Rate of Gully Expansion on Major Land Uses, the Case of Huluka Watershed, Central Rift Valley, Ethiopia

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Abstract
Gully erosion is among the many phenomenon which has been interweaving the socio economic and environmental issues of Ethiopians. Actions have been taken to address the problem inadequately. This study was thus aimed at determining the distribution and expansion rates of gullies on the major land cover – land uses in *Huluka* watershed. This was achieved through collecting historic land cover – land use data using Geographic Information System (GIS) and Remote Sensing (RS) and gully expansions using gully assessment method called 'Assessment *of Gully Erosion Rate Through Interview and Measurements (AGERTIM)*'. Field observations, discussion with elders were also employed to validate results from remotely sensed data. Accordingly, about 58km length of active (unstable) gullies with 4.7m width and 2.6m depth was registered in the study watershed. Out of this majority of the active gullies were found on lands commonly used for grazing purpose followed by on the land used for crop cultivation purpose. Unlike the frequency, the dimensions of the gullies on crop land were found larger than the gullies on the lands used for grazing purpose. All active gullies in the watershed have showed continuous and progressive expansion in the last 30 years though the tremendous expansions were seen with in latest period 2005 – 2009 indicating exacerbating rate of gully expansion in the study area. Despite the rapid gully expansions, no any protection and treating measure was registered in the watershed. This study has thus recommended an intervention of concerned bodies to reverse the rapid gully expansions in the study watershed.
Keywords: Major Land use, land cover, critical period, AGERTIM, Gully development

1. Introduction
Soil erosion is one of the major problems confronting Agriculture worldwide. Although the problem is as old as settled agriculture, its extent and impact on human welfare and global environment are more now than ever before. A continuation of high soil erosion will eventually lead to a loss in crop production leading to increase the demands for input like fertilizers and other inputs often result in increased yield in the short term. The economic impact of soil erosion at global scale is not available (Eswaran *et al.* 1999) except some information for local and regional scales. Productivity of some lands in Africa (Dregne 1990; Hurni 1993) has declined by 50% as a result of erosion. Yield reductions in Africa (Lal 1995) due to past soil erosion may range from 2 to 40%, with an annual mean loss of 8.2% for the continent. If accelerated erosion continues unabated, yield reductions by 2020 may be 16.5%. Annual reductions in total production for 1989 due to accelerated erosion was 8.2 million tons for cereals, 9.2 million tons for roots and tuber crops, and 0.6 million for pulses. On a global scale the annual soil loss of 75 billion tons of soil costs the world about USD 400 billion per year or approximately USD 70 per person per year (Lal *et al.* 1998). From this, it is possible to imagine the impacts of soil degradation on the agricultural production of Ethiopia.

Gully erosion is geographically a wide spread problem and is the worst stage of soil erosion. In Africa about 29 million ha of land is affected from gully. In Ethiopian high lands, gullies particularly sever and widespread on 7.6million ha. Gully erosion is more difficult and expensive to control than sheet and rill erosion. It is also more spectacular than inter-rill erosion. Contrary to rill and sheet erosion, the damage done to land by gully erosion is more permanent. Gully erosion also causes depreciation in land value by lowering the water table and depleting the available water reserves. Buildings and infrastructures are also undermined by rapidly advancing gullies. This all can clue us how much gully erosion is affecting the well being of humans (agriculture) than the other type of soil erosion.

To reduce the effect of gully erosion, it is important to understand the extent of gully distribution, on which type of land use is more distributed and why. Despite this fact, the attention paid to gullies research and treatment in Ethiopia specifically central rift valley is very limited. Therefore, this research was initiated to assess the distributions and expansions rate of gullies on major land uses of central rift valley, Huluka watershed specifically.

2. Materials and methods
2.1 Area description
The study area (Huluka watershed) is located geographically 7^0 16.4'to 7^0 30.7' N and 38^0 47.7' to 38^0 44.3' E

(Figure 1) and elevated on average 1977 m.a.s.l. It is found in Ethiopian central rift valley system and located 235 km south of Addis Ababa, the capital of Ethiopia. The Average annual temperature ranges 10-25 °C. The area has bimodal rain fall distribution, i.e., in the period July to October (wet season) and March to June (small rain season). 83 % of the soil in the area is sandy loam whereas 9% is sand soil (EARO 2002). Andosols and Nitosols soil types are the common soil class in the study area (ORS 2004). Huluka watershed is dominated with *Acacia-Balanites* with some thorny shrub lands supporting crop-livestock based farming systems. Farmers are mainly involved in producing annual crops and livestock product.

