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APPLICATION OF GIS ON ENVIRONMENTAL DEGRADATION DUE TO THE OFFSHOOTS OF HIGHWAY DEVELOPMENT PROJECTS: CENTRAL ETHIOPIAN HIGHLANDS.

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Abstract

Physical land degradation after road building has been observed in Central Ethiopian highlands through gully erosion. In this research work by using a number of methods such as Field observation, gully measurement, GIS technique, the 1997 and 2006 topomap and socio-economic questionnaires, the impacts of the road on land degradation has been studied. It investigates how highway construction in the Ethiopian Highlands affects the gully erosion risk by quantifying the catchment area before and after road construction, the number of gullies created, and its characteristics in two selected cases: Addis Ababa-Fiche and Addis Ababa-Ambo. Accordingly; since the building of the road, 17 new gullies were created immediately down slope of the studied road segments and 8 other gullies at a radical change in its dimensions. The average catchment area is now 58.28 hectares and 74.52 on the road segments of Fiche and Ambo respectively, which is significantly different (p<0.001) from the average pre-road catchment area of 8.45 and 14.52 hectares (paired average). The total surface area occupied by gullies in the side of Fiche road and in the side of Ambo road transects was about 63,892.6 m2 and 59,214.25 m2 respectively. The volume of soil loss was calculated between 12,530.38 m3 and 71,420 m3 from each road segments. The result of statistical analysis indicates that variation of the gully length contributed 95% of variation in the volume of soil loss. The Gully density (5.7m/ha to 14.06m/ha) implies that the sampled roadside areas were moderately to severely degraded. The damages and associated problems of the gullies, as explained by farmers, include loss of land, dissection of farms, and deposition of sediments on growing crops and in extreme cases putting agricultural fields out of production. Hence roads should be designed in a way that keeps runoff interception, concentration and deviation minimal. Techniques must be used to spread concentrated runoff in space and time and to increase its infiltration instead of directing it straight onto unprotected slopes.

Key words: *Gully erosion Risk, catchment area, Road design, Ecological destructions*

Introduction

Land degradation is a human induced or natural process which negatively affects the land to function effectively within an ecosystem. The link between a degraded environment and poverty is direct and intimate. As the land resource base becomes less productive, food security is compromised and competition for dwindling resource increases, and leads to potential conflict in the society. The most important on-farm effects of land degradations are declining potential yields. The threat of degradation may also be reflected in the need to use a higher level of inputs in order to maintain yields. Serious degradation sometimes leads to a temporary or permanent abandonment of some plots (Scherr and Yadav, 1996).

More than 90% of Ethiopia's population lives in the highlands including about 93% of the cultivated land, around 75% of the country's livestock and accounts over 90% of the country's economic activity. Land degradation is seriously threatening the economic and social development of the country as a whole (Hawando, 1997). The Ethiopian Highland Reclamation studies (EHRS) revealed that the Ethiopian highlands, which cover 44% of the country's total land area, are seriously threatened by soil and biological degradation (FAO, 1986). Some 27 million hectares representing approximately 50% of the highlands are already significantly degraded. Of this area, 14 million hectares are badly eroded and if the trend of soil degradation continues, per capita income in the highlands will fall by 30% in 20 years time, (FAO, 1984), fifty percent of the remaining highlands are highly susceptible to erosion.

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According to Peter and John (2002), for rill and sheet erosion, road surfaces are the cause; whereas for gully erosion risk, road culverts and ditches are the major cause. Culverts and cross drainage channels are used to convey water from one side of a road to the other. This is accomplished by conveying water under the road through the culvert, or by allowing water to flow over the road using a ford, water bar, or dip. Ditch is a long narrow channel dug in the ground parallel to a road usually used for drainage and as a boundary marker. Good ditches make good roads. Properly designed and constructed ditches serve a number of essential purposes.

Statement of Problem

While road network bring about huge benefits to society, the adverse impacts of road development on environment such as disturbance and destruction of ecosystems have become more and more obvious. Unfortunately such adverse impacts have long been neglected. Great attention should be paid to this problem, and urgent work should be undertaken on the control of physical degradation along roads. Road construction without adequate provision for drainage is a major cause of gully erosion. Inadequate drainage systems for roads such as small number of culverts, insufficient capacity of road ditches etc are some of the causes of gullying. Although the road caused gully erosion may occur anywhere in the world, the problem is particularly severe in developing countries due to neglect in maintenance and the lack of provision for safe outlets to the excess runoff.

