practices. These indicate that majority of the catchment was very sensitive to runoff, soil erosion/sediment yield due to cultivation practices. Therefore, best watershed management practices should be applied to protect this watershed by concerned stakeholders.

Table 3
Major land use/cover classes in Fincha watershed

S.No	Land use/cover category	Area covered (Km ²)	Watershed area(%)
1	Bush land	55.785	2.13
2	Dominantly cultivated	958.519	36.599
3	Moderately cultivated	763.123	29.138
4	Irrigated land	50.720	1.94
5	Grass land	278.669	10.64
6	Water bodies	298.987	11.42
7	Swamp area	66.34	2.533
8	Urban	40.332	1.54
9	Woodland open	106.332	4.06
Total		2,619	100%

4.3.2 Soil type analysis

Arc SWAT model require soil data to provide both the distribution of the soil type in the watershed and the various parameters describing the soils hydrological and textural properties. The soil textural and physicochemical properties include soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for each soil type. Fincha basin was overlaid with Ethio - soil map and clipped.

Clipped Fincha soil map was projected to UTM zone 37, projection area of Ethiopia and nine major soil types were obtained. These soil categories and spatial distribution of the catchment was presented in Table 4 and Fig. 7 respectively.

These major soils were: chromic luvisols, chromic vertisols, dystic cambisols, eutric cambisols, eutric nitosols, eutric regosols, haplic phaeozems, humic cambisols and water. From these, soil type that covers most part of the watershed were dystic and eutric cambisols with 39.98% of a total area. As of the soil properties, cambisols show variations in colors, structure and carbon. They have medium to fine textured materials that result from the decomposition of a wide range of rocks. Cambisols exist on a level to mountainous topography of all-weather climates.

They are favorable for a wide range of vegetation growth and have good production potential for agricultural activities. Under uncontrolled agricultural activities and poor land management, the soil was exposed to a high potential of erosion occurrence and sediment yield. The second soil class was eutric regosols and eutric nitosols with 21.65% of total area of the watershed. Regosols are very weakly developed mineral soils in unconsolidated materials that have only an ochric surface horizon and that are very deep. They are extensive in eroding lands, in particular in arid and semi-arid areas and in mountain regions.

Nitosols mostly found at higher altitudes. They are inherently fertile of the tropical soils because of their high nutrient contents and deep, permeable structure and exploited widely for plantation agriculture.

The third category was chromic vertisols and chromic luvisols that cover 20.27% of the watershed. The reference soil group of Luvisols holds soils whose dominant characteristics is a marked textural differentiation within the soil profile, with the surface horizon being depleted of clay and accumulation of clay in a subsurface argic horizon. Most chromic luvisols were well drained but shallow groundwater may occur in luvisols in depression area. From soil properties these soils have high activity clays throughout and lack the abrupt textural change of planosols. Luvisols are fertile soils and suitable for a wide range of agricultural use when in controlled system. So, under poor watershed management clay will be washed down from the surface soil to accumulation horizon at lower depth.

Table 4
Soil category of Fincha watershed

S.No	Soil category	Covered area (Km ²)	Watershed area (%)
1	Chromic Luvisols	2.5955	0.1
2	Chromic Vertisols	528.3573	20.17
3	Dystic Cambisols	620.6453	23.7
4	Eutric Cambisols	426.269	16.28
5	Eutric Nitosols	21.823	0.83
6	Eutric Regosols	545.178	20.82
7	Haplic Phaeozems	34.837	1.33
8	Humic Cambisols	132.969	5.08
9	Water	306.377	11.7
Total		2,619	100%

4.3.3 Slope analysis

Slope was another watershed characteristics and critical for watershed management. As the slope of the catchment became steep, runoff and soil erosion were increased. Example, sub-watershed with steep slope might contribute more soil losses, sediment yield to water bodies than with flat landscapes.

The slope of the catchment was classified into four multiple classes 0-3%, 3-6%, 6-9% and above 9% based on the DEM data used during the watershed delineation and the topography of the catchment and shown in Fig. 8.

