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LONG TERM LAND -USE CHANGES AND IMPACTS ON GULLY DEVELOPMENT IN SOUTH ETHIOPIA

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ABSTRACT

Unsustainable land use causes land degradation, and subsequently one of the major challenges of sustainable development goals achievement. In Ethiopia, environmental changes are taking place at unprecedented rate, causing sever soil degradation such as gully erosion. However, there is only little attempt to study on the processes and phases of gullies development in the context of long term land use and land cover change, LULC. The objective of this study is to examine the effects of the land use land cover changes over the last four decades on the development gully processes including incision, aggradations, and stability and soil formation under different agro-ecological zones in southern Ethiopia, the case of Chencha and environs. Spatial data on land use land cover required and interpreted using the satellite images and GIS. The characteristics of gullies were described by field surveys. Group discussions and interviews were used to enhance the field survey data. The study's findings demonstrated that, throughout the previous 40 years, there has been a rise in unsustainable LULC in the area, including deforestation, excessive farming, overgrazing, and shrinkage of grasslands. Due to unsustainable LULC, gullies are frequent in highland basaltic soils, colluvial deposits of rift valley escarpments, and lowland alluvial deposits. The area's gully system is marked by a cyclical succession of phases that include entrenchments, aggradations and stability and soil formation. The chronostratigraphy of a gully system comprising 14 phases of gullying and sedimentation cycles has been identified and reconstructed. If the current pattern of gulling continues, a considerable amount of land will be abandoned for farming and grazing which in turn worsen the poverty condition of the people and the food insecurity. Thus land use planners should take into account consider in the interaction of the environmental changes and soil degradation. For environmental scientists, land managers, and policy-makers, evaluating the relationships between environmental change and land degradation is crucial. Sustainable land management through watershed management that is based on grass-roots level community participation from the conception phase to implementation and maintenance is recommended

Keywords: Sustainability, Soil Degradation, Gully Chronostratigraphy, Environmental Changes, Human Impacts, Land Use, Ethiopia,

INTRODUCTION

The dynamics of land use and land cover, which are major contributor to land degradation such as gullies, have a significant impact on sustainable land management (Qu et al., 2023). More specifically, the land use of developing nations that heavily rely on the agricultural sector for their livelihoods has changed at a high rate and significantly contributed to the high rate and intensity of land degradation worldwide (Li et al., 2020; Qu et al., 2023). Hence, changes in land use and land cover are the main factors affecting the sustainable use of terrestrial ecosystems (UN, 2015). To improve the attainment of SDG 15 (UN, 2015) which focuses on halting and reversing land degradation, studies of this kind that depicts the effects of changing land use on gully development and incision suggest potential solutions that capitalize on the opportunities provided by practices and activities aimed at enhancing sustainable land management.

Gully erosion is a widespread phenomena of soil degradation process in the world that affects many regions in the world (Castillo & Gómez, 2016; Poesen, 2011; Vanmaercke et al.,2016; Ionita, I.,2015). It is the formation and expansion of erosion channels in the soil due to concentrated water flow, occurring in a verity of environmental setting (Yibeltal et al, 2019; Castillo & Gómez, 2016 ; Guan et al., 2016). Numerous studies (Poesen et al., 2003; Valentin et al., 2005; Imwangana, 2015) showed that gullies can cause significant damage to land, crops, roads, buildings and other infrastructures and also sediment loads to dams, reservoirs. Gully is therefore a great concerns in many region of the worldwide. It is a key process of land degradation and desertification, posing a significant threat to various biodiversity, endangering a wide range ecosystems and ecosystem services (Poesen, 2011;Díaz,2019; Ionita, I.,2015; Dotterweich et al.2012). At present the gully erosion is increasing at high rate as compared with the past (Zhang, et al, 2023;; Bennett & Wells,2019; Dotterweich et al.2012). The occurrence and development of gully erosion in mainly associated with the unsustainable land use and land cover including deforestation, over cultivation, over graining and road mal design are among the other (Castillo & Gómez, 2016; Yibeltal et al, 2019). The gully research has received less attention despite the severity of the issue and the growing trends. It was said that the gully accounts for only 10% of the land degradation research (Castillo & Gómez, 2016). This is therefore call for more research on the gully erosion. The extent and severity of gully erosion can vary significantly over time and space. Thus conducting the site specific study on the development of the gully erosion play vital role in order to find specific site solution.

In Ethiopia, gully erosion is a major form of land degradation in Ethiopia, which gullies covering around 7.6 million hectares (Haregeweyn, 2017). In Ethiopia, a gully erosion phenomenon is ubiquities A gully erosion phenomenon is ubiquities in Ethiopia since long period of time (Mahcado et al., 1998; Billi and Dramis, 2003; Carnicellie et al., 2009; Frankl et al., 2011, 2015). For example, Carnicellie et al. (2009) found and studied Gllying that occurred 5000 years ago in the Main Ethiopian Rift. Among other reasons, soil degradation contributed to the collapse of Ethiopia's Axum civilization by the year 800 AD (Butzer, 1981). In Ethiopia, gully erosion has been alarmingly increasing during the second part of the 20th century, according to various studies. For instance, Moges and Holden (2008) reported that between 1974 and 2006, the rate of gully erosion increased in a region in south Ethiopia, Awassa, raising from 11 t ha-1 yr-1 to 30 t ha-1 yr-1. Daba et al. (2003) showed that between 1966 and 1996, gully erosion increased in Hararghe, eastern Ethiopia, from 9 t ha-1 yr-1 to 26 t ha-1 yr-1. In a similar vein, Tebebu et al. (2010) reported that within an investigation area spanning 17.4 hectares, the area impacted by gully erosion in the Lake Tana area of northern Ethiopia increased significantly, from 0.56 ha in 2005 to 1.43 ha in 2008. Another study conducted in Gumera watershed in northwestern Ethiopia found that the surface area damage and soil loss had increased from3.31 to 11.42 ha, and from 60.58 to 273.07 tons respectively (Mengie et al, 2020).However, studies conducted in northern Ethiopia's Tigray region by Nyssen et al. (2004) and Frankl et al. (2011, 2015) revealed that gully erosion rates have not increased since 1990.

A wide range of study demonstrated that the most dominant causes of the gullying are attributed to deforestation, intensification of agriculture, overgrazing , and roads (Valentin et al., 2005; Garcia-Ruiz et al., 2015; Yang et al., 2003). For example, in Iran, excessive farming, deforestation, and overgrazing resulted in the loss of protective cover, which resurfaced in the longest gully that appeared on the flat area in the semi-arid country (Jahantigh., & Pessarakli, 2011). Similarly the unprecedented rates of erosion by gully in Ethiopia since the middle of the 20th C are mainly as a result of the attributed to changes of land use and land (Haregeweyn et al, 2017, Daba, et al., 2003; Nyssen, 2006; Moges and Holden, 2008). The land use in most regions of Ethiopia is characterized by intensive agriculture, deforestation and overgrazing. Various studies in Ethiopia revealed that forest clearance took place at high rate or in an unprecedented ways. Since 1900 about 23 M ha of forest land were cleared, mainly driven by a conversion to arable farmland (Resuing, 2000). More recent satellite image analysis of the period between 1973 and 1990 for the entire country also revealed that about 2,4543km² of forest (2.14% of the total forest resources of the country) was cleared, mainly because of the demand for acreage (Resuing, 2000). Moreover, a considerable portion of grassland was also shifted to cultivated land (Benin et al., 2001). Furthermore the extent of cultivated land in Ethiopia has significantly increased, particularly during the last hundred years. From 1900 until 1989, about 4.7 million households required arable land for cultivation (Hurni, 2007).

Additionally, it is discovered that a variety of other causes are exacerbating Ethiopia's gully system's incision-aggradation. There is also a lot of land degradation on farmed land that aggravate gully development. Furthermore, during the 1990s, gully formation has been exacerbated by road construction in Tigray, northern Ethiopia (Nyssen, 2006; Frankl et al., 2011, 2012). Vertisols is also to be one of the variable that promote tunneling, or subsurface erosion, and gully development (Moges and Holden, 2008; Frankl et al., 2011). In Ethiopia, gullying forms and develops more readily due to steep slopes and heavy precipitation (Frankl et al., 2012; Moges and Holden, 2008). The primary factor responsible for the cutting and filling of gullies in Ethiopia's major Rift Valley during the Holocene was extreme precipitation episodes(Carnicellie et al. 2009). In general the sensitivity of the land is also the primary factor for the recent devolvement and widespread of gullies in Ethiopia.

There are several reasons for this research. In comparison to other forms or types of soil erosion, gully erosion has received less attention from researchers and the government, despite gullies being the most common and dominant form of soil erosion in Ethiopia. For instance, measurements of sheet erosion at the plot level and extrapolations using USLE-type models served as the sole basis for estimations of the magnitude and economic costs of soil erosion in Ethiopia(e.g. Hurni, 1988; FAO 1986; Bojö and Cassells, 1995). Gully erosion was not taken into account in the estimations of annual soil erosion in Ethiopia (1.9 billion tons per year according to FAO (1986) and 1.5 billion tons per year according to Hurni (1988).As a result, these estimations of the actual amount of soil lost to erosion are not accurate or reliable. Moreover, , they do not accurately reflect the vast swaths of the nation that are characterized by a greater diversity of soils, slopes, climates, and land use activities. Conversely, in several regions of Ethiopia, gullying is the predominant form of soil erosion. For instance, Tebebu et al. (2010) found that in the Lake Tana region of northern Ethiopia, the rate of gully erosion was twenty times larger than the rate of rill and interrill erosion. Thus in the future the policy makers should take into account this issues while making environmental management plan and measures to halt soil erosion. Hence, it is imperative to conduct additional research on gully erosion.