One of the components of the road sector development system project is to upgrade and rehabilitate trunk roads and rural roads. The road upgrading will cause some adverse effects on local water resources. The likely sources of impacts will include the need to redirecting water courses at culverts and bridges; road cuts and other exposed sites that may trigger erosion and landslides (that may threaten the road itself); temporary road diversion that may affect people’s property and safety; operation of quarries and burrow pits (Radoane,1990).

A neglected and newly constructed drainage system without provision of proper and adequate accessories (energy dissipaters, soil and water conservation structures) quickly causes soil erosion and deteriorates components of the road system like ditches and culverts .The ultimate result may even be a loss of a road section or even many sections greatly hampering the traffic flow that negatively contributes to the mobility of the road users in general and the socio economic well being of the people in particular.

Road stream crossings and ditch-relief culverts are commonly sites of ongoing or potential erosion. Erosion from failures of these structures can be a source of significant impacts to aquatic and riparian resources far removed from the initial failure site. The initiation of this research is driven by:

1. The fact that little or no empirical research has been carried out in the area on land degradation due to the formation of gullies as the result of road construction in Ethiopian highlands.
2. The study area has unutilized productive land for crop and Livestock production making it vulnerable for land degradation if no sustainable land management practices are introduced.

Therefore, it is essential to document the baseline data of land degradation in relation to the new road construction development program.

Objectives

The overall aim of the study is to provide a general over view of land degradation due to faulty road drainages along recently rehabilitation road projects and to assess the perception of farmers on the problem of physical land degradation caused by road construction in the Central Highlands of Ethiopia.

1 To enumerate the number of gullies, measure the depth, width, and length of the gullies and its morphological relationship created as a result of road construction.

2 To quantify the volume of soil lost and the nature of gully morphology which are formed by the inappropriate drainage structure.

3 To quantify gully density, gully texture and the proportion of degraded land by the action of gully erosion risk in the selected road segment.

4 To show the natural water flow pattern and the runoff concentration made due to road construction and to compare area drained to the gully head before and after the road construction using Digital Elevation Model.

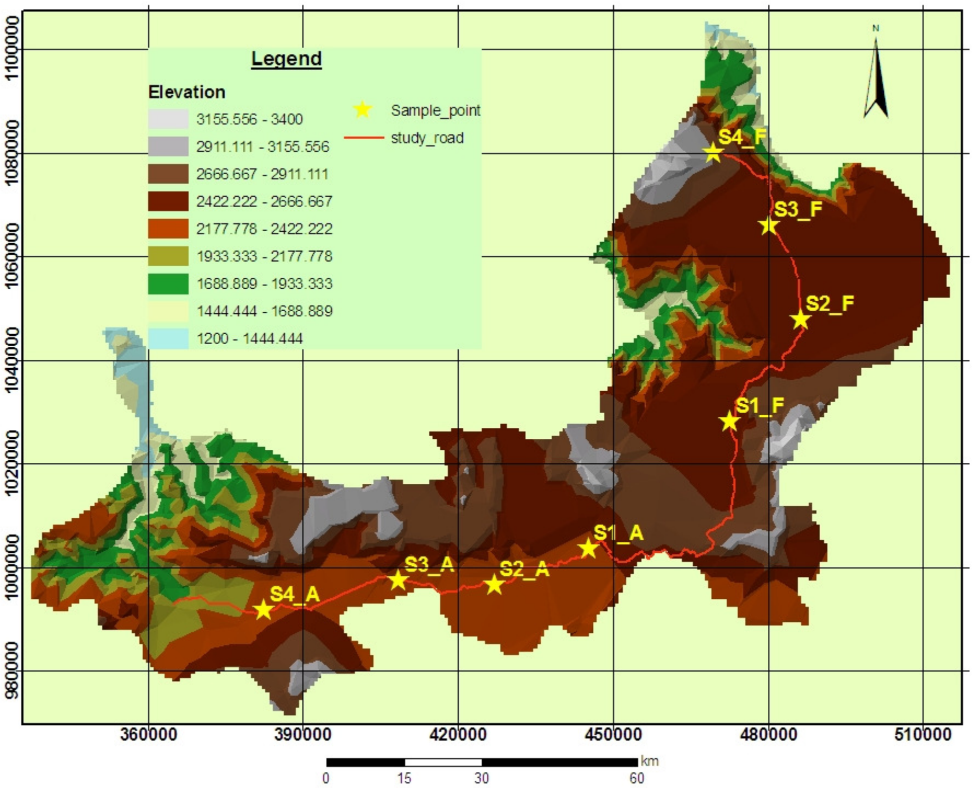
5 To assess the perception of farmers around the road about land degradation as a result of the road.