General flat slope covers about 56.43%, moderate slope 28.54% and steep slope 15.03% of the total catchment. These indicate that of the catchment area had high general flat.

Table 5
Slope classes in Fincha watershed

S.No	Slope class (degree)	Covered Area (Km ²)	Watershed area (%)
1	0-3	393.6564	15.03
2	3-6	414.3073	15.82
3	6-9	333.1661	12.72
4	> 9	1,477.9198	56.43
Total		2,619	100%

4.4. Soil loss discussion at HRU and Sub basinlevel

The assessment of the spatial variability of sediment yield at HRU and sub basin level is useful for catchment management planning and reservoir protection. At sub basin level the highest and lowest average sediment yield was from sub basin 11 and sub basin 18 with values of 582.022ton/ha and 0 ton/ha respectively.

This indicates sub basin 11 was under extreme soil erosion and the most prone area of Fincha watershed at sub basin level from a total of 21 sub basins. So, priority of watershed management practices at subbasin level should start from this subbasin and proceed to the rest. The spatial prone area in relation to soil erosion of Fincha watershed was shown in Fig. 9.

Soil erosion prone area was classified based on the classifications of erosion rates in the Ethiopian high lands. It was classified into four main classes in this study as very high, high, medium and low. Very high from sub-basin 1, 8, 11, 14, 17 and 20 that covers an area of 27.84%. High erosion level from sub-basin 3, 7, 9, 12, 13, 15 and 16 with covered area of 36.03%. Medium erosion level from sub-basin 4, 5, 6, 10 and covers area of 24.24%. The last classification as low was from sub-basin 2, 18, 19 21 and covers an area of 11.9%. The average annual sediment yield total sub basins is 231.2ton/ha. The statistical data of the soil loss class and corresponding area ratios were presented in Table 6.

Table 6
Statistical data of the soil loss class and corresponding area ratios

Soil loss classes	Soil loss rate (ton/ha/yr)	Sub basins	Area ratio (%)
Low	< 105	2, 18, 19 and 21	11.9
Medium	105–202	4, 5, 6 and 10	24.24
High	202–358.3	3, 7, 9, 12, 13, 15 and 16	36.03
Very high	358.3–582	1, 8, 11, 14, 17 and 20	28

5. Conclusions

The watershed was classified into 21 subbasins, 205 HRUs with a total area of 2,619 Km². From the results, there are nine land use land cover and nine major soil types were obtained. According to LULC analysis, about 67.677% of the Fincha watershed was under cultivation practice. Due to this activity the catchment can be easily exposed to runoff, soil erosion and sediment yield if best watershed management practice will not implemented. As so analysis, Cambisols were major soil types of the catchment and covered around 39.98% of the total area. Sub-basins 1, 8, 11, 14, 17 and 20 were the most prone erosion areas of the watershed in relative to the other subbasins and occupied about 27.84% of the catchment. So, best watershed management practice should be recommended for Fincha watershed by conserved bodies.

Declarations

6.1 Availability of data and materials

All data generated or analysed during this study are included in this manuscript and it can be found from authors if required latter.

6.2 Competing interests

As authors, we have no competing interests to disclosure our submitted article in this section.

6.3 Funding

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6.4 Authors' contributions

SK literature review, data collection, analyzed and interpreted the required data accordingly regarding with LULC analysis, soil type analysis and soil loss estimation and major contributor in writing the manuscript.

FF performed on check up and comments, writing the manuscript. Finally, all authors read and approved the final manuscript.

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Figures

Figure 1

Map of the study area

Figure 2

General framework of methodology used

Figure 3

Topographic map of Fincha watershed

Figure 4

General procedure of Fincha watershed delineation process

Figure 5

Delineated watershed and sub-basins of Fincha watershed

Figure 6

Major land use classes in Fincha watershed

Figure 7

Major soil classes of Fincha watershed

Figure 8

Slope classes of Fincha watershed

Figure 9

Spatial distributions of soil losses inFincha watershed