Several gully erosion research in Ethiopia have been concentrated in the north parts of Ethiopia (Carnicellie et al. 2009). For instance the study on the intensity of gully (Frankl et al.2012); dynamics of gully (Daba et al., 2003; Moges and Holden, 2008), head cut of gully (Yibeltal et al, 2021). Given the heterogeneity of the environmental circumstances and the vast region covered, such studies in the northern portion of Ethiopia could not be typical for the other parts (east, west, south, and center) of Ethiopia. Nonetheless, as the living gully attests, there are a great deal of different and numerous gullies that have an impact on the social-economic, topographical, and human aspects of the country, particularly the farmers in Ethiopia's south (Yibeltal et al, 2019). Specifically, as the population grows and more people choose to cultivate steep slopes, more fallow land is left uncultivated, various forms of soil protection are destroyed, and gully formation is promoted, a variety of soil degradations are created.

Furthermore, most studies on gullying in Ethiopia focused on the magnitude and extent of the gully's dynamics; the impact of the gully on land production); and effects of gully erosion on the hydrological and drainage patterns (Daba et al., 2003; Moges and Holden, 2008; Frankl et al.2012). However, there has been little to no research on the formation of gullies, their incision and aggradation, and their connection to Ethiopia's unparalleled changes in land use and land cover. This type of research, however, is important for a number of reasons. It includes for better understanding of the historical aspects of soil degradation, such as gully erosion, which in turn plays a very important role in the development and implementation of strategies to halt or reduce the adverse environmental and socio -economic impacts caused by land degradation. In order to demonstrate the significance of the past land degradation, remember the saying, "If a person does not understand the past, they are likely to repeat it." Additionally, it adds to the body of knowledge on the relationship between gully erosion and the environment. Providing relevant empirical data is essential for policy makers and environmental planners to successfully handle issues originating from dynamics of land use and cover.

The objective of this study is to examine the effects of the land use land cover changes over the last four decades on the development gully processes including incision, aggradations, and stability and soil formation under different agro-ecological zones in southern Ethiopia, the case of Chencha and its environs. Thereby, to look at the interplay of the long-term land use land cover change and its effects on cutting, infilling and stabilizing of the gully erosion and to reconstruct the stratigraphy of gullying

Thus, the intent of the study is to generate valuable information regarding the gully's origin, processes, causes, and effects. As a consequence, the study's findings advance knowledge of how soil degradation and environmental change interact The decision-makers and planners will employ evidence based knowledge to plan and implement sustainable land use and management, which will also significantly impact institutional and governance responses to unsustainable land use and the advancement of sustainable agricultural land use. By implementing this, SDG 15 and other sustainable development targets will be improved. It also contributes to the nation's efforts to reduce poverty and contributes for the solutions for the food security of the county.

The investigated areas Chencha, southern Ethiopia is one of environmentally most sensitive areas of Ethiopia. It is marked by high rates of land use and land cover changes, which exacerbate the gully erosion. Aged rills and gullies are still visible, indicating the impacts of the past land use and it is manifestation of the relationship between human and environment.

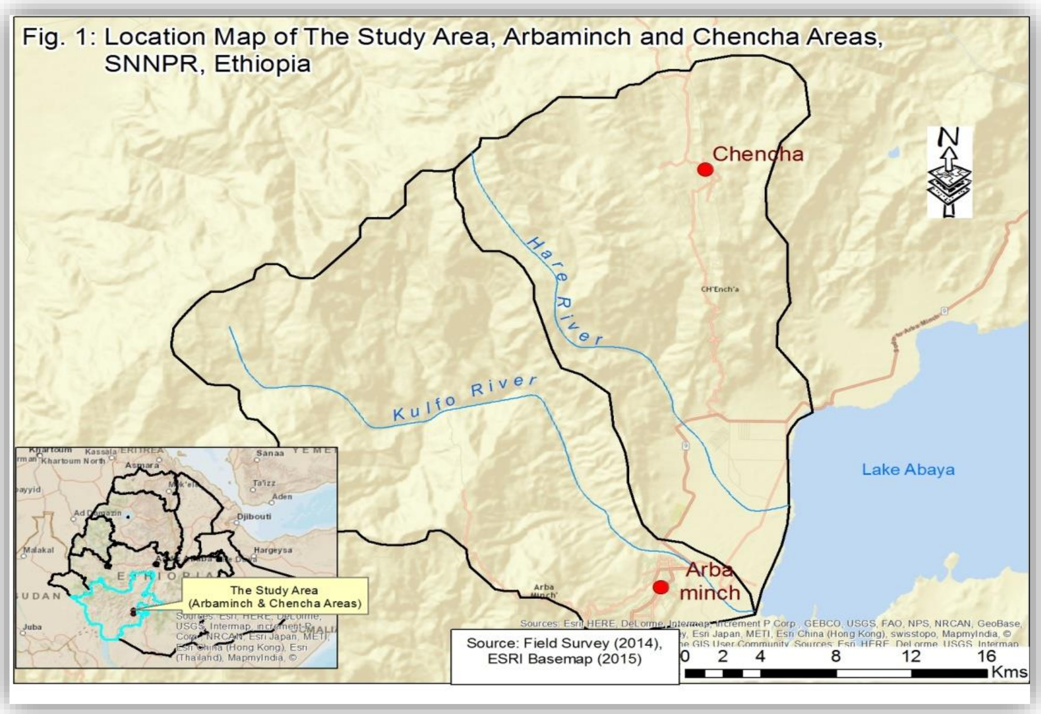
MATERIALS AND METHODS

Description of the study area

Chencha is located in the GamoGofa Zone, Southern Nations, Nationalities, and People's Regional State (Fig.1). It is situated about 480 km southwest of Addis Ababa and are bounded on the east by Lake Abaya and Lake Chamo. The topography is characterized by a series of undulating and rugged landscapes, which include from east to west the Rift Valley Plain, the escarpment with incised valleys, and high plateaus, which are topped by hills and mountains. The valleys of the perennial rivers (Kulfo and Hare,) are steep in the upstream (highland) and midstream (escarpment) areas, and flat in the Rift Valley (Fig.4)

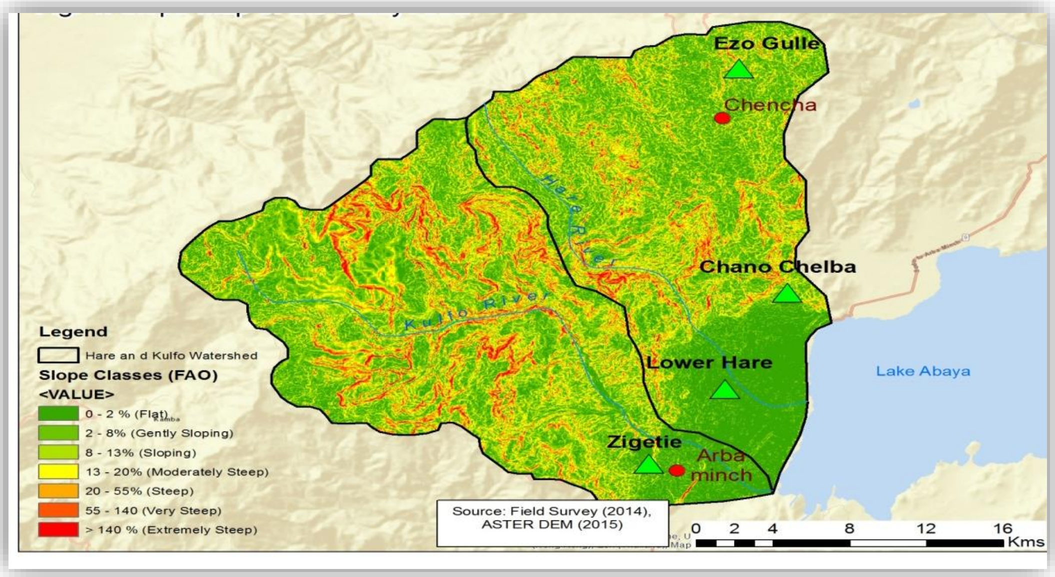
The mean annual rainfall of the investigation areas, based on meteorological records from Arbaminch, 1,200 m a.s.l.(Zigetie from middle watershed and Lower Hare) and Chencha, 2,700 m a.s.l. (EzoGulle from the upper watershed) from 1970 to 2008, varies from 781mm (Arbaminch) to 1,392mm (Chencha). Elevation is the most important factor for the variation of the mean annual rainfall. The rainfall distribution in Chencha is monomodal, occurring from April to October. The highest monthly rainfall occurs in April, which amounts on average to 185.4 mm. It occurs when moist wind from the Atlantic and Indian Oceans converge over the highlands. The season here is not as distinct as in Arbaminch. The rainfall in the rift valley is marked by short heavy bursts with intensities of up to 100 mm per hour, whereas in the highlands high intensities may only reach 60-70 mm per hour (Bekele, 2001). The intensity of rainfall is an important factor for exacerbating soil erosion. The patterns of rainfall occurrence have impacts on gully formation and expansion. The peak precipitation falls after the long dry period (December to February in Arbaminch and Chencha) in which the vegetation cover is sparse and plowing takes place. The dry conditions (the low soil moisture content) thus enhance the formation of cracks in the soils. Then, the rain falls on soils with low soil aggregate stability, low soil moisture content and accelerated erosion rates, resulting in gully formation (Cerdà, 1998; Cerdà, 2000; Ziadat and Taimeh, 2013).

