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# Assessment of drivers and dynamics of gully erosion in case of Tabota Koromo and Koromo Danshe watersheds, South Central Ethiopia

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## Abstract

Globally erosion has been considered as an environmental and agricultural problem since the first agricultural revolution. In Ethiopia gully erosion has been recorded as a very serious and common socio-economic and environmental problem of several watersheds. Therefore, the objective of this research was to assess the drivers, dynamics and impacts of gully erosion in case of Tabota Koromo and Koromo Danshe watersheds, South-Central Ethiopia. The intended objectives were achieved by triangulating the image analysis with the data obtained from GPS, group discussion, interview, house hold survey, field observation and field measurement. The result of the study indicated that gully erosion was initiated in the steep slope following the 1970s and 1980s land cover change and other anthropogenic factors. In addition, the soil properties and steep slope (gravity) of the land have contributed in exacerbating the problems. Gully erosion caused physical, social and economic impacts in the area. According to the participants on group discussion and interview, the socio-economic impacts of gully erosion were loss of life for a 12 year boy, injuries of five live stocks, and decline of yields throughout the year. Result from field measurement and observation depicted that loss of soil (1,080,782.6m<sup>3</sup>) and loss of biodiversity are the major physical impacts of gully erosion. Yet there are promising conditions to rehabilitate the gullied area for sustainable ecosystem services in the watersheds. These promising conditions are the availability of high labour forces, access of transportation, civic societies working on natural resource conservation and the green economy development policy of the country. Therefore, concerned government bodies and the local communities at different level need to set plan and work for implementation in a way to use the existing opportunities.

**Keywords:** Gully erosion, Dynamics, Drivers, Impacts, Rehabilitations

## Introduction

Soil erosion is one of the natural processes which have lasted for a long period of time (Parikh and James 2012). Natural soil erosion will take place at a given place with normal rate, but the equilibrium conditions mainly change due to anthropogenic factors (Vijith and Dodge-Wan 2019). Though, historical documentation is lacking how soil erosion has been perceived, scholars argue soil erosion had already been in earlier prehistoric times. However, since the Neolithic period agricultural activities have

allowed human being to modify the natural environment (Dotterweich 2015).

Loss of soil is one of the most challenging global environmental problems (Tebebu et al. 2010). According to El-Swaify (1994) soil degradation via water erosion accounted for about 55% or 2 billion ha in the world. Moreover soil erosion is very sensitive to both natural and human factors (Pimentel and Burgess 2013). Among different forms of soil erosion, gully erosion is an environmental threat throughout the world. And its effect on soil, land functions and sediments is attracting attention from scientists (Ionita et al. 2015).

The major driving forces for gully erosions are high population growth, poor rangeland, lack of vegetation

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cover, overgrazing, intensive and short-period rainfall, improper land use (cultivation on steep slopes), improper irrigation design, wrong discharge of water in the channels, and soil characteristics (Jahantigh and Pessarakli 2011; Tamene and Vlek 2008).

Gully form of soil erosion causes extensive socio-economic and environmental impacts, and most of them are negative (Valentin et al. 2005; Marzloff et al. 2011). According Zgłobicki et al. (2015) gully erosion decreases the agricultural land, farm productivity/crop yields and grazing land. Also gully-based valley sediment yield accounted for 10 to 94 % of the total watershed sediment yield (Poesen et al. 2003).

In Ethiopia dense gully erosion is typical parts of the landscape (Gebrehiwet 2004; Frankl et al. (2010). According to the Hurni (1988) estimation the average erosion rate in infertile crop land are 70 tons / ha / year. Yet the CRSPT, U. (2000) report has indicated that, the average annual rate of soil loss in Ethiopia is estimated to be 12 tons/ ha /year and it can be greater than 300 tons/ha/year on steep slopes where vegetation coverage is little.

Particularly in the highland area loss of top soil via gully erosion reach over 1.5 billion tons, this amount of loss could have added about 1.5 million tons of grain to the country's harvest (Tamene and Vlek 2008; Taddese 2001). Due to soil erosion problem the national average yields for maize, sorghum, and finger millet are 3.0, 2.0 and 1.7 t ha<sup>-1</sup>, respectively in 2012/2013. This amount of yield is the lowest in the world and unable to meet the basic food needs of the population (Bewket 2007).

Agricultural based economy and widespread problem of soil erosion in Ethiopian has made natural resources management, particularly soil and water conservation practices the major area of interest in the country. Though, massive reforestation and modern soil and water conservation schemes were launched before 49 years the impacts were far below expectations and land degradation continued as problem (Demeke 2003).

There are several factors for the less effect of the past conservation activities in Ethiopia. Failure to balance land management interventions with the dynamic nature of land degradation is the major factor for small-holder farmers to sustain both economic and environmental issues (Shiferaw and Holden 1999; Gessesse et al. 2009).

This implies to the soil conservation activities primarily need to look for identifying drivers and dynamics of a site level gully erosion based on scientific and systematic ways before taking treatment measure. Because it gives chance to design suitable and effective gully controlling activities. Therefore, the objectives of this research were to assess drivers, dynamics and effects of gully erosion in case of Tabota Koromo and Koromo Danshe watersheds South Central Ethiopia.

## Study area

The study watersheds are located in south central rift valley areas of Ethiopia at about 285 km from Addis Ababa. The south central rift valley region of Ethiopia is part of the Great East African Rift Valley. It originates from Arabian Plate in the Middle East and traversing longitudinally in the eastern African countries, such as Djibouti, Eritrea, Ethiopia, Kenya, Uganda, Tanzania, and Mozambique (Ayenew 2007).