Materials and Methods

Study Area

The road projects are found in the Oromiya Regional State of Central Ethiopian Highlands. The commencement date for the Addis Ababa to Fiche road rehabilitation was 1999 and the completion date was 2004. And that of Addis Ababa to Ambo road rehabilitation commencement and completion date was 2002 and 2006 respectively. This road project is found in North Shewa Zone of Oromiya Regional State in Central Ethiopia. It is part of the road that connects Addis Ababa to Bahir Dar and Gonder. The total length of the proposed road is 113km and 81% of the road segments are crossing farmland and grazing land; and the remaining road segments are crossing built up land and reforested land. 35% of the road segment is also constructed by following a new rout alignment; whereas the remaining road segments are constructed over the former alignment but a complete destruction and reconstruction was made during rehabilitation. This road project is found in the West Shewa Zones of the Oromiya Regional State in Central Ethiopia. The Addis Ababa – Ginchi - Ambo Road was originally built in the 1930's by Italians with a base varying from 4 to 6 m width. In the 1950's and 1960's, the road was partially rehabilitated and upgraded to bitumen standard. The existing road is some 102km long and passes through the Western Shewa Zone in a westerly direction. As one drives from Addis Ababa to Ambo, the road passes through the major towns of Holeta, Addis Alem and Ginchi. route, the road passes through some 33 kms of flat area, 66 kms of rolling to hilly terrain and 3 km of hilly to mountainous terrain.

The major towns, such as Addis Alem, Holeta and Ginchi through which the road passes, have populations of 8,447, 20,896 and 164,441 respectively. The road passes through 3.7 km of bush land, 21.3 km of built-up area, 35.6 km of farmland, 15.7 km of re-afforested land and 42.1 km of grazing land.



(SA=Ambo site, SF=Fiche site),

Figure 1 Topography and drainage map of the study area.

Altitude is one of the major factors that determine the temperature of the area. About 50 percent of the North and West Shewa lies in Weina Dega Region (altitude 1500-2500m) whilst Kolla (altitude <1500m) and Dega (altitude 2300-3500m) constitutes 50.3, 16.7 and 33 percent respectively. The average annual temperature of the study area ranges from 16.4 to 25oC. The project area enjoys ranging from 813mm substantial annual rainfall to 1699mm.The dominant economic activity in the study area is crop production integrated with livestock rising. The crop pattern and production depends on agronomic factors such as altitude, climate, soil and rainfall. A wide variety of crops are grown in the study area. However, crop production is at subsistence level. The major factors responsible for the low productivity were increase in population growth, land scarcity, loss of soil fertility and erosion problem, shortage of farm oxen, lack of agricultural inputs, occurrence of drought, erratic nature of rainfall and pest occurrence. Livestock husbandry is also an important sector of the area's economy.

Data Collection

This study was designed in the way that relevant and accurate information could be obtained about the adverse impacts of the road on the surrounding landuse types. Accordingly, 4 sampled road segments with a radius of 1km were used at every 25km distance outside of any urbanized area along each road projects. For each sampled road segments a semi-structured questionnaire and open ended interviews were used to collect data from households and focus groups and experts working in governmental and nongovernmental organizations respectively. Gullies were quantified and measured with respect to slope, landuse type, and soil texture. The boundary of watersheds, the drainage area of gully heads and gullies before the rehabilitation of the roads were determined on the topographic maps with a scale of 1:25000 ArcGIS 9.3 software. The geographic coordinate systems and the elevation of the selected sites were taken from the center of each road segments using Geographic positioning system (GPS) during the field survey.