Natural vegetation is sparse and only small patches, such as sacred forests, are found in the highlands due to the cultivation of most land areas. However, eucalyptus trees are common around the homesteads and on community woodlots. Cultivating crops and livestock rearing have been the dominant economic activities since the beginning of settlement in the area (Arthur et al., 2010; Cartledge, 1995). The farming systems in the highlands are marked by small scale agriculture entirely dependent on rainfall. In the lowlands, small-scale irrigation is also practiced for growing bananas and other crops.



Source: Field Survey (2014), ESRI Basemap (2015)

Fig.1 Location map of the study area



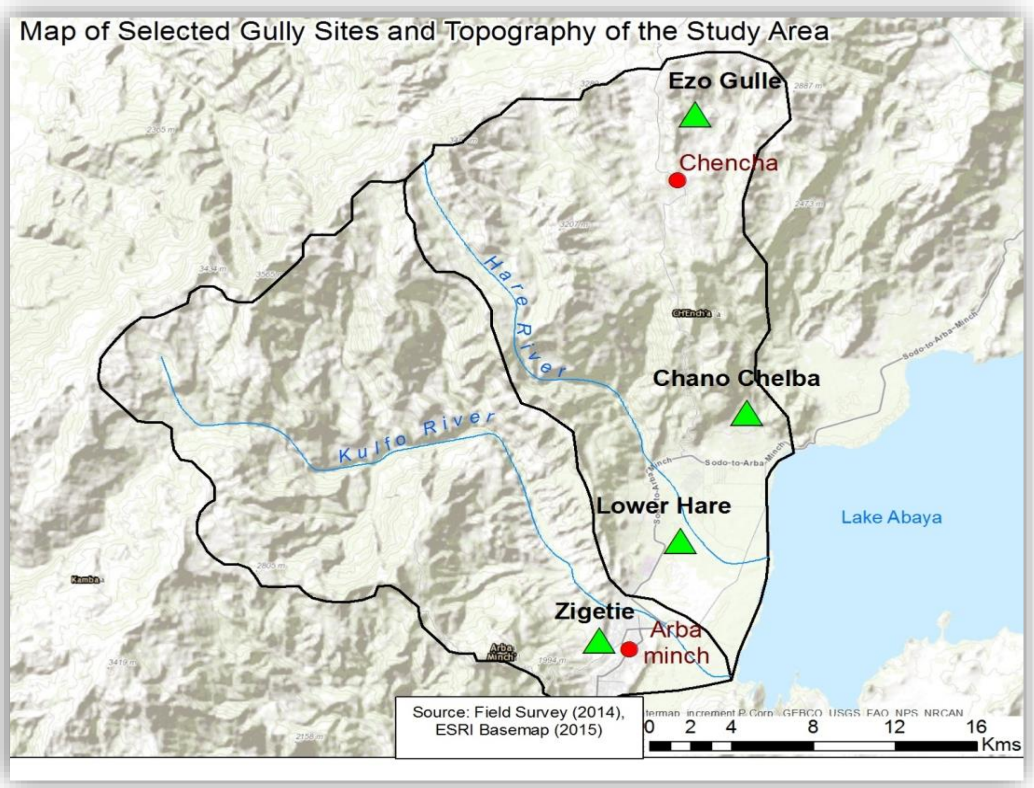
Source: Field Survey (2014), ASTER DEM (2015)

Fig. 2. Slope map of the study area.

Study Sites Selection and Characteristics

Our investigated areas, Chencha and the surrounding environs, are marked by various geo-environmental settings that trigger the formation of gullies. They are characterized by high altitude differences within short distances; about 2400 m of elevation difference within 20km distance. However, despite their altitudinal differences, these areas are spatially highly interconnected. The disturbance of the natural environment of the highlands, for instance, affects runoff generation that in turn causes gully formation and development in the lowlands. Accordingly four representative gully systems located in different environment and agroecology were selected for investigation. These are: EzoGulle from the upper watershed, ChanoChelba and Zigetie from middle watershed and Lower Hare from lower watershed selected (Fig.2). Gullies were identified and gulley exposures surveyed.Figure 2. The breif descritpion of the sites is given below.

The areas that we investigated, Chencha and its surroundings, are characterized by a variety of geo-environmental conditions that have contributed to the development of gullies. They are distinguished by significant altitude differences over short distances; a 20-kilometer route can have an elevation difference of roughly 2400 meters. These places are geographically highly interconnected, despite their altitudinal variations. For example, disruption of the highland ecosystem impacts runoff generation, which in turn results in the development of gullies in the lowlands. Based on the varying agroecological conditions, four representative gully systems were chosen for study. These include : lower Hare from the lower watershed, ChanoChelba and Zigetie from the middle watershed, and EzoGulle from the upper watershed (Fig. 2). Gully exposures were identified and surveyed . The site's brief description is given below:



Source: Field Survey (2014), ESRI Basemap (2015)

Fig 3. Map of selected gully sites

(1) The highland **(**EzoGulle **):** the topography of the highlands consists of high plateaus with river valleys, hills and mountains. Mountaintops are mostly gentle to almost flat.The dominant soil that cover the area is Nitisols. In some cases, shallow soils sometime is the saprolite is found the on steep slopes of the plateaus and on summit of the plateau. The area is also marked by the intensive cultivation of crops and livestock raising.

(2) The Rift Valley escarpment and footland **(**ChanoChelba and Zigetie). It is situated in between the plateau and the flat plain shore lake. The topography is marked by the steep slope and undulating and rugged surface features. The area is dominated by the escarpment which is also dissected by the concave valley. The dominant type of soil is Cambisols which is developed on colluviums. In most cases the land is covered with trees which is which is the main sources of fuel wood for inhabitants of the plateau. The cattle from the neighboring areas use the areas mostly for grazing as a source of feed.

(3) The low land **(**Lower Hare from lower watershed**)** : It covers the areas close to the lakes. The area has a sufficient accommodation space that is used as a trap for sediments from the surrounding escarpments and highland. . The most common type of soil is fluvial. This soil type is productive and distinguished by its deep profile. A river flows through the area, and there is some small-scale irrigation going on. The settlement is a relatively new phenomenon. Because of the prevalence of malaria in the past, people did not live in the area.

Methods

The methods used in this investigation include satellite and digital elevation model, field observation.Moreover group discussion and participatory rural appraisal and secondary data were also employed.

Sattlite Image Interpreton

Different Cartographic resources were employed to map the Digital Elevation Model (DEM) and the patterns of land use and land cover in the area. These included a topo map of the area, satellite images, and Google Earth. We were able to map the slope, elevation, and other geomorphologic parameters using Digital Elevation Model that we derived from ESRTI. Using a time-series analysis of satellite images, land use land cover maps were produced. Field surveys were conducted in conjunction with Landsat MSS, TM, and ETM satellite photos acquired in December of 1986, 2000 and 2017. The month of December is a dry season with little clouds. These photos were geometrically matched to the topographic map of the area at 1:50,000 scale. Different land uses such as forest, cultivated, grazing land, barren land, and settlemns were identified from the images by supervised classification method. Data for ground referring (ground truth) were employed from extensive field observations and interviews. In addition, we used the topographic maps of 1984 with a scale of 1:50,000 for ground validation.

Participatory Gully Assessment and Field survey

Gully exposures were identified and servyed in our investigation sites. The familiarity with the area was also very important parts of the techniques of investigation. We measured various attributes of gullies., which has a paramount importance. In order to detect and ascertain the processes of initiation, formation, and development of gully in the context of historical and present land use and land cover, we measured a variety of gully parameters. The various tools such as GPS, tape meter, digging materials etc were utilized to measure the characteristics of gully such as incision, aggradation, stability, and chronostratigraphic at the study sites.

Participatory gully erosion assessment method was also used. This method is used to gather data about the historical variation of the gully and thus to determine the trends and changes of the gully (Nyssen..). This methods involving the old people who liven in the areas for long period of time and determine the historical gully erosion magnitude and rates in different period of time. Participatory rural techniques have been proven to be effective in generating information, for a range of natural resource research.These techniques also enable new technologies to be better adapted to the local circumstances. (Stocking and Murnaghan, 2000.Various studies used participatory rural appraisal techniques to determine rates of gulling in Ethiopia (Nyssen, 2006; Moges and Alden 2008; Tebebu, 2010).

Moreover, three This study also employed participatory rural appraisal techniques for collecting a variety of information. In this technique, farmers describe how they recognize the processes and effects of gully erosion on their cultivated land and the surrounding areas. In discussions with the key informants, checklists were prepared which include the history (the formation and progress of gullies), causes, and consequences. The key informants were the experienced older people and the ritual leaders. The event calendar was also established as a benchmark for comparison of changes of the gullies over time. People usually remember a certain situation by associating it with specific events. One example of such an event was the change of the government. In Ethiopia, two major radical government changes took place in 1974 and 1990.

Focus Group Discussions were also held in the investigated sites. Ten informants were selected from each area. Participants in the discussions were elders (mainly over 50 years of age, both sexes) who could remember and convey past events of agriculture land use and the occurrence of specific forms of relief. The discussions were carried out based on the checklists that focused on evolution, process, dynamics, causes and consequences of gully erosion and gulling.

Additionally, the interview was also administered. From the lists of the households in the kebeles, forty informants from each Kebele, a total of 120 household heads were randomly selected. The interview questionnaires were composed of both close and open-ended questions that include farmers' perceptions on the processes and effects of gully erosion on their cultivated land and the surrounding areas. It also included the history (the formation and progress of gullies), causes, consequences and the various measures employed to halt gullies (e.g. soil water conservation practices).