The watersheds are situated at 7° 3' to 7° 6' north latitude and 38°19' to 38° 23' East longitudes with total areas of about 8km<sup>2</sup> (MoWR 2009) see Fig. 1. The rift valley area of Ethiopia is characterized by very dynamic and fragile landscapes (Bekele et al. 2018). The watersheds are distinguished by highly dissected and non vegetated mountain terrain with big gullies that run down the steep slope (EOSA 2007).

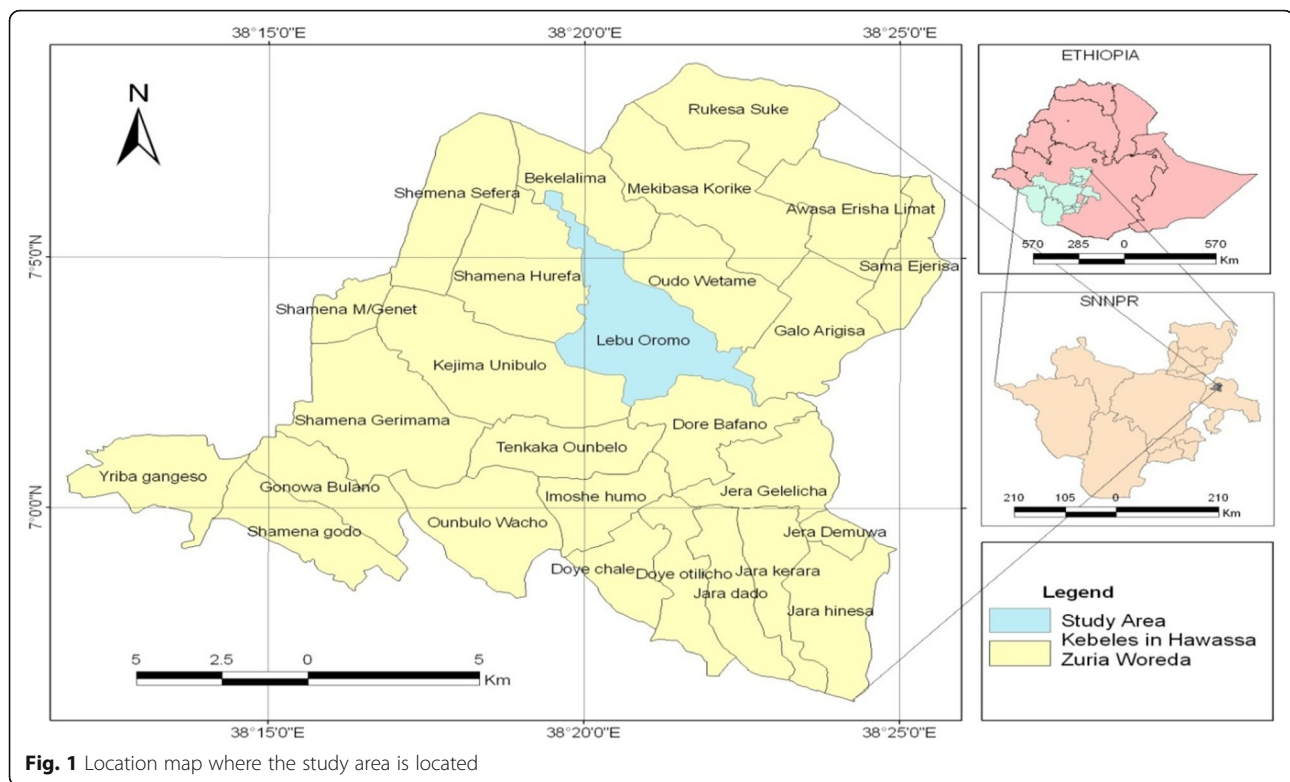
Climate of the area characterized by the annual rain fall ranges from 700 to 1200 mm and the mean annual temperature range between 18 - 21°C. The rain fall is characterized by dry, cold and windy winter and warm and wet summer (Mechal et al. 2015). And the agro-climatic zone of the area falls within dry mid altitude category. There is no perennial river and the only water resource available is Lake Hawassa, one of the biggest lakes within the rift valley.

According to Ministry of Water Resources (2009) the soil type which is dominantly covered the watershed are young and not well consolidated Cambisol, and highly hydrated dried Andosols. These soils are characterized as weak soil horizon, fine textured material, reduce infiltration, increase runoff and easily remove with surface runoff water (FAO 2006). The soil types of the study watersheds combined with the steep topography, poor land cover and anthropogenic factors are highly contributing for the gully formation and expansion in the area.

The major economic activities of the watersheds are agriculture (mixed farming) that covers around 83 % and the rest are small trades and labour hiring. In the area cultivation practice lasted for long time in which almost all potential lands are put under crop cover. But the problem associated with climate variability and land use and cover change causes crop failure once in every ten years and sometimes even more frequently (Ministry of Water Resources 2011).

## Methodology

The formulated objectives was addressed with the primary sources, such as field observation, field measurement, household survey, key informant interview, focused group discussion, aerial photo and satellite image analysis. Also the unpublished documents, archives, statistical abstracts and reports from different offices were used as secondary sources.



**Fig. 1** Location map where the study area is located

Sample size was determined using Cochran (1977) procedures.

$$n = \frac{n_0}{1 + \frac{(n_0 - 1)}{N}}$$

According to this formula the total house hold population is 860

n at 95 % confidence level and at  $\pm 10\%$  precision level  
n = 86

For this study the data collection activity has used mixed approach (quantitative and qualitative) and simple random sampling technique that was implemented in sequential exploratory design methods. The data for gully initiation; size (length, depth, width), density, width-

depth ratio, incision period, and volume of soil loss was obtained from analysis of satellite image, aerial photo, group discussion and interview.

