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Socioeconomic Impact Assessment of Highway Drainage Outlet Erosion, Case Study of Mekelle to Adigrat Highway, Tigray, Ethiopia

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Abstract

Roads are backbones for one's country economy and play great role in public's mobility. To make these well function proper drainage systems must have; and these drainages are major causes for land degradation and gully formation. This assessment was conducted in selected road drainage (bridges, culverts and side channels) of Mekelle to Adigrat 113 Km road. The study focuses types, causes, impact of road drainage erosion, and government attentions to protect erosions and possible remedial measures by selecting 60 farmers which are 26.67% of the total population in the study area (225) randomly downstream of the road; 17 DAs selected based on their profession of 4 Woreda experts. Major findings from the socioeconomic assessment using interviewing and field survey are 1) There are three types of erosions (splash and sheet, rill, and gully) but most common is gullying in 87 culverts (44.39%) 2) Major causes of gully from interview of experts are: 38.81% lack of conservation works upstream and downstream of the structure, 14.93% design problem and lack of appropriate energy dissipaters, 20.90% improper land use practices.

Keywords: Bridges and side channel; Culverts; Drainage; Land degradation and gully erosion; Roads; Socioeconomic assessment

Introduction

Background and justification

Currently Ethiopian road network is calculated on the basis of the road sector development program 'eleven years later' performance report; the total length is an addition of 20,429 km federal roads, 23,930 regional roads and 70,038 km community roads. Regional the coverage of asphalt road and gravel road are 1593.78 Km and 1786.37 Km and total of 3380.64 respectively 1357 km rural road; and totally 4737 km road was constructed by the regional government, federal government and other donor organizations. Thus, when we see density network of Tigray regional state in 1000 km^2, it has grown from 53 in 2005 to 62.4 Km per 1000 Km^2 in 2013 and in population number of 1000, the road coverage has increased from 0.41 km which was in 2005 to 0.64 km in 2013. To make the road well function for transport sustainable and suitable drainage system must have; these drainage systems are culverts, bridges, fords and ditches. Highway drainage outlets are main causes for land degradation and gully formations in many areas, the main causes for gulling, after road building, are overland flow concentration by the establishment of artificial drains and increased catchment area [1]. Road construction through steep lands, without adequate provision for drainage systems, is a major cause of gully erosion. Inadequate drainage systems for roads (small number of culverts, insufficient capacity of road ditches, etc.) are a major cause of gulling. If road cuts and fill slopes are not re-vegetated during or immediately following road construction, gullies may form on both sides of the road [2]. 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 [3]. Therefore construction of road and road drainage will increase the concentration of flow of water and lead to soil erosion and land degradation. There are two types of drainage systems, surface and sub-surface, are commonly used to conduct water away from the area surrounding the road and to evacuate extra water from the road structure. The design of road drainage systems varies with factors such as road importance and age, traffic load and rural/urban area. A surface drainage system (ditch) collects and diverts storm water from the road surface and surrounding areas to avoid flooding; prevents damage to sub-surface drains; decreases the possibility of water infiltration into the road and retains the road bearing capability [4,5]. Open ditches are the most common form of drainage ditches in Tigray. Subsurface drainage systems drain water that has infiltrated through the pavement and the inner slope, but also groundwater. Subsurface drainage systems usually comprise culverts and have a direct linkage to surface drainage systems. The usual design is a tube form. According to culverts are road constructions with a theoretical span of ≤ 2.0 m; when exceeding the theoretical span of 2.0 m, the structures are referred to as pipe bridges, and according with span ≤ 4.0 m and when exceeding are referred to bridges. This investigation is to assess highway drainages outlet erosion (bridges, culverts and side channels) of Mekelle to Adigrat 113 Km main road based on socioeconomic assessment, hydrologic and hydraulic analysis; to come up with conditions of erosion, causes and impacts. The main reason for this thesis is the existing of big gullies and land degradations downstream of highway drainages in the study area in many sites. The study area covers from Mekelle; located around 780 kilometers north of the Ethiopian capital Addis Ababa, at a latitude and longitude of 13°29′N 39°28′E Coordinates: 13°29′N 39°28′E, with an elevation of 2084 meters above sea level. to Adigrat; located in the Misraqawi Zone at longitude and latitude 14°16′N 39°27′E Coordinates: 14°16′N 39°27′E with an elevation of 2457 meters above sea level. The main problems of highway drainage structures in the study area are downstream; 1) Soil erosion and land degradation; which have great impact on soil fertility, productivity of the soil, loss of the farming land, formation of gully's, downstream scouring of the structure itself and leads to failure in many cases [6-8]. 2) Economic and social impact on the society whom they live downstream of the road, because of the land degradation degraded their farming land and affect their environment.