The information which was derived from the field survey and measurements of gullies, along with discussions with farmers, was combined with the general geomorphological setting,climate data, information about land use systems and landscape structure. Finally, a stratigraphy was reconstructed based on the gullying processes in a relative chronological and spatial sequence of incisions and aggradations. The anthropogneic causes and consequences of gully erosion were discussed and suggestions for improvements were put forward.

RESULTS

Patterns and trends of land use and land cover changes

The spatial distribution and the areal extent of the land use and land cover, LULC, of the area over the last three decades were presentd in Table 1 and figure 3-4. In 1986, the dominant LULC was cultivated land, forestland and grass land with proportion of 59, 19 and 17.3% of the total area, respectively. Built-up areas, bare land (degraded land) and water body accounted the smallest proportion of the study area. Likewise, the he dominant LULC in 2000 were cultivated land, forestland and grass land with 66, 2, 17 , and 11.9 % respectively. In the year 2017, cultivated land was the dominant land use which accounted for 68.1 % while forest and grass land accounted for 16.5 and 8.0 % respectively.

Landscapes of the study site have experienced a marked change in land use and land cover over the last three decades (Tables 2 and Figs. 2) . In the period from 1986 to 2017 forest land and grass land declined by 13%and 53.8% respectively while in the same period of time cultivated land, bulid up areas and barren land increased by 15%, 37.5% and 467% respectively.

Table 1. Land use/Land cover in Chencha

LU LC year	1986		2000		2017	
	ha	%	ha	%	ha	%
Cultivated land	44252.2	59.0	49652.5	66.2	51077.4	68.1
Forest land	14250.7	19.0	12750.6	17	12375.6	16.5
Grass land	12975.6	17.3	8925.4	11.9	6000.28	8.0
Bareland	3000.0	4.0	3600.2	4.8	4125.2	5.5
Builtup area	225.0	0.3	375.1	0.5	1275.1	1.7
Waterbody	300.1	0.4	300.1	0.4	300.1	0.4
Total	75003.7		75003.7		75003.7	

Table 2 Land use/Land cover Change in Chencha during 1986 - 2016

LU LC	1986- 2000		2000 -2017		1986- 2017	
	ha	%	ha	%	ha	%
Cultivated land	+5400.3	+12.2	+1424.9	+2.9	6825.2	+15.4
Forest land	-1500.1	-10.5	-375	-2.9	-1875.1	-13.2
Grass land	-4050.2	-31.2	-2925.12	-32.8	-6975.32	-53.8
Bareland	+600.2	+20.0	+525	+14.6	+ 1125.2	+37.5
Builtup area	+150.1	+66.7	+900	+239.9	+1050.1	+466.7
Total	75003.7		75003.7		75003.7	

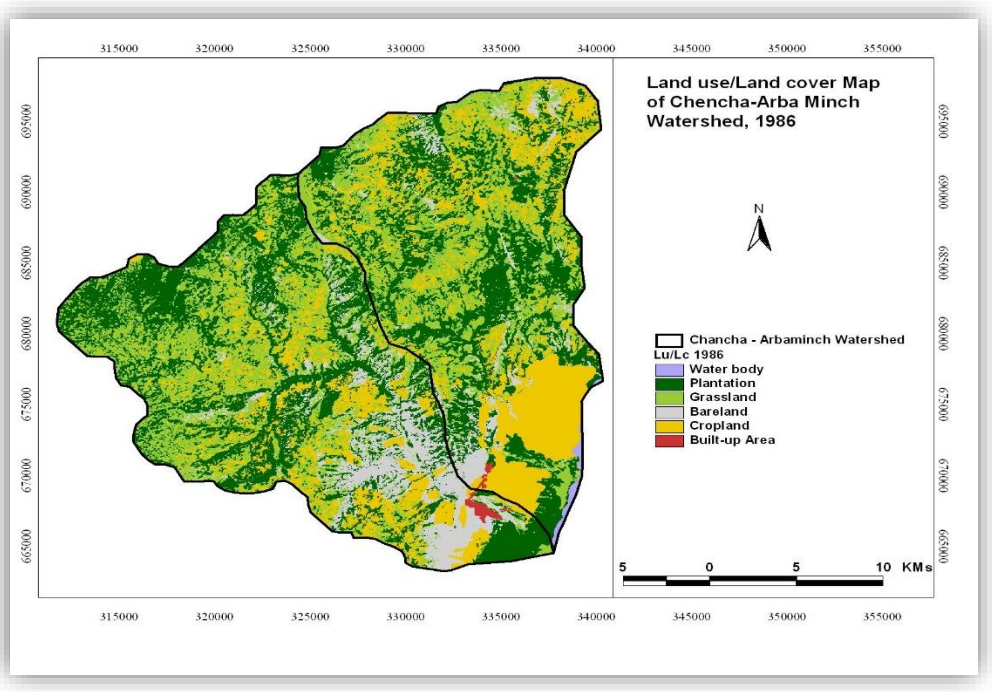


Fig 4. Land use land cover of Chencha_Arbaminch, 1986

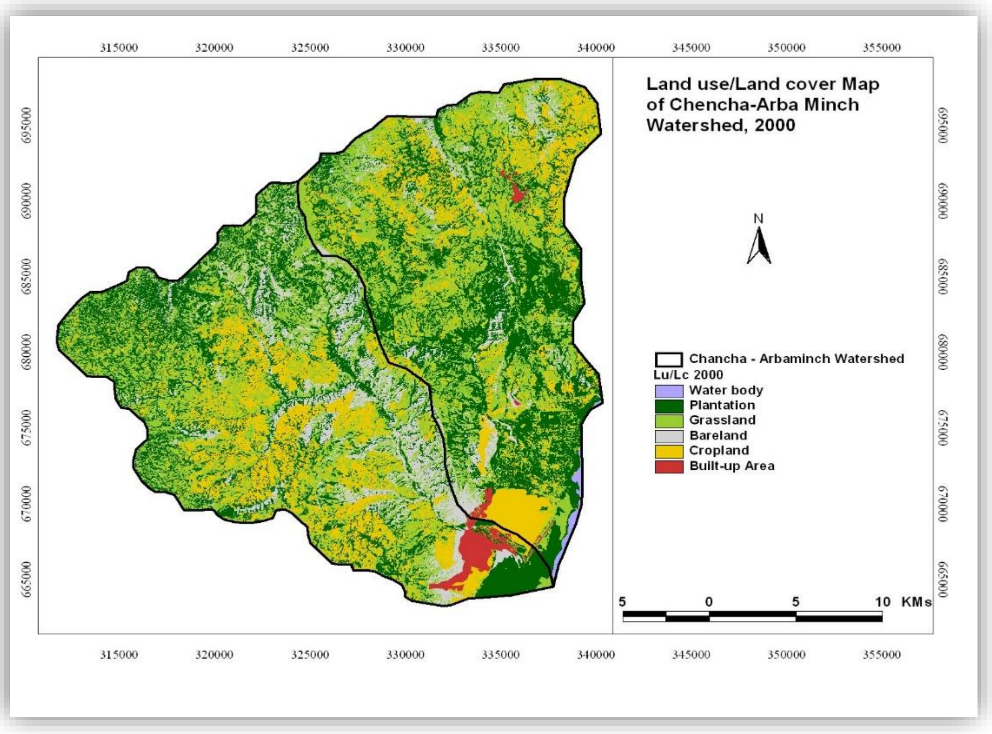


Fig 5.Land use land cover of Chencha_Arbaminch 2000

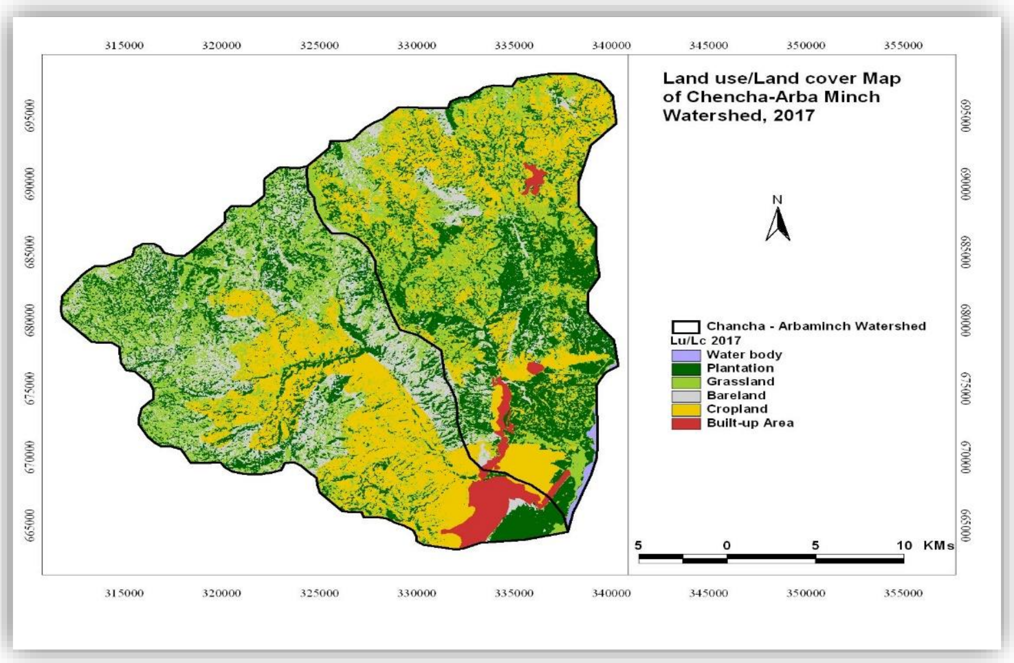


Fig 6. Land use land cover of Chencha_Arbaminch, 2017

Gully Initiation and Development

Gullying occurs on various topographies and at various intensities. Gullies develop on the cultivated land, in the grazing areas, at the fringe and within town, on and near footpaths and roads, and in irrigated fields. Here below discussion on the formation, development and stratigraphy of gullies at different places or sites.