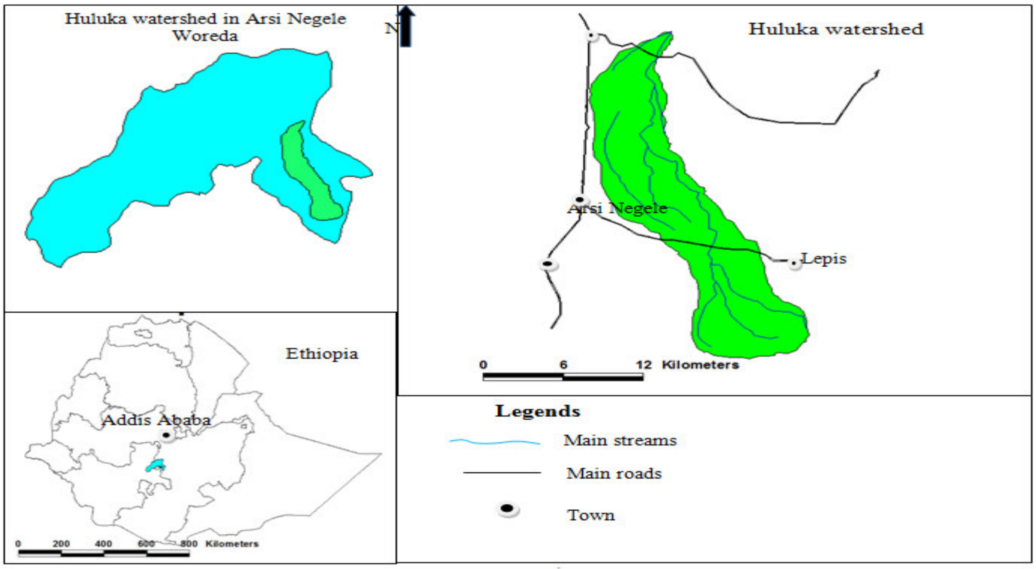

Figure 1: location of study area

2.2 Methodology

The major source of land use data was mainly from the land cover data derived from multi temporal satellite images and topographic maps. Five dates of remotely-sensed land sat images acquired in dry season was collected from different sources. These images procured and processed using image processer ERDAS IMAGINE 8.4 software. To generate the land cover related data, all satellite images have passed three processes (pre processing, classification and post classification). As obvious, it could not be difficult to guess the land use type after identifying the land cover class of a given land. Topographic maps collected from Ethiopian mapping agency was also good source of spatial information.

Assessment of Gully Erosion through Interviewing followed by field Measurement (AGERTIM) adopted from Nyssen *et al*. (2006) was used to collect the data related to gully. All active gullies were first assessed based on land use and slope class distribution. The cross sections were determined using GPS tracking. The proximate age of each gully was assessed from the local elders. For the purpose of estimating rate of gully development in the periods 1973 – 1986, 1986 – 2000, 2000 – 2005 and 2005 – 2009, active gullies were sampled randomly from the old gullies formed before 1973. Based on this, 8 active gullies were sampled from cultivated, grass, shrub and wood lands of the medium and gentle slope classes. Each of the selected gullies was subdivided based structure homogeneity. String, tape meter and graded staffs together with three personnel at a time were used to measure the dimensions (bottom width, depth, top width, length, area cross and volume) of the gullies. In this study, the excavated volume of gullies and bulk density of the soil was important to compute the amount of soil lost due to gully expansions.

A total of 60 respondents were involved in assessing the rate of gully development. The respondents were selected purposely based on age above 60 years and their proximity to each selected gullies or part of gullies. From the discussion, identification of head, transport and tail parts of the gully was possible. The part of gully formed within each period on the upper (inlet) direction was taken as 'Head' while to the lower (out let) direction was considered as 'Tail'. The remaining part was considered as transport zone. To increase the accuracy of the data related to gully, each period was linked with different events commonly known by the local farmers happened in each period. Besides to this, different features like bridge, big trees and crosses of public roads were used as references.

3. Result and Discussion

3.1 Result

3.1.1 Gully Inventory

Slope of *Huluka* watershed ranges from 0.8 to 83.3%. This range of slope was classified into three slope categories i.e steep slope, medium slope and gentle slope. The steep slope class was from 19% to 83.3% covered about 10773 ha of the watershed. The second (medium) slope class is 6-12 % which covered about 6765 ha. The 3rd and the lower slope class was 0.8-5% covered about 5361ha. The field survey in Huluka watershed has indicated 40 dynamic gullies which are currently existed on the two slope classes (medium and gentle). Of these dynamic gullies, 25 were on the medium sloped part of the watershed while the remaining 15 dynamic gullies were on the gentle slope. But, nothing gullies were found in the steep sloped part of the watershed.