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Objectives

The main objective of the study is; to investigate cause of highway drainage outlet erosion and its impact on socioeconomic for Mekelle to Adigrat highway, using socioeconomic assessment.

Specific objectives

1. To assess and investigate the existing conditions of highway drainage outlet of selected highway drainage of Mekelle to Adigrat highway,
2. To assess socioeconomic impacts of highway drainages outlet erosions in study area.

Research Methodology and Data Collection

Investigation and assessment of highway drainage outlet erosion is very complex and multi-disciplinary approach; which relates with Hydraulic and Geotechnical engineering. Research descriptive; means describing the existing condition and explanatory, means exploring the existing cause of failure and suggestion of possible solution was apply in doing this research [9].

Nature and source of data

Both primary and secondary sources of information have been exploited to conduct the study. The major data variables considered include effect of drainage on the farming land, causes of highway outlet erosion, land loss due to highway outlet erosion, government attention after construction, effect on the farmers economy, different between downstream and upstream with comparing after and before the structure constructed [10]. The primary data was collected through interviews to selected farmers living down side of the highway, Woreda experts and DAs and field observations on the degree of erosion and impact on the farming land.

Sample Size of the Study

The study areas have a total of 113 Km length asphalt road; with 22 Bridges and 196 culverts and estimation of around 113 Km long paved and unpaved ditch (field survey). The total cultivable and uncultivable land directly affected by the road drainage structures (culvert, bridge and ditches) is estimated about 450 Ha d/s of drainage structures (from expert's interview). The numbers of households in the study area directly affect by the road drainage flood and erosions are estimated to 225 house holders (field survey) [11,12]. The study area covers four Woreda's of Ganta Afeshum, Saesie Tseada Emba, Wikro Kilte Awillalo and Enderta. The Respondents were selected from Woreda Office of Agricultural Rural Development (WOoARD) and soil conservation experts, Woreda Office of Construction Road and Transport (WOoCRT) road construction expert and Developmental Agents (DAs) of conservation in each Woreda's and Tabia's respectively. And 26.67% of the farmers selected from the study area using randomly sampling technique and Experts were selected based on their profession.

Field work and data collection

A field work was conducted from April to May 2015, and the objective was to collect relevant data, understand the perception of stakeholders in highway drainage effect on land degradation, the hydrologic system of the area, and the hydraulic system of the research area.

Questionnaire

Questioner was prepared and survey was conducted to find out the degree and condition of the drainage out let erosion and impact of the erosion on the farmers and region's economy. Interview and group discussions were carried out with selected individual households, DA's and Woreda experts of WOoARD and WOoCRT of the four Woreda's.

Result and Discussion

The assessment is focusing on physical observation, surveying and interviewing through structured questionnaires to farmers and experts. The questioner's including; general backgrounds of respondents, common causes of erosion, and types and impacts of highway drainage outlet erosion of the drainage structures. From these the common types, causes and impacts of highway drainage outlet (culverts, bridges, and side channels) are summarized in the following sections.

Types of highway drainage erosions on the study area

Erosion is a natural process but is often intensified by human land use practices. From the surveyed drainage structures and experts interview the major types of erosion in the study areas are: splash and sheet erosion, rill erosion and stream and ditch bank /gully/ erosion as summarized in the Table 1.