Case 1: gully development in the lowland (along the river ; case in Hare river flood plain)

In the investigated gully profile (figure 5) in the flood plain of Hare river, a fine soil material was deposited in a thickness of more than 2.5m (Table 3). Loamy floodplain sediments are dominant. In the upper part of the profile, runoff intensities have been higher and sand was deposited there. The floodplain sediments contain the lower segment of a buried trunk of an acacia tree, which is still in its original position. The acacia tree started to grow on top of layer F1, before layer F2 started to be deposited; on a former soil surface, which is buried today at a depth of 239 cm below the recent surface. The acacia tree grew during the period when F2 and the lower part of F3 were deposited. Then, humans cut the trunk and burnt the cut surface, at the latest after F2 and 55 cm of layer F3 were deposited. The trunk has a maximum diameter of 15 cm. Since the tree is not decomposed at all, a young age in the middle and upper part of the sequence (F2-F4) is probable. We can conclude that erosion increased intensively when the clearing of the woodland on the steep slopes of the escarpment of the rift valley and agricultural land use began some decades ago.

Figure 7: Gully of Lower Hare Watershed

Table 3. Description of the layer of lower Hare gully

Depth below recent surface	Name of the layer	Short description of the layer
0-79 cm	F4	Recent floodplain sediment of River Hare, brownish sandy loam and loamy sand, intensive oxidation of iron from 30-79 cm depth
79-92 cm	F3 fAh	Humic horizon which developed in layer F3, flood-plain sediment of River Hare, dark greyish sandy loam, medium-high content of organic Matter
92-202 cm	F3	Floodplain sediment of River Hare, from 92-102 cm brownish, from 102-140 cm depth light greyish sandy loam, accumulation of salt
202-239 cm	F2	Floodplain sediment of River Hare, greyish loam (similar to F1, separated from F1 by a buried surface on which an acacia tree has grown)
239-(>250 cm)	F1	Floodplain sediment of river Hare, greyish loam

Until the mid-twentieth century, erosion rates were low in the highland, which has long been used agriculturally, and very low on the steep parts of the escarpment, which were mostly covered by woodland that was grazed at a low intensity. Indigenous terrace systems in the highland enabled low erosion rates. In the 1960s the clearing of the steep slopes of the escarpment started and thus intensive hillslope erosion and massive sedimentation in the lower part of the Hare floodplain began. As a result, an acacia tree was partly buried by sediment and later cut by humans.

The extreme intensification of sedimentation caused severe problems in the wide floodplain of the lower Hare River. Sediments covered woodland as well as arable land. Intensive land use had to stop in these areas.

When the soils were totally eroded at several sites of the steep slopes, infiltration capacity was reduced and thus flood intensities increased during the rainy seasons. As a result, runoff from the areas with stripped soils has low sediment concentrations, and the tributaries and River Hare are cutting into the floodplain sediments which were deposited during the preceding years. A secondary effect of the intensified flooding is the destruction of several bridges along the main road leading from Addis Ababa to Arbaminch.

Parallel to these effects, the land use in the low land surrounding Lake Abaya was intensified since the 1960s. Due to low average rainfall, some areas were irrigated to grow cotton for example. Over the years, sediments were deposited in the irrigation channels. Thus, their capacities were reduced and the water spilled over into neighboring areas, causing gully erosion there. Employees of one farm reported that a gully developed in just four years as a result of sedimentation in an irrigation channel.

Case 2: Continued active gully development _Upper Footland (case in Zigetie area)

Zigetie area, in the Arbamich Rift Valley escarpment, has a prevailing feature of deep tension and desiccation cracks (figure 6). In the middle segment of the escarpment a complex gully system was identified. A gully has cut 3 to 8 m deep here, into fine-layered sediments which fill an older gully. The development of the gully system could be reconstructed as follows:

A first gully cut into non-compacted sediments. The age of this first period of gullying is unknown. Then this first gully was filled with thin-layered sediments. The fine layering is the result of several heavy rainfall, and thus runoff and hillslope erosion, events in the catchment of the gully. Runoff generation, hillslope erosion and sedimentation were enabled by the clearing of parts of the escarpment, which started approximately half a century ago. In the middle of the fine layering a large stone was observed, which gravitational processes had transported into the gully from the neighboring slope; this gravitational process may have been the result of an earthquake. Today, the primarily fertile soils on the slopes are mostly eroded. Thus soil fertility on the segments of the escarpment which were used agriculturally for up to half a century has been reduced dramatically. At some sites agriculture has therefore ended or will cease in the near future for a long period of time; until new soils have formed from the bedrock which is exposed there, namely by chemical weathering processes requiring at least several centuries.

After the first gully was almost completely filled with fine-layered sediments, a second gully cut into these gully-sediments, right down to their base. This second phase of gullying was enabled by the construction of a road(to connect Arbaminch town with the highlands), which took place in 1981 above the catchment of the gully(figure), . Runoff concentrated on this road and flowed down it during heavy precipitation events. These masses of water were concentrated into the filled first gully, and thus caused the incision of the second gully. Without the road construction, the filling of the first gully would have continued.

After the construction of the road, flooding, erosion and deposition of sediments caused severe damages in the lower segment of the gully system near Arbaminch. These processes are still active.

In 1986, some areas with intensive gullying and steep slopes on the escarpment were afforested with Pinusradiata, Eucalyptus spp. and Corpurseslustanica. However, as expected, runoff generation on the road and thus gullying downstream continued.

This example of sudden gullying proves the sensitivity of the escarpment ecosystems of the rift valley. Forest clearing and then agriculture enabled runoff generation, hillslope erosion, and thus a slow filling of the first gully, while infrastructure measures immediately resulted in strong gullying. In the uppermost part of a neighboring catchment, gully erosion already has removed a part of the road.

Figure 8: Gully of Zigetie

Case 3: Gully sequencing in the highland, the case in EzoGulle area

A sequence of almost parallel gullies has developed during the last four decades in EzoGulle area (figure 7). Gullying started with the establishment of a path which was leading down a steep slope, and which was used frequently by humans and animals. Since the weathered bedrock has a low infiltration capacity in this area, runoff was already generated during minor intensive precipitation events.

When the first gully was cutting in, people and animals continued to use the path. When retreating erosion caused the generation of steep steps in the gully, it could no longer be used as a path. Then people and animals walked a few meters to the side of the gully and a new path developed there. Due to the compaction of the soil along the second path, runoff generation began there during precipitation events.

The subsequent heavy rainfall events resulted in the undercutting of the walls and the bottoms of the gullies, leading to their deepening and widening. This also caused the collapse of gully walls. More heavy rainfall events with concentrated runoff, coupled with land use changes, triggered more erosion and further deepening, widening and extending of gullies downslope. In addition, the retreat of the head gully cutting was also observed.

A second gully started to develop. The development of the second gully followed in the same way as the first one. After some years, people had to give up the second, now incised, path. They used the neighbouring space, where the development described then occurred a third time, causing the development of a third deep gully. The gullies have cut into the lower and middle slope segments, causing the deposition of sediment in the grassland of the adjacent valley. Thus, to date a sequence of gullies has developed merely as a result of soil compaction by human activities along the small lines.

Figure 9: Gully of EzoGulle

Gully Chronostratigraphy in upper footslope : case in ChanoChelba area

In the chronostratigraphy of the youngest development of the ChanoChelba System, about fourteen phases have been identified, and a thick black soil in the interfluvial areas between the gully systems is still preserved. The details of the chronostratigraphy of ChanoChelba are as follows (Figure 8 and 9)

1. The first incision of the ChanoChelba gully took place during an extraordinarily heavy precipitation event with concentrated runoff. A gully with a width of several decametres and a depth up to 5 m developed.

2. In the second phase, silty sediments (in small channels with higher velocities of runoff gravel) were accumulated in a thickness of 1 – 2 m during several minor yet intensive flood events in the first ChanoChelba gully. Several subphases of deposition were identified.

3. During a short period of geomorphic stability vegetation was established across the whole catchment of ChanoChelba and also in the gully.

4. The woodland vegetation was removed in vast areas of the ChanoChelba catchment, and a period of intensive land use in the catchment began (after the mid-twentieth century).

5.-9. Runoff generation and sheet erosion occurred on the cleared slopes. Gravel, sandy and silty sediments were deposited in the ChanoChelba gully during five medium intensive precipitation and runoff events. Some remaining trees were partially buried.

10. During a heavy precipitation event with concentrated runoff, the second incision of the ChanoChelba gully system took place to a depth of 2 m. Runoff with an initially low sediment load concentrated mainly on paths which were compacted by humans and animals.

11. Gravel was deposited in the second ChanoChelba gully during several medium intensive precipitation and runoff events, with a thickness of 1- 2 m.

12. During a heavy precipitation event with concentrated runoff mainly on paths, the third incision of ChanoChelba gully system proceeded. The third gully has a depth of 1.5 m.

13. During several medium intensive precipitation and runoff events, gravel was deposited in the second gully to a thickness of a few decimetres.