Whereas, the data acquisition on gully drivers, impacts and opportunities for rehabilitation were carried out with field observation, household survey, group discussion and key informant interview. Identification of gully age and historical development was obtained from monitoring event calendar and reference time approach of (Moges and Holden 2008). In this regard elders and community leaders were purposefully selected to give the major event which could serve to guess the age of each gully (Table 1). Based on Table 1 the average gully age was estimated, which is important in the attempt of calculating the volume of soil loss from each gully since its onset. The volume of soil loss estimation of the study

**Table 1** Event calendar used to monitor gully age estimate

Year	Event calendar used to monitor gully age estimation
1974	Overthrow of Emperor Haileselassie
1977	Sinkale clash, the fight between neighbouring Sidama and Arsi Oromo of the study area Or it is after three years of Dergue come to power.
1979	Wege clash, the fight between neighbouring Sidama and Arsi Oromo of the study area. Or after five years of Dergue come to power.
1988	Villagisation (resettlement) program. Before three years of the overthrow of military government
1996	Toge clash, the fight between neighbouring Sidama and Arsi Oromo of the study area. After six years of the FDRE come to power
	Field measurement result of each gullies

Source: Elders and key informants

**Table 2** Perceptions of HHR on the drivers of gully erosion

Factors of gully erosion	Tabota Koromo		Koromo Danshe		
	Respondents	Precent	Respondents	Precent	Average %
Human factor	13	34.2	16	33.3	34
Natural factor	–	–	1	2.1	1
Both human and natural factors	25	65.8	31	64.6	65
Total	38	100.0	48	100	100

Source House hold survey

watershed has been used with Field Office Technical Guide/ FOTG (2002) formula of soil loss estimation as equation number 1 and 2.

$$V = Lx[(W_t + W_b)/2] \times D_f \quad (1)$$

Where L = the total length in meter

$W_t$  = the average top width in meter

$W_b$  = the average bottom width in meter

$D_f$  = the average depth measured in meter

V = the displaced volume in cubic meter

To convert this calculated volume to a weight of soil lost over time (tones/year) equation 2 was used.

$$E = [(V \times W / 1000) / Y] \times N \quad (2)$$

Where E = the soil loss in tons per year

V = the volume in cubic meter calculated above

W = the average weight of soil in kilogram per cubic meter (Bulk density)

1000 = the weight in kilogram per tone

Y = the numbers of years the gully has been active

N = the number of similar classic gullies

The other important element on gully dynamics assessment is the soil bulk density, this data was obtained from earlier work in the watersheds. According to Abdurrahman (2012) the average soil bulk density of soil of the study watersheds is 0.97g/cm<sup>3</sup>. This result is consistent with Moges and Holden (2008) in neighbouring watershed, where the average soil bulk density ranges

from 0.90 to 1.06g/cm<sup>3</sup>. Therefore the soil bulk density of the study watersheds is 0.97g/cm<sup>3</sup>.

### Data analysis and interpretation

Data were computed and analysed with a combination of different techniques. The drivers, dynamics and impacts of gully erosion identification was carried with analysis of GIS based data processing, topographic map of the 1976, aerial photographs of 1965 and 1972 and the spot satellite image of 2006. Topographic map with the scale of 1:50,000 were used as a base map in order to geo-reference the satellite image and aerial photos. In addition, it was also used to extract contour lines to analyse the slope, and change in length, width and spatial distribution of gullies for the reference years of 1972–2006.

To perform analysis of gully pattern and spatial distribution the steps below were properly carried out.

Step1, Scanning; after purchasing the topographic map and aerial photos from Ethiopian Mapping Agency (EMA), it was converted from analogue to digital' format.

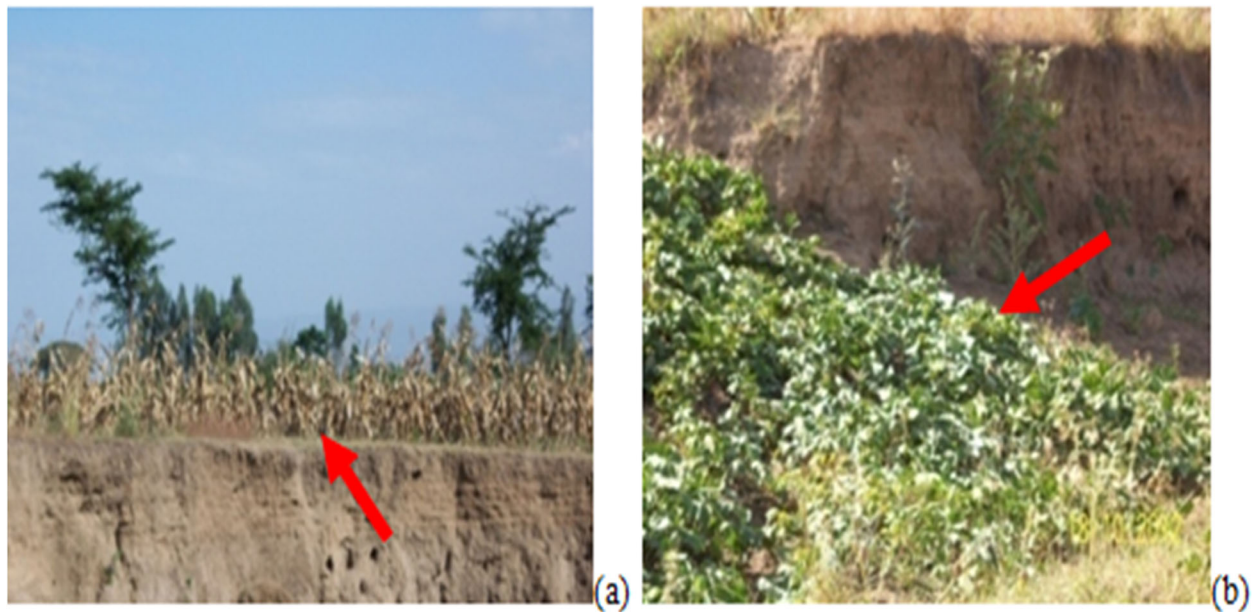
Step 2, Geo-referencing; in this stage two type of image registration was made; the first is image to map registration, which was inserting the coordinates manually to geo reference the GIS data for the topographic map. The second is image to image registrations; it was applied to geo reference the satellite image by using the map as a reference. Similar technique was used for aerial photos with support of geo-referenced satellite image as a base. Both type of