The gully head area with and without road were done by using Raster Calculator of Arc GIS spatial analysis tool. Information on the exact position of gully heads and road culverts in the study area collected during the 2009 field survey was then used to reduce errors when manually deriving the drainage area from a digital elevation model.

The contour map of the study area is derived from SRTM (Shatter Radar Topographic Map) data. First SRTM data was exported from DEM software to Arc GIS 9.3 and converted in to a raster DEM data format using the spatial analysis tools; surface analysis in Arc GIS 9.3 Arc toolboxes. And finally a 10m contour interval is generated using surface analysis tools. This made possible in the determination of the natural drainage pattern ,the drainage area of the gully head with and without road ,the concentrated runoff (gullies) ,the sediment deposited (debris cone), and the redirected flow patterns.

Data Analyses

In the Analysis part, the correlation between the volume of gully erosion as dependent variable and morphometric characteristics of gullies as independent variables was considered using stepwise method in SPSS software statistical analysis to identify the significant and useful index to estimate the volume of gully erosion. US-SCS (1966) by using width per depth (W/D) ratio of erosional channels found that in the cohesive soils, the width of the gullies is 3 times of their depth while in non-cohesive soil, this ratio is 1.75 times (Relationship 1 and 2).

$$D=0.34W \text{ ---------- cohesive soil} \quad (1)$$

$$D=0.57W \text{ ------ non-cohesive soil} \quad (2)$$

Radoane *et al.* (1990) presented a linear relationship between W/D and gully length (Relationship 3)

$$W/D=1.287+0.00199L \text{ ------- } R^2 = 0.39 \quad (3)$$

Also, correct estimation of gully length would estimate the gully cross section correctly. Nachtergaele *et al.* (2001b) in their research found a power relationship between gully volume and gully length (equation 4)

$$V = aL^b \quad (4)$$

Where;

D=depth, W= width, L= length

V=volume, and a and b= parameters which take different values under various environmental conditions.

On the other hand, data obtained from GIS technique, which were used for calculation of basin area boundary of each gully head before and after the construction of the road using the three dimensional approach (DEM), was analyzed and the difference in (unpaired) average values tested for its significance by t-test (Diem, 1963; Beguin, 1979).

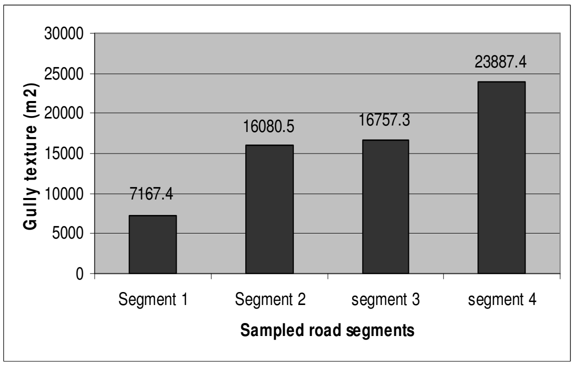
Results and Discussion

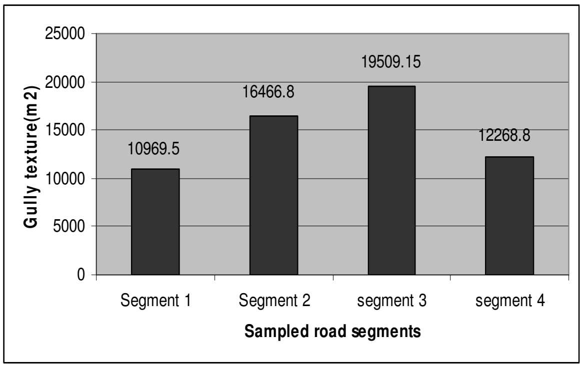
Table1 Summary of Gully characteristics in each sampled segments on Fiche road site