1. **Splash and sheet:** This occurs mostly over the slope of side channels and it may be unnoticed until the top soil has been lost and rill erosion is formed; around 25 km side channels are affected by splash and sheet erosion, as shown in the Figure 1 of Kihen Wukiro Kilte Awillalo. Vegetation covers is vital to prevent sheet erosion because it protects the soil, impedes water flow and encourages water to infiltrate to the soil.
2. **Rill erosion:** Rills can usually be removed with farm machinery and can be reduced by reducing the volume and speed of surface water with grassed waterways and filter strips, ripped mulch lines, and contour drains. Rill erosion is often described as the intermediate stage between sheet erosion and gully erosion and around 56 culverts and 7 Km side channel are sever by rill erosions as shown in Figure 2.
3. **Gully erosions:** According the field assessment 4 bridges and 31 culverts are severing by big gullies; 35 culverts and 2 km side channel by medium gully; and 21 culverts and 1 km by small gully. As shown in Figure 3 and in most areas the three types of erosion have high risk. Most of the culverts and bridges in the study area have this problem of different sized gully formations based on gully size and area Based on.

Investigation the causes of highway drainage outlet erosion

Downstream soil erosion and land degradation of highway drainage are imitates due to different factors. Identifying the cause of highway

Structure	Total number of structures	Splash/sheet erosion	Rill erosion	Stream bank or Gully erosion		
				Small	Medium	Big
Bridges	22	-	-	-	-	4
Culverts	196	-	56	21	35	31
Side channels/Km	113	25	7	1	2	-

Table 1: Types of erosions in the study area. NB: The results are estimation from the observation and interview.

Figure 1: Sheet erosion in side channel; Kehen Wukiro kilte awillao, April, 2015.

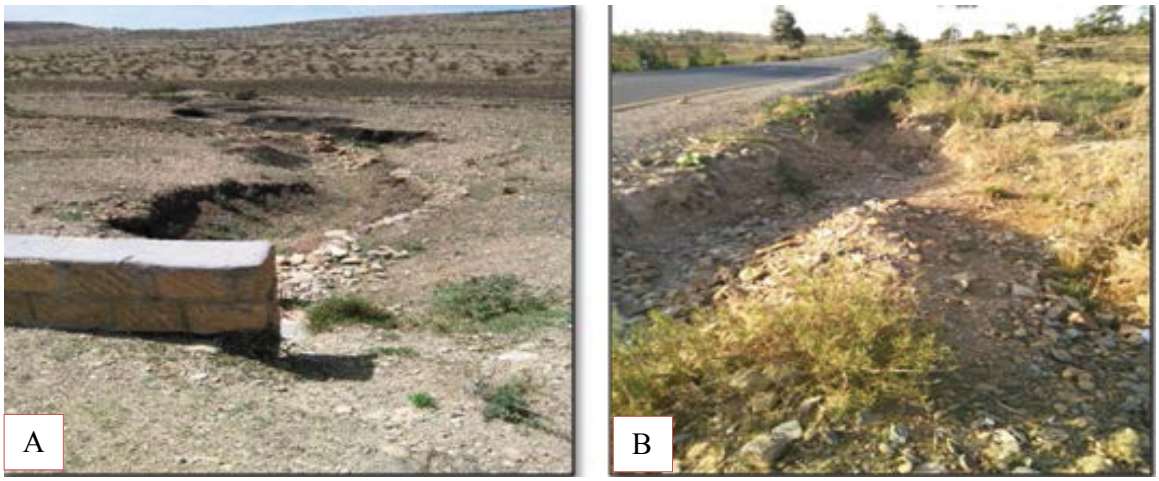

Figure 2: Beginning of rill erosion in culvert of: A) Kehen Wukiro kilte awillao; B) Adiabagie Negeash, April, 2015.