**Table 3** Awareness of the people on land cover change of the area

Type of land cover change	Tabota Koromo		Koromo Danshe		
From forest or grazing land to resident	7	18.4	9	18.7	19
From forest to bare land	1	2.6	1	2.1	2
From forest and grass to cultivated land	30	79	36	75	77
I have no opinion	–	–	2	4.2	2
Total	38	100.0	48	100.0	100

Source House hold survey





**Fig. 2** Gully bank and gully bottom cultivation from left to right

image registration were performed using the image processing software of ENVI 4.3.

Step 3, Digitizing was carried out in ARC GIS 9 and Arc Map version 9.3. This step is helpful to extract contour lines from the scanned topographic map and to map time serious gullies from the satellite image and scanned aerial photos. Finally, the digitized contours and gullies were exported as graphics so as to be incorporated in the result and discussion part.

For the data obtained from interview, group discussion, field observation and secondary sources content analysis technique was used. This technique is important to assess the socio-economic characteristics of households and their perceived responses on drivers, dynamics and impacts of gully erosion. The quantitative data that was obtained through household survey, field measurement, and different secondary sources

analysed by descriptive statistics using computer software statistical package for social science (SPSS) version 20.

## Result and discussions

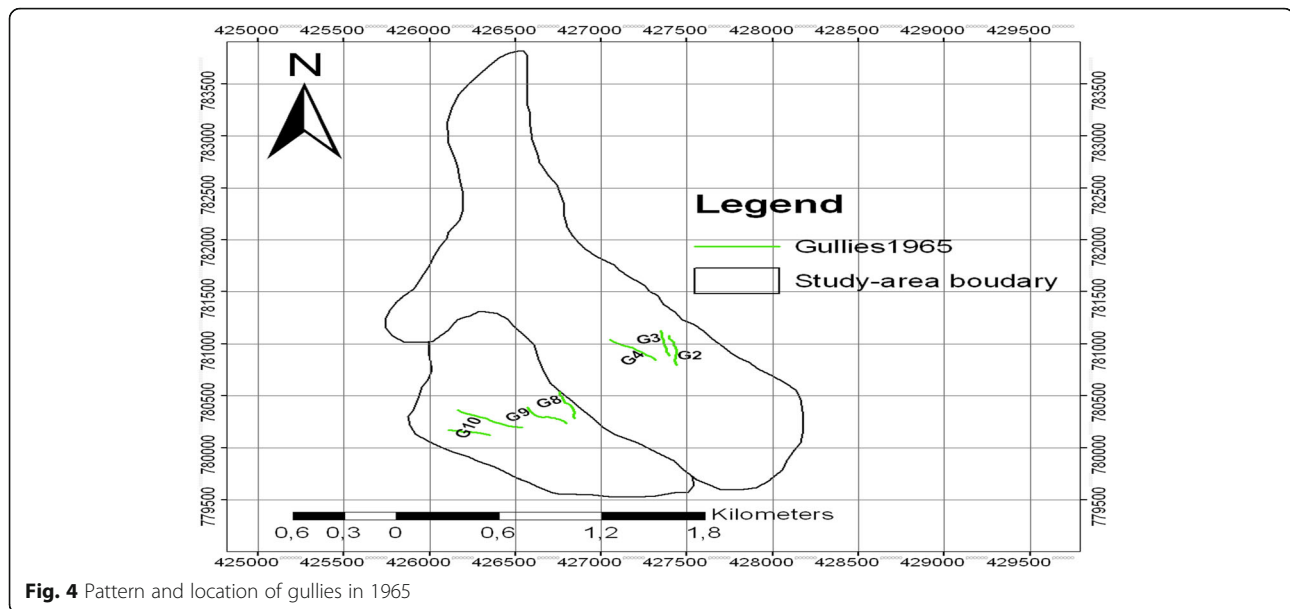
### Drivers of gully erosion

The data on driving force of gully erosion was obtained from house hold survey questions and field observation (see Table 2).

According to Table 2 from the total house hold respondent about 34% of the participants were responded the human activities are factor for gully initiation in their village. The majority about (66%) were perceived that the driver of gully erosion has the result of both human and natural factors. This finding is in agreement with (Konana et al. 2017; Valentin et al. 2005).