The gullies on the medium sloped area have 4.7m and 2.4m average width and depth, respectively. The width to depth ratio of the gullies in medium sloped part of the watershed was 2.2 m for each 1m. From the 25 dynamic gullies in medium slope, eight were formed before 1973, four were formed in the period 1973 – 1986, eight were formed in 1986 – 2000 and the remaining five were formed after 2000. Out of 40 dynamic gullies 31 were found in shrub and grass lands and 5were found on cultivated land. The remaining 4 dynamic gullies were found on wood land and open land. But, relatively wider, longer and deeper gullies were found in cultivated land. The average gully length to area ratio (gully density) in medium slope was estimated to be 7.3m in each hectare.

In the gentle sloped part of the watershed (around the Lake Langano), surface and sub surface gullies were identified. Local farmers have listed many possible indicators which insure the existence of sub-surface gullies beside to the surface gullies. Some of the indicators were (1) conversion of surface flow in to underground flow i.e. the flowing water is not visible to human eye. (2) Events such as land sinking. The other active gullies observed in this slope class were the surface active gullies. Unlike to the sub surface gullies, the surface gullies were very accessible for assessment.

The gullies on gentle slope have 4.7m of average width and 2.7m of average depth. The average width to depth ratio of active gullies in gentle slope was 1.8. That was each one meter deep active gullies were 1.8 meter wide. This was small as compared to the gullies in medium slope. Most of the active gullies in gentle slope fall on periods before 1973 and after 2000. It means that the gullies in the gentle slope of the watershed were both young and old like that of in middle slope class of the watershed. The average width of the active gullies in cultivated land and open land were registered to be 6.2m and 6.4m, respectively. The average gully density was estimated to be 1.5m in each hectare was found to be much lower than compared with that of on middle slope class.

3.1.2 Rate of Gully Development

Ones the gullies were formed by different factors; some of them ceases their expansion and changed in to stable gullies while others continuously expand through time along the three sections. The total length of the active gullies in *Huluka* watershed was about 37km. based on the length of the gully it was estimated that about 51 thousand ton of soil was displaced in each year. The development of the gullies varied based on slope class, period, land use types and section of gullies. Higher expansion of gullies was observed in the medium slope class than the gentle slope class. About 61% of soil losses were registered to be from medium slope while the remaining 39% was from gentle slope. Increasing Progression of gully development was observed from the earliest period (1973 – 1986) up to the more recent period (2005- 2009). The trend of soil loss from *Huluka* watershed during the last 37 years (1973 – 2009) is displayed in figure 8.

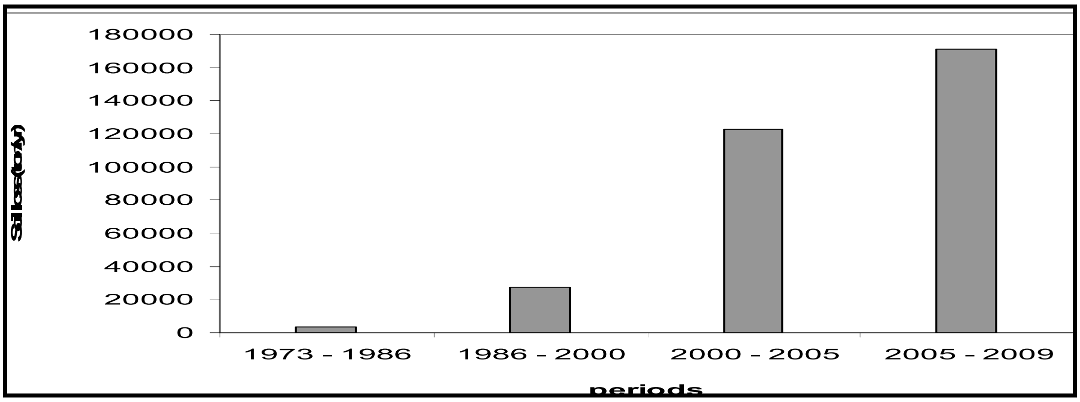

Figure 2: Estimated soil loss in different periods due to expansion of old gullies

Figure 1 show the soil displaced from its original place due to the expansion of old gullies. The rate of soil loss due to old gully development has shown continuous increase. It increased from about 3.3 thousand ton in each year of the period 1973-1986 to 170 thousand ton in each year of the period 2005-2009. Dramatic increase of old gully development was observed in the last two periods. From the total soil lost within the last 37 years, 77% was displaced within the last ten years only, while the remaining about 23% was displaced in 27 years of the period 1973-2000. Moreover, local farmers indicated that the development of gullies were fast in the past few years. The rate of gully development registered in Huluka watershed was not uniform across different LU. It varied from one LU type to other type of LU (figure 2).