Gully characteristics	Segment 1	Segment 2	segment 3	Segment 4	mean	st. dv.
No. Gullies	2	4	4	4		
Total length(m)	1780	4348	4415	5425	3992	1554.79
Average width(m)	3.83	3.33	3.72	3.76	3.66	0.2247
Average depth (m)	1.80	2.40	2.45	1.78	2.11	0.367
Surface area(m2)	7167.4	16080.5	16757.3	23887.4	15973.15	6850.86
Volume(m^3)	12530.38	36206.29	39830.16	40883.78	129450.6	13372.43
Area ratio	0.00023	0.00512	0.005340	0.00761	0.0046	0.0031
Density (m/hec)	5.70	13.85	14.06	17.28	12.72	4.938

Table 2 Summary of Gully characteristics in each sampled segments on Ambo road site

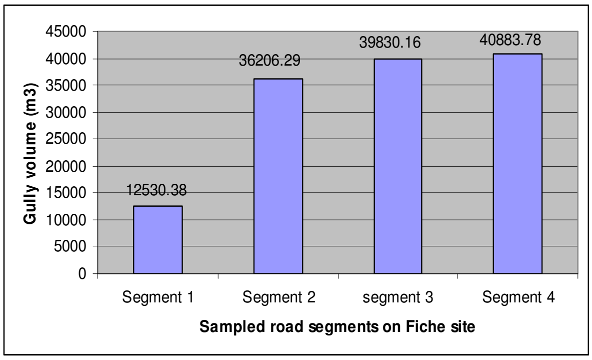
Gully characteristics	Segment 1	Segment 2	segment 3	segment 4	mean	St.Dv.
No. Gullies	2	3	3	3	-	-
Total length (m)	2859	3840	3705	4117	3630.25	542.031
Average width (m)	3.68	3.61	4.73	5.00	4.26	0.714
Average depth (m)	2.1	2.2	3.55	2.6	2.61	0.661
Surface area (m^2)	10969.5	16466.8	19509.15	12268.8	14803.56	3917.226
Volume(m^3)	25528.56	31733.14	71420.27	61205.35	47471.83	22296.12
plot to area raio	0.0035	0.0052	0.0062	0.0039	0.0047	0.00124
Density (m/hec)	9.11	12.23	11.80	13.11	11.563	1.724



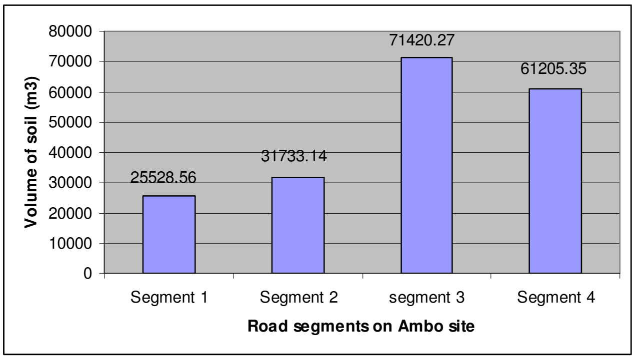


Gully Texture area covered along Fiche road site

Gully Texture area covered along Ambo road site



Volume of soil lost in m3 Fiche site.



Volume of soil lost in m^3 From Ambo site.

Figure 2 Volume of soil lost in the sampled sites

Table 3 Relationship between morphometric parameters of the gullies

	standard coefficient	R2	P
D=2.146 + 0.173W	0.55	0.26	0.05
W/D=2.27 + 0.006L	0.66	0.41	0.05

Relationship shown in Table 3 implies that gully widening is happening along the road sides indicating the risk of land degradation (rangeland and rain fed farms) is higher in these regions. Also, there is a linear relationship between W/D ratio and gully length (Table 3). It implies that with increasing one unit in the gully length, 0.66 unit of W/D ratio will be increased.

Table 4 Volumes of gully and its morphometric characteristics

variable	(β1)	(β2)	(β3)	R2	P
L	0.931			0.870	0.01
L,D	0.966	0.326		0.980	0.01
L,D,W	0.872	0.217	0.158	0.978	0.01

The volume of gully erosion had a significant correlation with length, top and bottom width ($P<0.01$) and with from factor, D/wt ($P<0.05$). The simplest linear equation existed between the volume and length of gullies indicates that more variation in the volume of gully erosion was due to the length of gullies. In addition to gully length, gully depth R^2 increased to 0.980 but with adding gully top width (Wt), to the relationship, R^2 was not increased significantly (Table 4).