**Fig. 3** Local people using the gully channel for foot way

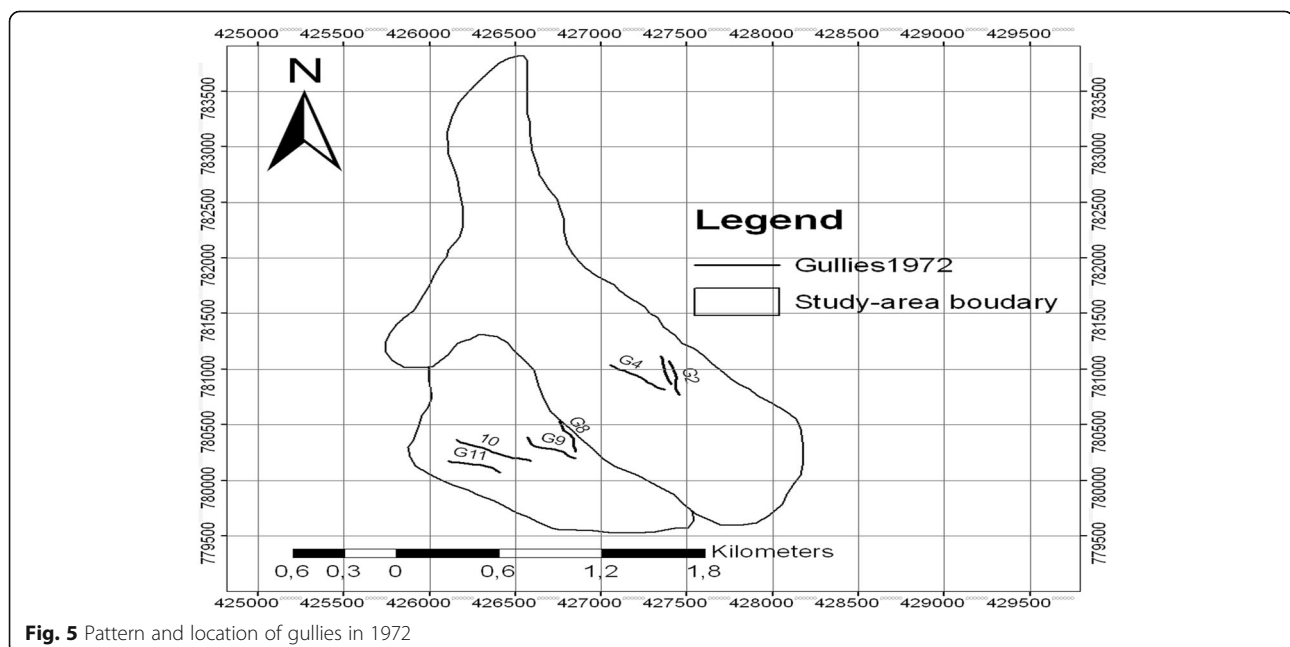


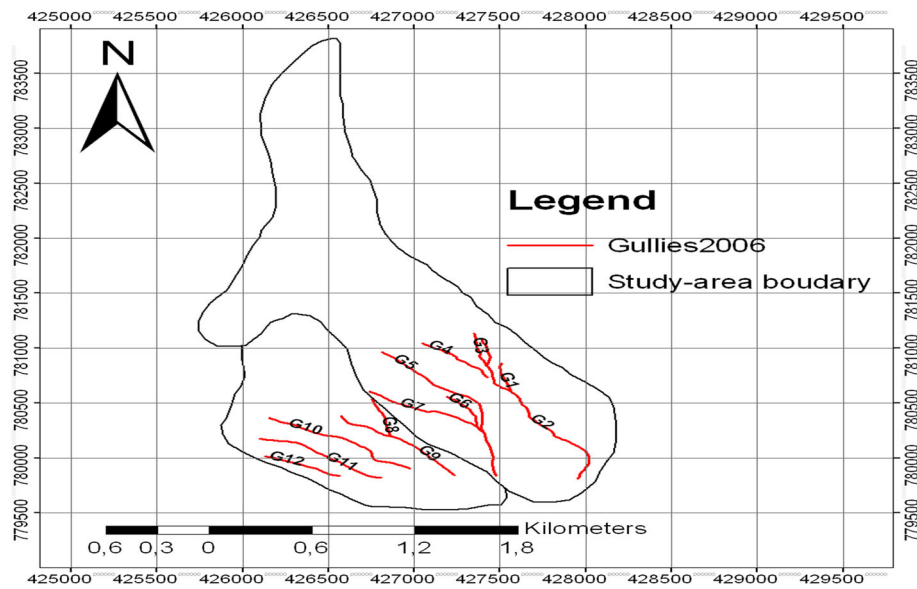
#### Human activities as drivers of gully erosion

According to the farmers in the watersheds formation and development of gullies were related with socio-political factors, high population number and associated human activities. According to the participants the major human activities that caused gully erosion in the watersheds are land cover change (deforestation), improper irrigation design, wrong discharge of water, expansion of agricultural land, overgrazing, improper land use (steep slopes cultivation, farming close to the gully bank and gully floor) which was in line with (Valentin et al. 2005, and Lal 2001 cited in Jones et al. 2008).

In the Table 3 of the total respondents 77% have said that land cover has changed from forest and grass land to cultivated land (production of crops) particularly since the 1970s. For instance; Fig. 2 shows that, the farmers who are settled near the gully have been cultivating the gully bank close to 50 cm and some others were ploughing the gully floor. As mentioned above mixed farming accounts about 86% of the watersheds economic activities.