14. The fourth (and until today, last) incision of the ChanoChelba gully system occurred recently, during a heavy precipitation event with concentrated runoff on paths. The third gully has a depth of several decimetres.

Figure 10. Gully of ChanoChelba

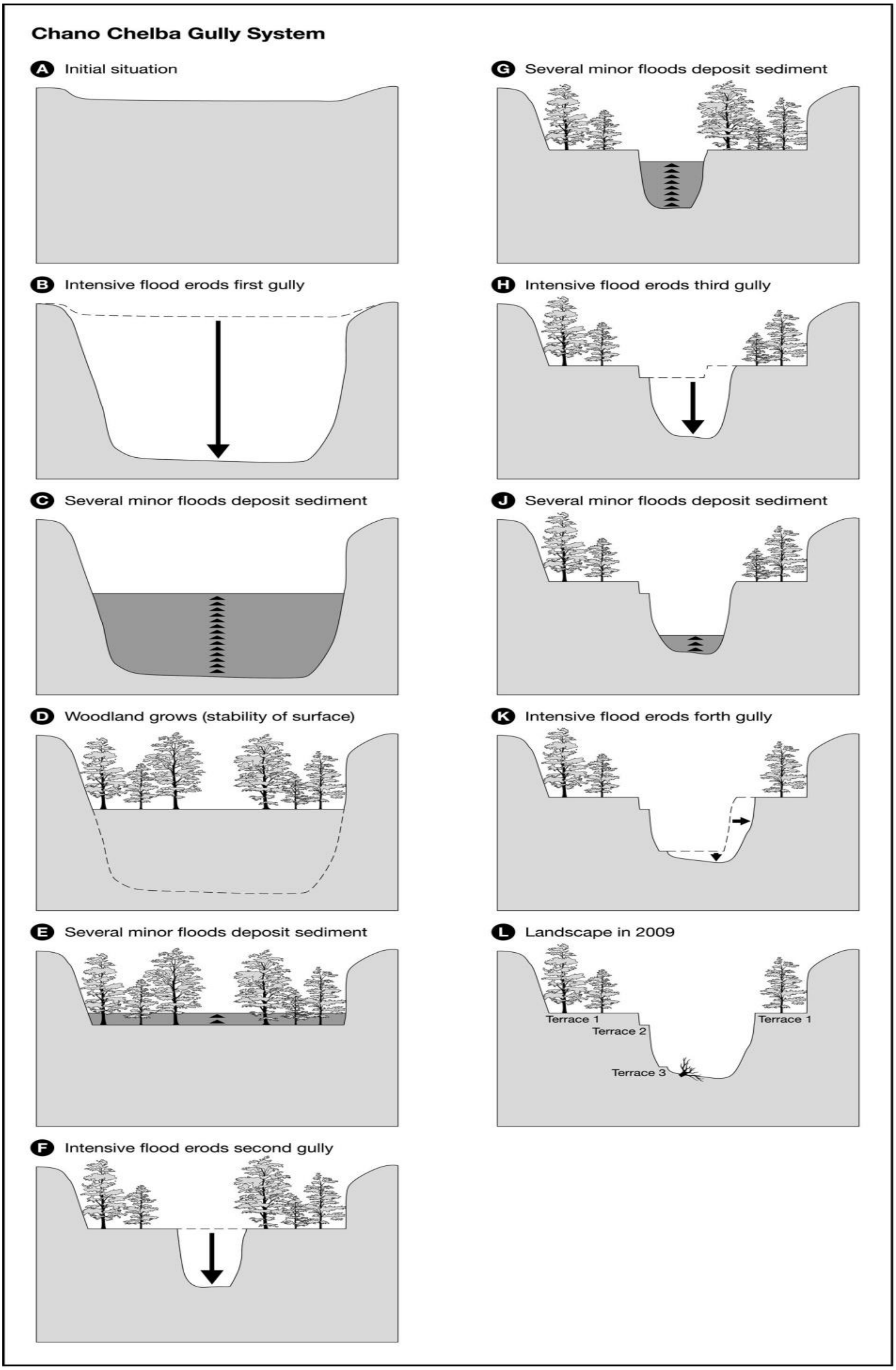


Figure 11. ChanoChelba Gully System

Gully trends and consequences: local community's perspectives

Gullies have been expanding in an extreme fashion in the investigated area during the last five decades. A large proportion of interviewed farmers (57%) acknowledge the problem of gullying. Among these respondents, 45% conveyed the severity of the problem (Table 4). The farmers were asked if they had noticed the rate of changes with respect to the extension length, width and area of gully particularly in the last forty years. Eighty one percent of the interviewed farmers stated that the magnitude of gully erosion over the last 40 years has increased and the problem has becoming severe.

In our discussion with old people, they also pointed out that, in the past gullies were confined to along the escarpments. In the lowlands in particular there was no pronounced gullying before the 1960s. This is because the lowland area was not under cultivation before this time. At present, however, gullies are common across the investigated areas and their different land use types, namely cultivation, grazing, bush land and intensively used woodland. Gullies have also been formed on different slope gradients and topographic positions. They also expressed that attempts to combat gullying are low. If this trend of gully expansion continues unabated, large areas will be void of agriculture.

Table 4 : Farmers´ views of the dynamics of gully erosion

Views of gully erosion	Ezo Gulle (highland) % of respondents	Zigetie (Mid altitude) % of respondents	lower Hare (Lowland) % of respondents
How serious is gully erosion			
High	32	57	46
Medium	47	26	29
Low	21	17	25
Observed changes in the magnitude of gully erosion over the last 40 years			
Increase	80	72	92
Decrease	4	8	0
No change	16	20	8
If increase: How serious is the problem?			
High	50	62	63
Medium	33	28	25
Low	17	10	12

DISCUSSION

Gully Incision, Aggradation, Stability and cycling

In our investigation area, mainly in the Rift Valley, gullies are marked by alternations of incision followed by aggradation. The incision of a gully channel occurred due to the concentrated runoff that cut the unconsolidated deposited materials in the Rift Valley. Heavy rainstorms are a characteristic of the climate in the area and thus short duration heavy rainfall can trigger the formation of gullies at the sites mentioned. The same result has also reported by Bills and Dramis (2004).. Anthropogenic activities together with intensive rainfall resulted in an increase of the overflow. Moreover, the bare soils of the degraded land and a low vegetation cover density are also factors for high runoff rates during the rainy seasons. Hence, the incision of the gully channel increased in depth, length and width.

The channels formed by the incision vary from place to place in terms of length, width, area and gradient. Generally, the gully channels downslope are wider and have lower gradients. On the other hand, the gullies in the highlands and on the escarpments are deeper and narrower. This is attributed mainly to the material of the gully cuts. On the upper slope the rocks are dense and more resistant to erosion, while at the lower slope the rocks are unconsolidated. Thus the area coverage of gullies is larger in the downslope areas.

Aggradation phases occur in years when the precipitation intensities and thus the runoff rates are lower during the rainy seasons. The capacity of the runoff to transport material thus lowers enormously and the process of deposition is accelerated in the less inclined parts of the gullies in the Rift Valley. Hence, these lower segments of the gully channels are choked by fine-grained sediments. The source of these sediments in the gullies at the Rift Valley is hill slope erosion on the degraded land of the escarpment and on the intensively cultivated highland. In addition, gully bank collapses and the undercutting of the walls are also important ephemeral sediment sources. Aggradations also formed in the areas during the afforestation of the highland in the 1980s. The high vegetation cover resulted in a low amount of surface flow. Thus gullying declined and the materials that were eroded were reduced enormously.

We have also observed geomorphic stability phases that occurred between the incisions and aggradations. For example, in ChanoChelba during two phases of geomorphic stability in the catchment of the gully, soils were formed under vegetation, namely forest, on the deposited material. The trees were planted and provided cover for the ground and consequently low runoff generation.

It is evident from our investigation that the gully development had a pattern of cut-and-fill cycles. Gully cycling is marked by the processes of filling, which take place during periods of several years, interrupted by individual rainfall and runoff events with incision. For instance, in the gully system of the Zighetie area, the filling of the gully was interrupted by a deep incision. The backfilling could have continued for a somewhat longer period if the road had not been constructed. This road was a cause for generating high runoff, which led to the entrenchments. Similar observations were made for the ChanoChelba gully system in which depositions or back filling was interrupted by cutting which was enabled by deforestation, cattle grazing and road construction in the catchment of the gully. We observed four cut-and-fill cycles that occurred during the last century in ChanoChelba. This also shows the dynamics of the driving factors, which are responsible for cutting and backfilling. The incision-aggradation cycles were also reported for the late

Holocene in the central main Rift Valley (Carnicillei et al., 2009). They stated that gully entrenchments took place at the start of rainfall while gully filling took place directly before drier climate phases, and stressed that the cycle of the gullying system of the late Holocene was strongly linked to the climate.

Driving forces of gullying

The most common causes of gullyerosion in the study area are the unusutainble land use such as deforestaiton, dynamics of agricultural activities, intensive grazing and roads and footpaths

Deforestation

Deforestation is a serious environmental problem in the study area . The downward trend in forest cover and grass land is a widespread phenomenon in subsistence agriculture, characterized by an increase in the demand for cultivation land and for fuel wood. This result is also in line with the reports of various studies which were undertaken in different parts of the country. For example, Dessie and Carl (2008) have demonstrated a decline in forest extent in the Awassa region, southern Ethiopia, from 16 % to below 3 % from 1972 until 2000. Zeleke and Hurni (2000) have revealed a considerable decline of natural forest extent in Denbecha, Gojam region, from 27% in 1972 to below 1 % in 1997.The high rate of deforestation from 1986 until 2000 is explained by a particular episode in Ethiopian history – the political upheaval of the 1990s. During this time, there was a radical government transition: the present government took over from the Derg (1974-1989).However , the low rate of decline of forest from 2000 to 2017 compared to the previous was attributed to the plantation of eucalyptus trees.