As shown in Table 5 below, the area drained to the gully head before road construction were smaller than after the road has been constructed. The average catchement area is now 58.28 hectares and 74.52 on the road segments of Fiche and Ambo respectively, which is significantly different ($p<0.001$) from the average pre-road catchment area of 8.45 and 14.52 hectares (paired average). The higher drainage area implies that higher volume of water is flowing with higher speed towards the culvert and very long gully were created down slope of the road.

Table 5 Gully Head Drainage Area

Ambo Site				Fiche site		
Road segments	Gully head	Drainage area after the Road (hectares)	drainage area before the road (hectares)	Gully head	Drainage area after the Road (hectares)	drainage area before the road (hectares)
1	2	68.55	8.89	2	71.00	11.20
2	3	87.99	16.40	1	30.56	6.48
3	2	76.00	21.34	2	56.89	7.45
4	2	65.55	11.45	3	74.67	8.78
Mean		74.52	14.52		58.28	8.45
St .dv.		9.99	5.51		20.05	2.02

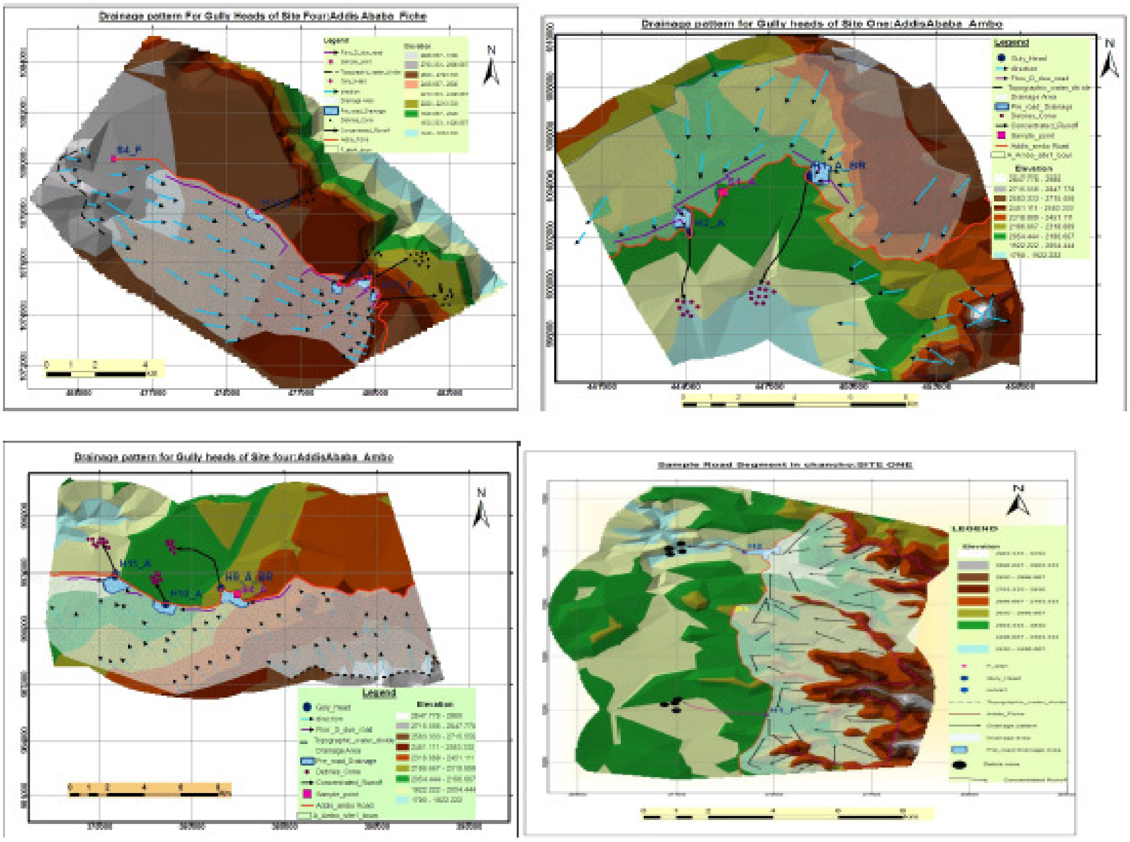


Figure 3 DEM of the sampled road segments

On the other hand, the data obtained from semi structured questionnaire shows that soil erosion is a common problem in both study areas. (80.6%) on Fiche site and 83.3% of farmers on Ambo site perceived that gully erosion is observed on their field after the road has been constructed.