Therefore, this economic activity combined with the agricultural activities as shown in Fig. 2 highly initiate gully formation, gully bank collapse, gully expansion and





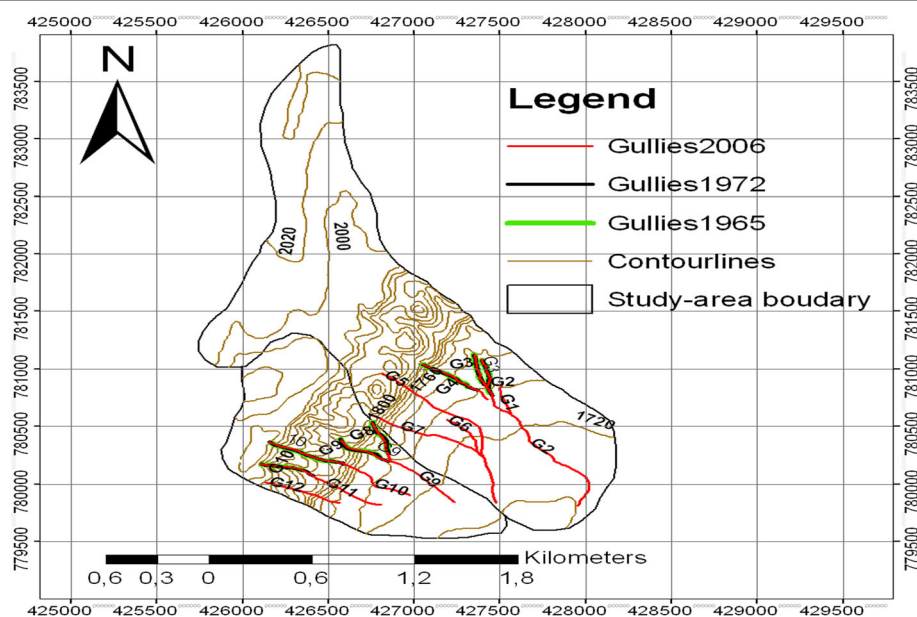
**Fig. 6** Pattern and location of gullies in 2006

limit natural stabilization. Fortunately during field observation the researchers had got a chance to observe the local children and animals walking on the bottom of the gully (Fig. 3).

These activities of the community also have a chance to expose the soil to different agent of erosion either water or wind and also it reduced the possibility of natural rehabilitation. The other threat of the Fig. 3 beyond soil erosion is a sudden gully bank collapse (mass failures) that will cause injuries or loss of human and animals' life.

#### Natural factors as a drivers of gully erosion

Natural drivers of gully erosion are mainly heavy rain fall, high temperature and steep slope /gravity factor (Frankl 2012; Faulkner et al. 2004). The data obtained from survey question, group discussion and interview were confirmed this facts. According to the participants the natural drivers of gully erosion of the study area are loss of vegetation cover, weak soil structure, steep slope, high intensity of summer rain, and frequent droughts.



**Fig. 7** "Overlaid maps" gully map

**Table 4** Size of gully length, and width from 1965-2012

Gully ID	1965		1972		2006		Field measurement		
	Length (m)	Width (m)	Length (m)	Width (m)	Length/m	Width (m)	Length(m)	Width (m)	Depth/m
G1	NG	NG	NG	NG	255	10	263	13	10
G2	295	9	317	11	1531	22	1559	28	15
G3	226	6	232	7.5	320	11	355	12	11
G4	337	6	386	7	472	17	480	22	9
G5	NG	NG	NG	NG	1416	12	1541	13	11
G6	NG	NG	NG	NG	398	6	550	7	6
G7	NG	NG	NG	NG	710	11	712	14	13
G8	281	8	303	10	573	13	600	13	9
G9	293	10	360	11.5	862	20	1055	25	9
G10	415	10	482	11	980	15	1020	16	11
G11	252	7	329	8.5	813	11	861	11	8
G12	NG	NG	NG	NG	473	9	500	11	7

Source: Aerial photo; satellite image and ground survey

### Pattern, period and origin of gully erosion

Knowledge on gully pattern (network) serves to understand the present relation of various gullies to look back in to the history of their development and to determine the stage of development (Rowntree 1991). Based on the aerial photos of 1965/1972 and satellite image of 2006 totally 12 gullies have been identified and assigned as G1 (gully 1), G2 (gully 2), G3 (gully 3), up to Gully 12.

In the 1965 and 1972 aerial photo only 7 gullies have been identified, which are G2, G3, G4 in the Koromo Danshe micro watershed and G 8, G 9, G 10 and G11 in the Tabota Koromo micro watershed (see Figs. 4, 5, 6 and 7 and Tables 4 and 5) respectively. Image analysis of Figs. 4 and 5 were depicted similar gully pattern, origin,

size and density for the period 1965 and 1972 in the two micro watersheds. The statistical data in the Table 6, Figs. 6 and 7 shows significant increment of gully sizes between the mid 1970s and 2006. To check whether there is contributing factors or not for gully variation after 1970s, data have been collected from the elders and house hold respondents on the basis of critical period of gully erosion. In Table 6 of the total house hold representative 97% believe that the year 1970s to 1990s was the period of critical gully formation. This period was considered as the year of serious land cover change (deforestation) in the watersheds that was caused by power gap following overthrow of the military regime in Ethiopia (see Table 6).

Other studies conducted by Moges and Holden (2008) in the neighbouring Umbulo catchment showed that, the decisive period of gully development is estimated between 1974 and 1985. Therefore, the significant increment of gully size, density and pattern in the 2006 satellite image of the study area could have resulted from extensive removal of land cover and related factors of 1980s.

### Gully Morphometry and soil loss

Knowledge on gully morphology is essential to explain the reasons for current erosion and to carry out effective gully stabilization measure (Pathak et al. 2005). Morphological characteristics of gully erosion such as gully size, rate of development, volume of soil loss, width-depth ratio (cross-sectional area) and density in the watersheds were presented in Table 7.