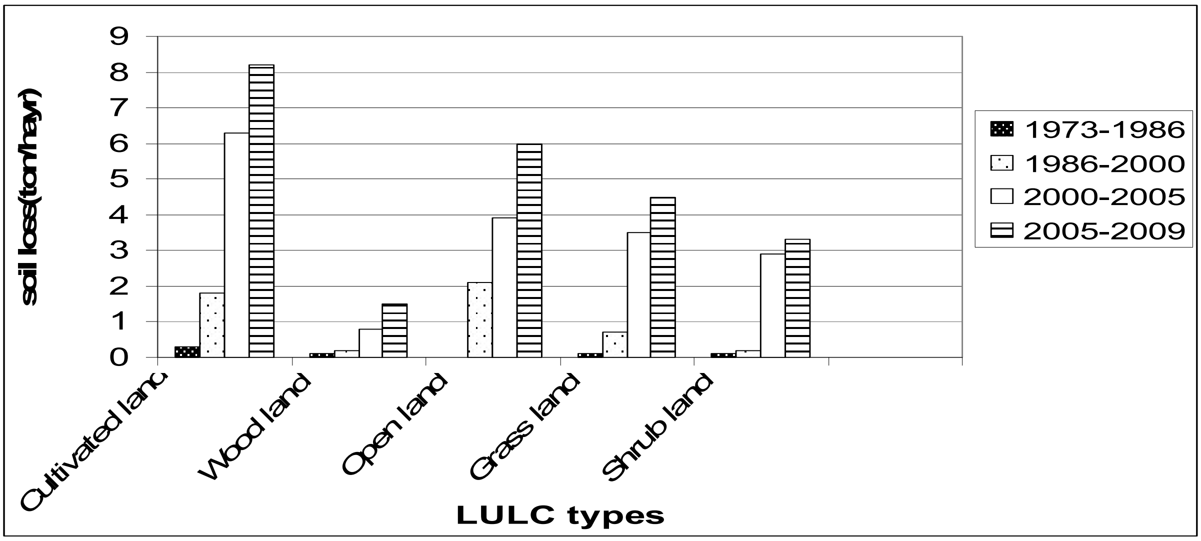

Figure 3: Rate of gully development for some LU classes in different periods

As displayed in figure 7, the rate of gully development on each LU have shown continuous increasing progress from the period 1973 – 1986 to the period 2005 – 2009. Rate of soil loss due to expansion of gullies on open land increased from 2.1 ton ha^{-1} yr^{-1} in 1986 -2000 to 6 ton ha^{-1} yr^{-1}in 2005-2009. The old gullies in cultivated land have also expanded dramatically. There was 0.3 ton of soil loss from one hectare in each year for the period 1973 – 1986 and this rate of gully development was increased to 8.2 ton ha^{-1} yr^{-1} in the period 2005 - 2009. In the case of grass and shrub lands, the rate of gully development was increased from 0.1ton $ha^{-1}yr^{-1}$each by the period 1973 – 1986 to 4.5 ton $ha^{-1}yr^{-1}$ and 3.3ton $ha^{-1}yr^{-1}$ during 2005 – 2009, respectively. Slight expansion of old gullies was registered in wood lands and increased from about 0.1tonha^{-1}yr^{-1} in 1973 – 1986 to 1.5 ton $ha^{-1}yr^{-1}$ in 2005-2009.

The expansion rate variations of old gullies were not only among gullies. But, it was also within the gully it self. It was varied from one part of the gully to the other part of the gully. The gullies in the study area had shown different rate of expansion through its transport zone, tail and head. Based on this, the active gullies in different slope and LU class in *Huluka* watershed has lost on average about 39 thousand ton only from their transport zone in each year. About 11 thousand ton of soil was displaced from the retreat of head section of the old gullies, while about 1.5 thousand ton of soil was removed from the progress of these gullies along the tail in each year.