Regarding the causes of gully formation, most respondents mentioned that water from the road surface and culverts (89%), inappropriate drainage of culverts and ditches of the road (75.4%), and cut and fill of slope during road construction (54.0%) as important causes of gully development.

Farmers' Perception of Physical Land Degradation after the Road Rehabilitation

In the final assessment, concepts of land resources, the interaction between human and land resources, problems and causes of physical land degradation, land resources management, sustainable agriculture, and infrastructure were discussed. Interviewed residents on both road sites have common view and perception on the importance of infrastructural development such as road and its adverse impact on the environment. Participants of chancho, mukature, chagel, keyu, and awaro describe land resources as physical and biological entity that include farmland , grazing land, forest, mountains, and vegetation from which human, domestic and wild animals sustain their lives. As of the interaction between human and land resources, they viewed that human beings obtain benefits from land such as food, fiber, wood for fuel and construction purposes. They also recognized that land provides sites for construction of houses and for other development activities. Meanwhile, they believe that the impact of human activities have been degrading land resources.

Inappropriate drainage of culverts and ditches and concentration of water along the road were identified as the major proximate causes of physical land degradation through the formation of gullies. The exposure of land to erosive forces due to the above mentioned activities exacerbate the deterioration of the quality and size of the land.

On the other hand, the data obtained from semi structured questionnaire shows that Soil erosion is a common problem in both study areas. Farmers along Addis Ababa to fiche and to Ambo believe that they face problem of soil erosion in their farmland, grazing land, and forest. They infer the presence of soil erosion by rills and gullies, sheet erosion, and pedestals in their surroundings (Table 6 and 7).

As shown in table 6, almost all farmers (80.6%) on Fiche site road segments perceived that gully erosion is the dominate type of problem observed on their field. On the other hand, 83.3% of farmers on Ambo site perceived that gully erosion problem observed on their field.

Table 6 Indicators of the presence of soil erosion as perceived by farmers on Fiche site

Farmers perception on erosion types in their field	No of respondents	% of farmers on erosion types in their field
Gullies	30	83.3%
Rills	3	8.5%
Sheet erosion	1	3.1%
Others	2	6.1%
Total	36	100%

Table 7 Indicators of the presence of soil erosion as perceived by farmers on Ambo site

Farmers perception on erosion types in their field	No of respondents	% of farmers on erosion types in their field
Gullies	38	80.6%
Rills	4	8.6%
Sheet erosion	3	6.4%
Others	2	4.4%
Total	47	100

The measures taken to mitigate problems of soil erosion are not effective in the study areas. For instance, on the biophysical survey, it is observed that, land covered by gully system is totally lost for production purpose along the roadside land types due to the influence of the road construction and the absences of rehabilitation measures by the community.

Table 8 Farmers' Perception of Gully Erosion by Degree of Severity

Degree of Gully erosion problem	Frequency	%	Cumulative %
No Erosion	6	7.2	7.2
Low Erosion	14	16.9	24.1
Moderate Erosion	22	26.5	50.6
Severe	41	49.4	100
Total	83	100	

As can be seen from Table 8, only about 7.2% of farmers indicate that no erosion problem on their farm land. The remaining 93.8% of farmers perceived that at least low level of soil erosion problem on their cultivated land. This is more than or comparable to the findings of other studies made in different parts of the country. For instance, the study made in Gununo Area in SNNPR at the beginning of 1990s indicated that about 74% of farmers interviewed perceived soil erosion problem on their cultivation field (Belay, 1992). Recent study in Digil indicated that about 98% of farmers surveyed perceive the problem of soil erosion on their own farm (Woldeamlak, 2003). In the study area the perception of farmers about the degree of the problem of soil erosion is different among respondents. About two-third of farmers interviewed indicated that there is moderate or severe erosion problem on their farmland. About one-third of farmers interviewed (29 %) rated the problem to be low on their cultivation land, one-fourth of interviewees (about 26 %) indicated that there is moderate level of erosion and the remaining 37% indicated that there is severe erosion problem.