To obtain the morphological data particularly about gully length and width field measurement was

**Table 5** Change of gully length and width from 1965 to 2012

Gully ID	1965 & 1972		1972 & 2006		1965 & 2006		2006 & 2012	
	L	W	L	W	L	W	L	W
G1	–	–	–	–	–	–	8	3
G2	22	2	1214	11	1236	13	28	6
G3	6	1.5	68	3.5	74	5	35	1
G4	49	1	86	10	135	11	8	5
G5	–	–	–	–	–	–	125	1
G6	–	–	–	–	–	–	152	1
G7	–	–	–	–	–	–	2	3
G8	22	2	270	3	292	5	27	0
G9	67	1.5	502	8.5	569	10	193	5
G10	67	1	498	4	565	5	40	1
G11	77	1.5	484	3	561	4	48	0
G12	–	–	–	–	–	–	27	2

Source: Aerial photo; satellite image and ground survey

Note ("NG" refers gully was not formed)



**Table 6** Opinion of sample households on the period of gully expansion

Critical period of gully expansion	Tabota Koromo		Kormo Danshe		Total average
	Respondents	Percent	Respondents	Percent	
Between 1960 &1980	–	–	2	4	2
Between 1980s &2000	37	97	46	96	97
Not known	1	2.6	–	–	1
Total	38	99.6	48	100	100

Source: House hold survey

carried out in all gullies of the study watersheds (see Fig. 8). According to the Table 7 and Fig. 8 the total lengths of the gullies in the micro watersheds are 9.5 km. Therefore, the annual average growth rate of the gully length, width, and depth of the two watersheds are 21m/year, 0.275m/year and 0.28 m/year respectively. According to (ul Rasool et al. 2011) the gully length growth rate  $>10\text{m yr}^{-1}$  is considered as catastrophic type of gully development.

Hence, the average growth rate of gullies in the study watersheds with  $21\text{ m/ year}^{-1}$  lies under catastrophic or destructive type of gully erosion. On the same topic data was collected from the house hold representatives to crosscheck their perception on morphometric result of gully development rate (see Table 8).

According to Table 8 of the total respondents approximately 70% perceive that there is fast increment of gully size and density in the area. Therefore, the result from house hold survey was indicated that perceptions of house hold representatives towards

gully development are consistent with the result obtained from image analysis and field measurement.

The other gully morphometry indicators are gully density and volume of soil loss. The average gully density of the two micro watersheds is  $1.4\text{km/km}^2$ . According to Zachar (1982) and Stefanovist and Várallyay (1992) gully density classification, the result of gully density of the study area can be categorized as sever soil erosion and big gully.

For this study the amount of soil loss has estimated with the formula given by FOTG. According to the FOTG (2002) formula for soil loss estimation ( $V = L \times [(W_t + W_b)/2] \times Df$ ) the total volume of soil lost from the watersheds is  $108,0782.6\text{m}^3$  and the average rate of soil loss has appeared to be  $6\text{ ton/ ha /year}$ .

### The effect of gully erosion

Obviously gullies have several consequences commonly on the socio-economic and physical environment of the area where it occurred. Result obtained from house hold

**Table 7** Field measurement result on gully erosion

Name of watersheds	ID of the gully	Length (m)	Width (m)	Depth (m)	W/D ratio	Volume of soil lost ( $\text{m}^3$ )	Age of the gully
Koromo Danshe Micro watershed	G1	263	9	10	0.9	22,355	17
	G2	1559	17	15	1.49	395,206	50
	G3	355	6	11	0.7	26,838	48
	G4	480	13	9	1.4	55,944	48
	G5	1541	9	11	1.5	144,083.5	35
	G6	550	5	6	0.8	17,490	20
	G7	712	8	13	1.1	75,358.08	24
Soil loss						737,274.6	
Tabota Koromo Micro watershed	G8	600	8.5	8.75	1.14	44,625	49
	G9	1055	14	9	1.6	135,862	50
	G10	1020	9	11	0.9	96,390	49
	G11	861	7	8	0.8	45,116	48
	G12	500	6	7	0.9	21,515	18
Soil loss						343,508	
Total soil loss						108,0782.6	

Source: Field measurement



**Fig. 8** Measurements of Gully Dimensions

survey, focused group discussion, interview, field observation and field measurement were showed that, the major impacts of gully erosion has listed here under the sub categories of social, economic and physical effects (see Tables 9, 10 and 11).

#### ***Social effect of gully erosion***

Gully erosion has negative impact on the social aspects of human being, such as; reduce land available for agriculture, displacement of people, workload, loss of life, injuries, and risk of flooding that affects infrastructures (Valentin et al. 2005). To assess the social impacts of gully erosion, data was collected from household survey (see Table 9).

According to Table 9 about 91% of house hold respondents argued that the social effect of gully erosion in the watershed are loss of life, injuries, separation of village, out migration, insecurity, poverty and famine. For instance, participants on group discussion and interview have told that since the gully has formed around five livestock are injured and one young 12 year boy has lost his life that dropped to the deep of the gully.

Also, the farmers settled closer to the gully in the study watersheds have said that, the sound of flood in the gully during the rainy season was created a great anxiety, this condition are damaging their psyche or affecting their health condition more than other farmers far away from the gully bank.

**Table 8** Perception of farmers on the rate of gully development

Rate of gully size and density increment	Frequency	Per cent
Fast	60	69.8
Slow	22	25.6
Not identified or not known	4	4.7
Total	86	100

Source: House hold survey

#### ***Economic effect of gully erosion***

Economic impact of gully erosion can be analysed from two perspectives, the first perspective is the on-site effect of plots on which the signs of runoff and erosion have developed and the second perspective is the off-site effect that damage further downstream (Boardman et al. 2003). For this research work both onsite and offsite impacts of gully erosion in the study watershed were considered for analysis (see Table 10).