According to farmers, the main driver for deforestation is agricultural land expansion in response to local population increase and decline in agricultural production. Growing fuel wood demand, locally and innearby towns, is another chief cause. Forests also suffered from recent settlement and cash-crop farm expansions in the lowlands, government upheavals, land tenure, and changing forest policies.

The vegetation removal has in turn resulted in the lowering of the resilience of the soil to erosion and aggravated soil erosion by water. Hurni (1993) has demonstrated the effects of vegetation removal on soil erosion in Ethiopia. He has estimated the average rate of soil erosion in forestland at about 1 ton ha^{-1} year^{-1},whereas soil erosion on cultivated land is as high as 42 tons ha^{-1} year^{-1}.

The Chencha escarpment, for instance, is one of the areas where wood resources are highly exploited. The people from the lowlands and middle altitudes have accessed this woodland for collecting fuel wood. A large number of people are also making their living by selling wood that has been collected from these places. In the 1970s and 1980s, there were strict rules and regulations on how to cut and use the wood from the woodland, and as a result the forests along the escarpment were not intensively exploited. However, the situation changed; deforestation was exacerbated during the transition of government in the 1990s and this forest exploitation has been continued until present. These woodlands also provide pasture for the cattle from the surrounding area. The over-crowded livestock graze inside the woodland during the rainy seasons when the lakeshores are covered with water. This has resulted in high surface runoff and flooding that strongly affects the adjacent lowlands during the rainy seasons. Hence, gully erosion and sedimentation are serious problems in the lowlands that hinder agricultural activities and affect the infrastructure. The farmers in the lowlands are aware of the causes of gullying and flooding. They stated that the massive destruction of forests in the recent past is one of the major causes. On the other hand, the people of the middle altitudes have been using the woodland as a source of fuel wood since the 1960s (Jackson et al., 1969). Thus there is a conflict of interest between the highlanders and the lowlanders. The highlanders see the woodland as a resource to be used for fuel wood, while the lowlanders see this woodland as something to be preserved to protect their land from gullying and flooding.

Cultivated land expansion and farming system dynamics

The cultivated land in the investigated areas has undergone unprecedented change over the last four decades. The results of satellite image interpretation show that cultivated land increased over time from 1986 to 2017. On the other hand, a large part of the increase of cultivated land in the period from 1986 to 2000 was partly attributed to the radical change of the government, from Derg regimes in 1989 resulted in the conversion of a large proportion of forest land and grass land into cultivated land.These were the periods when there were loose government controls. A similar finding was also reported by Dessie and Carl (2008), showing that a large proportion of forest and shrub land in the Central Rift Valley of Ethiopia was converted to cultivated land during these changes of government. In the past years, all cultivated land acreage in the highlands was situated on steep slopes. The steep slopes only came under cultivation during the last decades.

On the other hand, in the same period, the average size of cultivated land per household in the highlands has decreased from about 1.4 ha to 0.4 ha. Cultivated land scarcity can mostly be related to demographic pressure, which was exacerbated by government policy, land tenure, and the nature of subsistence agriculture. A high rate of increase of cultivated land was reported in the lowland area of the Rift Valley. This was mainly attributed to the recent movement of many people from the intensively populated highland to areas in the Rift Valley for settlement and cultivation. The expansion of cultivated land was at the expense of the forestland and grazing land

Moreover, sensitive landscapes with steep slopes and wetlands were also brought under cultivation. In some cases,farmers have also been cultivating shallow soils, sometimes saprolite, as observed during the field investigations. These human activities and anthropogenic process have modified the natural landscape and disturbed the natural equilibrium. This, in turn, results in the modification of overland flow due to a reduction in the infiltration capacities of topsoil horizons and a subsequent increase in the rates and magnitudes of surface runoff. Hence, the formation and enlargement of gullies have been enhanced.

Gully erosion in the area is also exacerbated by changes in land management practices. Among others, manuring, crop rotation, and fallowing have undergone significant changes during the last decades. Most farmers have used manuring to maintain the fertility of soil over generations. Nevertheless, since the 1960s, the application of manure on gardens and fields has been declining. This is mainly attributed to the shortage of livestock. Hence the soil organic matter content of topsoil horizons is deteriorating and subsequentlythe quality of the soil structure is declining, which increases soil erosion in the area. Crop rotation is another method used by a large number of farmers in the area to maintain soil fertility over a long period of time. It is characterized by a crop rotation of barley (2-3 years), wheat (2-3 years), beans (1 year), and peas (1 year). However, the frequency of crop rotation is decreasing because of the scarcity of adequate farmland. People increasingly prefer to only grow staple food crops such as barley, wheat and enset. In addition, they also want to maximize the benefits they get from the land by growing cash crops such as apples and bananas, so they devote their fields to the cultivation of these crops only. The decline of crop rotation also resulted in the lowering of nitrogen and organic matter in the soils. Thus the productivity of the soils is loweredenormously, the plant cover density is reduced, and consequently soil erosion is enhanced. Farmers in the highlands are also well aware of the benefits of fallowing to maintain soil fertility over a long period of time. When land productivity decreases for a certain period of continuous cultivation, it should be fallowed in order to be regenerated. At present, the land is only fallowed when crop yields significantly decline. Otherwise, farmers continue cultivation without interruption. The abandonment of fallowing affects the nutrient content and structure of the soils and thus aggravates soil erosion.

Moreover, the agricultural bureau of the Wereda also introduced terracing to the area in the early 1970s. However, these terraces are not popular among the farmers. Frequently cited reasons for the poor performance of these terraces are their labor-intensive construction and maintenance, that space is taken away from agricultural production, the problems of plowing narrow terraces, and the presence of rodents or other pests harbored by terrace walls. Additionally, the structural design problems of the introduced terraces and the top-down approaches to the design and implementation of the plans are other factors. Hence, not maintaining and eventually demolishing terrace walls are expressions of the unpopularity of introduced terraces. Some informants even reported that in one specific area the people have demolished seven times the introduced terraces which were constructed during last the forty years. Cultivated steep slopes without terraces have ahuge significance in triggering soil erosion.

Furthermore, the structural design problem of the terraces also resulted in the formation of gullies in the highland area. During our visit to the Ezo-Gulle region in theChencha highlands, we could observe the terracing of a slope by a group of persons. The activities were supported by food-for-workprograms. First, they removed the topsoil. Then they put the soil material from the upslope part of the new terrace onto the downslope part. The result was a terrace surface much less inclined than the slope before these activities. The surfaces of the new terraces were all inclined in the direction of the slope. The topsoil, which had been removed earlier, was then put on the surface of the new terrace and integrated into the saprolite. Then, at the lower end of each terrace a ditch with a depth and width of 40-50 cm was opened. The soil material which was extracted there was deposited in the upper part of a dam. It was planned to stabilize the dams with vegetation later. The ditches were opened for the collection of surface runoff during heavy precipitation events to enforce infiltration. Since several of these ditches were not installed along the contour lines, the bottom of the contours was inclined significantly. It can be expected that runoff will flow into those ditches with increasing velocity downslope, causing rill and gully erosion during the rainy seasons. In the same way, farmers in theZollo area also reported that the introduced terraces, which were built in 2004 by a food-for-work program, caused gully formation and expansion. This is because of the wrongly constructed waterways near the introduced terraces; long channels were built parallel to the sides of terraces, which do not allow the collection and infiltration of rainwater. A similar case was reported in Tigray, north Ethiopia, regarding the structural design problems of check dams, which failed to consider important parameters. As a result, check dams failed up to 39% after two years of construction (Nyssen et al., 2006).

Gullies in Zollo area formed due to the poor design of introduced terraces; hence measures have to be taken accordingly. In this regard, lessons can be drawn from how the indigenous terraces on steep slopes are constructed; for example, the traditional terraces at Dorze Belle, which have been used and functioning well as a protection against soil erosion and land degradation for at least seven centuries. The traditional terraces are constructed in such a fashion that a channel releases water nearly horizontally across short distances onto each farm field. Stone walls of the indigenous terraces are also porous to some extent, to allow the exfiltration of water. This promotes drainage by increasing infiltration rates, resulting in the improvement of soil moisture contents. As a solution for stabilizing the existing gullies, which were induced by the unsuitable design of introduced terraces, herbs and grasses have to be sown first on the gully walls. After some decades, when the gully walls are stabilized and a humic horizon has developed, trees should be planted. In addition, check dams can also be constructed to reduce runoff velocities and to increase infiltration. Generally, there has so far been hardly any attempt by planners to evaluate the performances of introduced terraces. Thus there is a strong need to carry out integrative activities in participation with the experienced farmers which help first to identify the reasons for the terrace failures and then to implement effective systems. High attention should be paid to the design and construction of introduced terraces when mobilizing a mass of people for terrace construction. Terrace monitoring systems should also be installed in order to avoid such errors.

High intensity of grazing

Grass land is on the important source of feed to cattle. The large area decline or shrak in the grass land of the areas in the period from 1986 to 2017 , attributed to conversation to the cultivated land. Large grassland areas were already converted to cultivated land in the 1960s as revealed by Jackson et al. (1969). In particular, private grazing land was totally abandoned as witnessed by the surveyed households. Today, further sources of past grazing land, such as grazing inside forests and the use of enset leaves, are also deteriorating. , In the study area as a result thedeciline in grass land contributed to the decrease of the number of cattle.