The section based gully development rate was dependent on LU types. Higher rate of gully development in the transport section was observed in the gullies which were found on cultivated land than on the remaining LU types. In the same way, high rate of gully development at head and tail was observed on the gullies in grass land than on the remaining LU types. Minimum rate of gully development in all sections was recorded from the gullies on wood land as compared to the other LU types.

3.2 Discussion

3.2.1 Gully Distribution

As presented in the result part, some of the gullies in *Huluka* watershed are old while others are young, some are active while others are stabilized and some are laid on the upper surface of the land while some others are incised internally in the sub-surface of the land. This all variations were attributed to the variations of slope, land use classes and other factors.

The distribution of the active gullies among slope classes and land use classes was not uniform. All of the active gullies were found in the medium and gentle sloped parts of the watershed. No gully was found on the steep slope of the watershed. This may be attributed to the relative variation of vegetation cover and public interference. In line with this assumption, Ephrem (2008) have found land sloped over 20% is less affected with soil erosion. This was in contrary to the reports by many investigators. For example, according to Morgan, (1996), Vanwalleghem et *al*. (2003), Zucca *et al*. (2006) and Parkner *et al*. (2007) showed that steep slope is positively correlated to gullying of land under insignificant interference of other factors. This can lead us to the conclusion that the determinant factor in Huluka watershed is more related to human interference than the natural factors.

The variation of gully distribution in the study area was not only across slope classes. Difference in gully distribution was also observed among the different LU classes of the same slope class. Higher gully distribution was observed on grass and shrub lands than on cultivated land. This may be due to the removal of the rills during the pre – stage of gullies development as a result of the recurrent cultivation practices on cultivated land which was not common in other LU classes. This agrees to the reports of Pathak *et al*. (2005) and Galang *et al*. (2007). Unlike the distribution, the cross sections were found somewhat larger on cultivated land as compared to other LU classes. This was due to the high intervention of the local community that made it susceptible for erosion.

The width of gullies was found longer than the depth. This was attributed to the faster development of gullies along sides to new lands than in to depth. This was in line with the result of Awdenegest and Holden (2008). Comparing to deep narrow gullies, the wider in width and shallow in depth gullies have more on – site impacts. Local farmers noted that it was through the side way of expansion that gullies have invaded their land. This agrees with the report of Bryan and Jones (1997).

3.2. 2 Gully Developments on major Land Uses

The result has indicated that gullies expand through side wall collapse, retreating toward the hilly direction and tunneling of gullies in the tail direction. Like the distribution of the gullies, the rate of gully development in *Huluka* watershed was not found uniform throughout the watershed. Instead, it varies based on the slope class, periods and LU types. Moreover, it was not equal among the different sections of the gully itself. Since the medium and gentle sloped parts of the watershed were highly interfered with intensive cultivation and overgrazing, fast rate of gully development was registered as compared to the steep part of the watershed which was comparatively under good vegetation cover (shrub land, fragmented and continuous natural forest). The result of this study strengthens Sidorchuk (1999) idea and confined that the main causes of gully formation were anthropogenic factors (clearing of native forests and tilling of fallow lands). Moreover, Valentin *et al*. (2005) has listed some of the anthropogenic factors such as inappropriate cultivation and irrigation systems, overgrazing, road building and settlements that were involved in gully formation

Rate of gully development has shown continuous progress across the periods considered. Especially, dramatic increase in rate of gullying in each LU classes was observed after 2000. Here, even though there were many factors that were determinant factors, the rapid LU change into cultivated land had a good contribution. As an additional clue to this, higher rate of gully development that was registered on the highly interfered LU classes (cultivated, open and grazing lands) than less interfered LU classes (shrub land and natural forests). Especially, the current rate of gully development in cultivated land of the study area (8.2 ton $ha^{-1}yr^{-1}$) was comparable to the sever rate of gully development reported in different agriculture dominated areas of Ethiopia. For instance, Awdenegest and Holden (2008) has reported about 11ton ha^{-1} yr^{-1} to Humbo catchment, southern Ethiopia; Nyssen *et al*. (2006) has reported 6.2 ton ha^{-1} yr^{-1} in Tigray, north Ethiopia and by Shibru *et al*. (2003) has reported 1.7ton m^{-2} in eastern Ethiopian high lands.