Table 9 Farmers' Identification of the causes of Gully erosion formation

no	Main cause of gulling	Responses (%)*
1	Water from the road surface and culverts	89
2	Population pressure	12
3	Lack of ditch and culvert layering	3.5
4	Cut and fill of slope during road construction	54
5	Inappropriate drainage of culverts and Ditch of the road	75.5
6	Over grazing and Deforestations	35
7	Increasing built up area around the road	45.5
8	Others	15

*The sum may not add up to 100 % due to repeated responses

Regarding the causes of gully formation, most respondents mentioned that water from the road surface and culverts (89%), inappropriate drainage of culverts and ditches of the road (75.4%), and cut and fill of slope during road construction (54.0%) as important causes of gully development. Significant number of farmers (about 45.5%) also perceived increasing built up area around the road as a cause of gully formation.

As shown in table 10 below 87.0% of the respondents had ever seen gully on their land before the road construction, 67.0% of the respondents said that gullies were on their land before the road but brought significant change in the length, depth, and width after the road construction.

Table 10 Farmers' identification of the time when gully appeared on their land

no	Time of gully appearance	Responses (%)*
1	Before the road construction	32
2	After the road construction	87
3	Before the road, but the size significantly increased after the road construction	67
4	Not known	23

* The percentages may not add up to 100 due to repeated responses

Table 11Problems faced by the farmers due to the formation of gully on their land

No	Types of problems faced	Responses (%)*
1	Decrease of the cropped area&/ loss of soil and yield	79.5
2	Obstruction of tillage operations	85.3
3	Restriction of movement from one farmland to the other	89.8
4	Taking away of materials by flooding during rainy season	45.5
5	Changing the natural beauty of the environment	44.5
6	Others	23

*The sum may not add up to 100 % due to repeated responses

Regarding the problem of gully, 79.5% of the respondents faced decrease of the cropped area and loss of soil and yield, 85.3% have obstruction of tillage operations, and 89.9% of the respondents are restricted movement from one farmland to the other.

Moreover; The damages and associated problems of the gullies, as explained by farmers during interview and observed in the field, include loss of land, dissection of farms, deposition of sediments on growing crops and in extreme cases putting agricultural fields out of production. Risks of falling into the gully for children and animals, increased distance to travel from the village and the associated burden to women are other problems. Additionally, farmers explained that crops growing close to the gullies usually dry up before reaching to full maturity and they believed that wind blowing through the gully has the capacity to dry up their crops.

Conclusion and Recommendations

Physical land degradation features which were observed along the studied roads were mass failure /landslide, sloughing, rilling and gullying. However; it has been noticed that gully erosion was found to be the most important causes of degradation. The road between Addis Ababa to Ambo and to Fiche in the highlands of Northern and Western Shoa (Central Ethiopia), built in 1999-2004, caused gulling at most of the culverts and other road drains. While damage by runoff to the road itself remains limited, off-site effects are very important. The road induces a concentration of surface runoff, a diversion of concentrated runoff to other catchments, and an increase in catchment size, which are the main causes for gully development after road building.

Therefore, with a responsibility for the sustainability of whole society, the environmental protection will be deemed as one of the important factor in the procedure of road planning, design, construction, operation, administration and scientific research. We should fully consider the saving of resources and energies, diminish pollution of air, sound, water and soil, and reduce influence of road to scene. We should also consider the influences of road to animal and plant, human society and soil, develop eco-friendly road system. Ethiopia, as a mountainous country, has different landforms which are a strong obstacle in the construction of road transport system. Hence roads should be designed in a way that keeps runoff interception, concentration and deviation minimal. Techniques must be used to spread concentrated runoff in space and time and to increase its infiltration instead of directing it straight onto unprotected slopes. Set out recommendations listed below for construction sites and rights-of-way:

- Construction contractors should contain erosion and sediment control requirements and fully application of the law of rural road construction.
- Proper road construction design and as many culverts as possibly construction to
- minimize concentration of runoff by decreasing the drainage area.
- Road contractors must reach the concentrated runoff to the nearby natural water ways.

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