The data from house hold survey (Table 10) illustrate that, around 88% of house hold representatives believes the major economic effect of gully erosion are (a) loss of property (b) decline of food and income and (c) change of livelihood system through time.

The participants have said that before the extensive gully formation the common foods items of the study area were root crops, fruits, cereal crops (maize, teff, haricot beans, barley, and green papers), and cash crops. But now most items are less productive, while some others are completely not growing because of land use land cover change, gully erosion, and related factors. During group discussion and interview very aged farmers have told to the researchers, before 1970s wild fruit was common food item to their feeding system, but now such access was become history. The result obtained from discussion, interview and observation clearly showed there are economic impacts as a result of gully formation in the study area.

#### ***Environmental effect of gully erosion***

According to, Stout, B. A. (1965) gully erosion causes loss of soil forever and it affect the physical feature of the land often making them unworkable and completely uninhabitable. In the same way the physical impact of gully erosion is visibly observable in study watersheds (Table 11).

According to Table 11 around 81% of the households' respondents' have expressed that due to the dramatic expansion of gully erosion, the area has experienced land

**Table 9** Social effect of gully erosion

Social impact of gully erosion	Respondents	Percent
Loss of human life and injuries	7	8.1
Increasing of poverty and famine	1	1.2
Loss of life and injuries, separation of village, out migration of people and insecurity feeling.	78	90.7
Total	86	100.0

Source house hold survey

use land cover change, shortage of agricultural and grazing land, loss of fertile soil, decline of biodiversity, loss of wild life and locally known vegetation, root crops and wild fruits (see Fig. 3).

## Conclusions

Watershed based knowledge of gully dynamics are more important for successful gully erosion control at least cost (Pathak et al. 2005; Poesen et al. 2011). In this regard, assessment of gully erosion dynamics, drivers and impacts in selected watersheds of South Central Ethiopia was carried out. For reliable and valid results of the study, various data gathering tools such as satellite image analysis, household survey, group discussion, interview, and field observation were applied. The results of the study showed that in 1960s and 1970s gully erosion was constrained in the steep slope of the watersheds. But in 2006 image analysis, the gully erosion expanded significantly to the middle and lower parts of the watersheds.

According to the data obtained from the primary and secondary sources, the major driving forces of gully erosion in the study watersheds are mainly related with both human activities and natural factors. Some of the identified drivers of gully erosion of the area are change of land cover, expansion of agriculture, population growth, unconsolidated soil, steep slope (gravity factors), frequent drought and high intensity of rainfall. In the Ethiopian context high deforestation in 1970s and 1980s occurred as a result of resettlement program of the military regime, invasion of land by small famers,

**Table 10** Economic effect of gully erosion

Economic impact of gully erosion	Respondents	Percent
Decline of food	4	4.7
Loss of property	2	2.3
Change of livelihood or economic activity	2	2.3
Decline of income	2	2.3
All the above problems (loss of property, change of livelihood, decline of food & income)	76	88.4
Total	86	100.0

Source house hold survey

**Table 11** Physical effect of gully erosion

Physical impact of gully erosion	Respondents	Percent
Loss of soil fertility only	7	8.1
Loss of vegetation only	9	10.5
Loss of soil fertility, biodiversity and expansion of degraded land	79	81
Total	86	100

Source house hold survey

fragmentation of lands and insecurity feeling of land users due to overthrow of the military government.

The socio-economic and environmental effects of gully erosion that has been observed in the study area were injuries and loss of life; separation of village; displacement of people; decline of products and income; loss of soil fertility and property; loss of biodiversity and wild fruits and expansion of degraded physical feature. However, there are conditions, which has good opportunity to secure the effort for gully rehabilitation and sustainable ecosystem services in the watersheds.

These are better labour force, access of transportation, positive perceptions of farmers for the gully rehabilitation, presence of different civic societies working in natural resource conservation, the national environmental policy that was drafted in 1995 and the recent integrated watershed management initiative of the country. Therefore, the result of this study will be a golden opportunities to set compatible conservation strategies for gully rehabilitation and to prevent further gully formation in the study watersheds.

## Recommendations

- According to the study, land degradation via gully erosion in the watersheds are worsening throughout the year, therefore all stake holders need to apply sustainable and participatory natural resource management practices.
- Continuous' and extensive effort must be there to work with civic societies in the conservation effort.
- The high human intervention on natural resource need to be minimized or controlled.
- Awareness creation must be there about consequence of land cover change (deforestation)
- Maximum effort must be given to conserve the remaining natural resources.
- Research based conservation design need to be prepared and implemented.
- Once gullies are formed huge investment are required to rehabilitate the gully, therefore, prevention of gully erosion is better than gully stabilization.

**Acknowledgements**

Not applicable' for that section

**Authors' contributions**

Corresponding author Mr GH has worked on data collection and analysis. Co author AB has worked on organization, edition and correction of the manuscript. Both authors read and approved the final manuscript.

**Funding**

Not applicable' for that section

**Availability of data and materials**

Applicable' in this section. All data generated or analysed during this study are included in this published article.

**Competing interests**

Authors of this research have no conflict of interest. Also the authors need to ensure that they are responsible for any conflict of interest that may arise. Also the researchers have not received any fee for patents of the manuscript. Concerning non financial computing interest the authors encourage the manuscript has significant value for intellectual and/or academic purposes on the fields.

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Received: 3 July 2019 Accepted: 20 November 2019

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