Though gullying of land is cumulative effect of many factors, the loss of vegetations and cultivating intensity were the main factors. Due to reduction of productivity and increasing household size, farmers have increased the recurrence of plowing from time to time and expanded cultivated land by devegetating other lands to increase yields. This made the land very easy to be penetrated by flowing water and be cracked through time. Both these conditions have increased the susceptibility of the land for erosion. In line with this, Nyssen *et al*. (2006) have given the same justification to the sever gully expansion in Tigray. The fast rate of gully development in case of open lands is related to the increased high concentration of surface run – off due to the diversion of flowing water toward the open lands (public roads). Moreover, the absences of vegetation cover had an input in accelerating gullying of land on cultivated land. But, gullying in open land was reduced due to the crusting of the upper surface resulted from movement of human being and animals. Not only this, there were also some acts of protection measures done by the vehicle drivers. In case of grass land, the animal trampling and over grazing were the responsible factor to worsen gullying of land. In general, it was the absence of vegetation and the intensive interventions as a main cause for fast gully development in different LU (eg., Sidorchuk, 1999; Bork *et al*., 2001; Valentin *et al*., 2005).

As stated in the above, the old gullies in Huluka watershed were still active in transport zone (middle section), tail (lower section) and head (upper section). Currently in most old gullies, the head parts was characterized with narrow and shallow cross - sections and free of any vegetation on its floor. This was an indication how much it is young and possibility of the gullies to increase along the head section in line with Valentin *et al. (*2005). Had it been with wide, deep cross - sections and with vegetations around its floor and walls like the report by Awdenegest and Holden (2008), it would have been assumed as old and stabilized section of gully. In the transport zone (middle part), it was through wall sliding and floor incision that the gullies expand. The width of this section was enlarging by tension cracks around walls at the two sides that displaced large part of land. This phenomenon was the major cause for soil loss from gullies in *Huluka* watershed. This agrees with the findings by Awdenegest and Holden (2008). There were gullies which directly contributed sediments to Lake Langano and main streams. In reverse to these, there are gullies with which some bottom part of them were buried with the soil that came from the area above. This was the reason why low rate of gully development in tail section of gullies. The same justification was given by Tigist *et al. (*2009).

In general, faster rate of gully development was seen in the middle section (transport zone) of the gully than the head and tail section. This agrees with Peter and Shiu-hung (1997) and Awdenegest and Holden (2008). The reason was related to the pressure from local community and due to the probability of collapsing part of the land due to caving of the gully sides through time in addition to incising by flowing water. Moreover, it is difficult to intervene with easy conservation measure. For example, it is unlikely to tackle it with recurrent cultivation practice. Instead, the cultivation practice around the sides make susceptible to be cracked and then collapsed. This may be the reason why development rate of transport zone was fast in cultivated land. Respondents have revealed the possibility of holding back the progress of head and tail gully development with simple conservation practice while they were at rill stage. This depended on the flowing water, which was not fast at head and tail as compared to the transport zone. Especially, the tail part of the gully was a zone of deposition where soil displaced from above deposited so that burry some part of the gully. It was due to the absence of recurrent cultivation practices why the rate of gully development in tail and head was fast in grass land as compared to on cultivated land. The same justification, i.e wide distribution of gullies on grass, bush land and continually forested lands than on the cultivated land and area converted from cultivated land to forest land (Pathak *et al*.2005 and Galang *et al.* 2007).

4. Conclusion

As presented in the result part, the gullies in *Huluka* watershed are old while others are young, some are active while others are stabilized and some are laid on the upper surface of the land while some others are incised internally in the sub-surface of the land. This all variations were attributed to the variations of slope and land use classes. As obvious, the economic activities (cultivation, grazing and forestry) done in the study area were found the main exacerbating gully erosion in the area. As in the result and discussion section implied, the cultivation practices (plowing) were found important factor in impeding formation of new gullies but exacerbating expansions of already formed gullies (gully sides). This was why abundant gully number was registered on lands used for grazing purpose (grass land, shrub land and forest lands) than on the lands used for cultivation purpose (crop land). This factor was also found important to vary the gully expansion from one section to the other section (head, transport zone, tail). Despite the rapid expansions of already formed gullies and formation of new gullies both on surface and sub surface, there was no any deliberately done protection and/or rehabilitation measures registered in the study area.

The worsening of gully erosion from time to time in *Huluka* watershed is mean to increasing the off – site and on – site impacts. This trend of gully erosion is not good to the watershed and to Lake Langano. Therefore, there is a need of an intervention with effective gully control measure to impede the gully expansion so that the degradation of lands of the watershed and sediment yields to the lake from gully erosion will be reduced. the intervention in cultivated lands should be in way that can rehabilitate the already formed gullies while in the case of the lands used for other purposes it should be in way how new gully formation can protected and stabilized

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