High intensity livestock grazing has also exacerbated soil erosion in our investigation area. Livestock tending is the main integral part of the agricultural system. It has played an important economic and ecological role in the area for a long period of time. However, the shortage of cattle feed is one of the major problems, mainly caused by a conversion of large grassland areas to farmland (Table 4). In particular, private grazing land was totally abandoned. The shortage of grazing land forces people to graze their livestock inside the remaining forests. It is clear that grazing inside the forests affects the regeneration of trees and other plant species. The land with the subsequent lower plant cover density is also susceptible towater erosion. Moreover, the tracks of cattle have caused the compaction and sealing of the soil. When soils are sealed, rainwater infiltration is reduced drastically and surface runoff is generated in large amounts during heavy precipitation events. As a result, visible soil erosion such as hollow-way gully erosion is apparent inside and along the forests. Similarly, the paths of sheep were the principal driver in causing gully formation and widening on Easter Island (Miethand Bork,2005). Generally, overgrazing has been one of the principal cause of soil erosion and degradation in Sub-Sahara Africa (Kiage, 2013)

Roads and footpaths

Along with deforestation and overgrazing, road construction was also a major factor regarding gullying in the area. A road that runs to Chencha town from the lowland and a road that runs to Arbaminch from Zighetee area in the escarpment were the major causes of runoff generation during heavy rainfall events, and thus for deepening and widening of gullies. On these roads, the unpaved ditches bordering them are too small to collect, allow the infiltration of, or remove, the surface runoff during extreme runoff events. In addition, concentrated runoff is not led after short distances into the neighboring forestland for infiltration. As a result, gullies were formed and enlarged. These gullies have also caused the deposition of a large amount of sediment in the cultivated land in the Rift Valley.Footpaths were also among the factorsenabling gully erosion as discussed in the preceding section.Nyssen (2004) has also reported the effects of roads on gullying in Tigray, Northern Ethiopia.

Road construction should also be given high attention in order to reduce gullying in the area. In the road design and construction, people should take into account the rate, intensity and magnitude of runoff. It is recommended that agents who are responsible for road construction are required to conduct a sound environmental impact assessment before a road is constructed.

Gullies in EzoGulle area have already changed to badlands. They have lost soils, including saprolite. Thus it is impossible to treat such gullies. The solution is to plant grass and trees to the closest immediate areas to avoid or minimize further runoff generation and expansion of gullies. Footpaths are responsible for the formation of such gullies and preventative measures should also be taken in the future.

In general, people and animals have to walk from side by side, from village to village. As such, the frequency of the use of paths cannot be reduced. Thus only the position of paths can be altered, with them being moved to less sensitive areas. Paths should not lead down a slope following the steepest inclination. They should be installed diagonally leading down from a divide to the valley with a low inclination of each path. Every 5 to 10 m on the uphill side of a path, holes should be dug where runoff can infiltrate during and after heavy precipitation events. During other periods, cattle might graze on the grass that grows at the holes. Thus the length of runoff streams will be reduced and gullying will be avoided. Theoretically, a second measure would be to vegetate the area beside a path. However, the high number of passing animals would unavoidably eat any nearby vegetation.

Sustainable Land Management: Remedial measures to combat soil erosion

Various attempts have been undertaken to combat sheet erosion and gullying in the investigated area. These include afforestation, terracing, and the setting of gabions. Forests were planted during the massive afforestation programs, known as the “Green Campaign”, which took place across the country in the 1980s. Most of the plantations took place on the top of mountains, on ridges and on steep slopes.

A large number of people participated through food-for-work programs. They first constructed terraces, using stones or soil depending on the available materials, and then they planted trees on the newly established terraces. The dominant tree species in the community wood plots are Eucalyptus globulus and Juniperus procera. Other tree species include

Hegannia abssyinica, Pinus patula and Cypressus lusitanica. The total area covered by community forests in 1987 was about 650ha, according to the agricultural bureau report. In general, the community woodlots have brought significant landscape changes to the area.

Terracing has been introduced and implemented in the investigation areas during the last five decades. The introduced terraces inconvenience farmers; they developed negative attitudes towards these terraces similar to those expressed towards the community woodlots. This is because the structure of the introduced terraces did not consider the existing problems and sizes of the individual farmers' land; they are instead marked by a rigid design that should be applied according to the universal features of the terrace planning. It has also failed to take into account farmers' traditional knowledge of land management practices.

Recently, gabions (cylindrical containers made of thick galvanized wire and filled with stones) have been set on gullies in the lowland. The basic intentions behind using gabions were to trap sediments and to decrease the velocity of the runoff and thus stabilize the gullies. Gabions have been implemented in the area with the assistance of Nongovernmental Organizations. Similarly, gabions have also been used in Ferta-Gonder, northern Ethiopia, with the help of German Society for Technical Cooperation (GTZ). A cost-benefit analysis of gabions for averting gully erosion was conducted and showed a positive signal (Yitabrek et al., 2012). However, the extent of coverage by gabions in the study area is small compared with the intensity of gullying. Combatting gullying can only be successful when the whole catchment of a gully system is managed sustainably; thus gabions are only one important measure.

Despite the various measures to reduce sheet, rill and gully erosion as discussed above, gully development remains rampant in the areas. Gullying occurs on various topographies and at various intensities. Gullies develop on the cultivated land, in the grazing areas, at the fringe and within Arbaminch town, on and near footpaths and roads, and in irrigated fields. Thus site-specific attempts to address the problem have a paramount importance and would also be very effective. The key question to be addressed is how can gullying be avoided, or at least reduced, under the conditions of a densely populated and intensively used area with sensitive soils and steep slopes?

The most important work on the prevention of gullying would be implementing sustainable land management through watershed management. As gullying is spatially interconnected and runoff is also generating in gully catchments, the measures at watershed level have a paramount significance. Watershed management planning should be based on community participation from the conception phase to implementation, evaluation and maintenance. The knowledge and practices of the local people have a great importance for the sustainability of land management. In the planning in addition to soil water conservation measures, fulfillment of livelihood requirements and strategies should also be given emphasis. This is because the techniques which were developed over generations have deteriorated due to poor living conditions during the last decades. For instance, the enormous decline in the use of manuring, fallowing, and crop rotation is attributed to the reduction of agricultural production and the scarcity of cultivated land.

CONCLUSION

The dynamics of land use and land cover, which are major contributor to land degradation such as gullies, have a significant impact on sustainable land management. Long term environmental changes- mostly in land use and land cover_ have been occurring in unprecedented way since the mid of the 20th C. owing to socioeconomic and demographic factors. These include deforestation, agricultural intensificatione, overgrazing and road expansion. The escarpment and other areas are highly deforested and also used for grazing. The intensity of grazing in the forestland is high, too. The study's findings demonstrated that, throughout the previous 40 years, there has been a rise in unsustainable LULC in the area, including deforestation, excessive farming, overgrazing, and shrinkage of grasslands. Before the 1960s there was no problem with gullying in the area but at present gullies has developed in the cultivated land, along the grazing areas, close to footpaths and highways, and in irrigation ground.

Gullying began with the escarpment's forest cover being cleared. Because surface runoff cannot dissipated in bare ground and rainfall cannot be intercepted, the barren land has exacerbated gullying.As a result, the amount of water running downslope that can erode is drastically increasing. Furthermore, the road that was built in the 1990s to connect Chencha town with the lowlands was another factor contributing to the gullies' enlargement and deepening. There is not enough drainage on the road. After a short distance, concentrated runoff is no longer led into the forestland.

As a consequence of this, gullying currently develops in a wide range of topographies and at various levels of intensity. Due to unsustainable LULC, gully formation has become prevalent in highland basaltic soils, lowland alluvial deposits, and colluvial deposits of rift valley escarpments. The gully system in the area is characterized by a cyclical succession of phases, including entrenchments, aggradations, stability, and soil development. A gully system with 14 stages of gullying and sedimentation cycles has been found and its chronostratigraphy reconstructed.

In addition to removing a significant amount of soil from the highlands, gullies significantly decreased the amount of water available for plant growth. Furthermore, a significant barrier to agriculture in the lowlands is the siltation of irrigation channels and weirs. The low-lying area has also been impacted by frequent flooding as a result of gullying in recent decades. Other negative effects of gulling in the area include blockages, cutting of road sides, and sediment deposits on the roads.

Large amount of land may soon no longer be suitable for agricultural cultivation if current trends of gulling continue. Therefore, the question that needs to be answered is: How can gullying be prevented, or at least lessened, in an area that is steeply sloped, densely inhabited, and has sensitive soils? Sustainable land management such as the grass-roots level community watershed management is advised to use. Since runoff is generated in gully catchments and gullying is spatially interrelated, watershed-level measures are crucial. Watershed management planning should involve the community from the conception to implementation, evaluation and maintenance. The local knowledge and practices play a pivotal roles for the sustainability of land management. Site-specific attempts to address the problem should also be considered.

The study generated evidence-based results about the dynamics of land use and cover trends and patterns and their impacts on the gully's development and dynamics. To improve the attainment of SDG 15 which focuses on halting and reversing land degradation, studies of this kind that depicts the effects of changing land use on gully development and incision suggest potential solutions that capitalize on the opportunities provided by practices and activities aimed at enhancing sustainable land management. It is recommended that future studies should undertake measure the quantity of soil eroded and silt deposited in rivers and lakes as a result of gullies. In addition, a cost-benefit analysis of the gully abatement measures should be completed prior to the measures' construction.

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