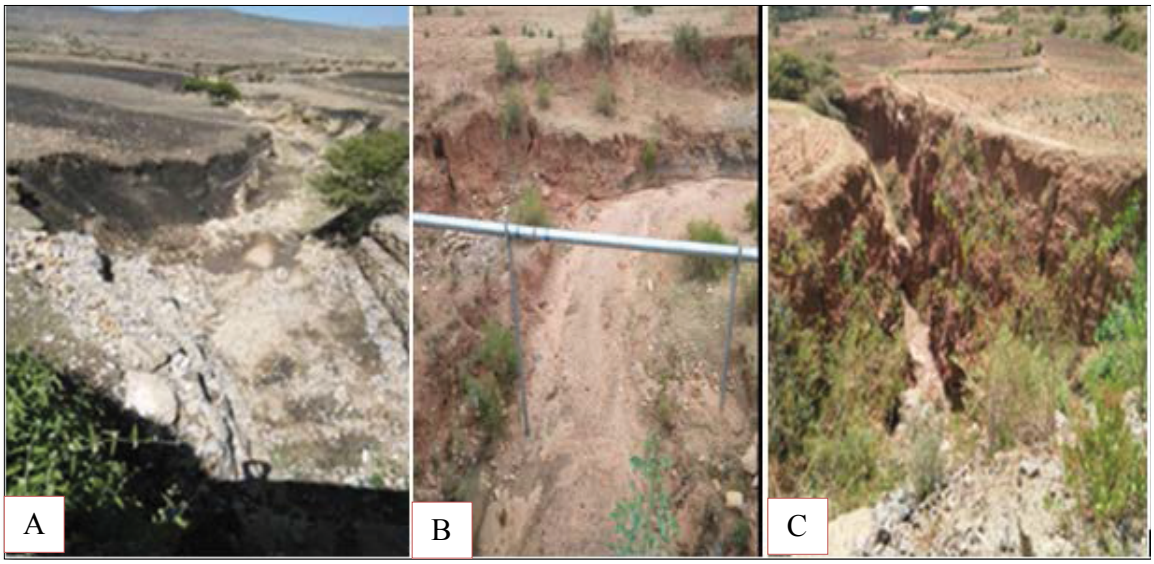

Figure 3: Stream/gully erosion in culverts of: A) Kihen, Wukiro kilte awillao; B) Tahtay Adikasend, Wukiro kilte awillao; C) Betehaweriat, GantaAfeshum, April, 2015.

drainage outlet gully erosion is needed to identify appropriate erosion control techniques. The cause of highway drainage out let erosion are many types, based on the questionnaires' survey and physical observation of the study area the major cause of highway drainage outlet erosion are 40% and 24% due to lack of conservation works upstream and downstream of the road and type of soil and lack of vegetation in side channels or ditches respectively, 48.39% and 19.35% due to lack of conservation works upstream and downstream of the culvert and improper land use practice respectively and 45.45% and 18.18% design and maintenance problem and improper land use practice of bridge as Shown in the Figure 4. Where; 1) lack of conservation downstream and upstream of the structure; 2) rainfall pattern change; 3) improper land use practice; 4) topography; 5) design and maintenance problem; and 6) soil type and vegetation cover.

Impact of highway outlet erosion

The main effects of highway drainage on the farming land and types of erosion are stated in section above, these leads to losing of fertile and productive farming land, land degradation and formation of gully, loss of natural resources, and restrict animal and human movement. According [13] Gullies formed and developed along the selected road segment have on-site and off-site effects. Specifically on-site effects include; a reduction in the area of arable and other agricultural land which divides the land into smaller parcels and leads to increase farming costs, restricts human and animal movement, reduces access to properties, and increases rates of erosion where more subsoil material is exposed. The major impacts of highway drainage outlet in the study area are, land and soil degradation that cause to loss the fertility of the land and direct impact on productivity, flooding and loss of the most fertile top soil, sedimentation and loss of crops. According the interview carried out for 60 farmers in the study area 75% of the respondents agree with; there is land degradation and cultivable land loss due to road drainage structures, 38.33% of the farmers said there exist non cultivable land loss, 15% of the respondents said there have lost of crops due to flooding; and 18.33% of the respondents said there is sedimentation problem the full result is as shown in Table 2. After construction of the road project and drainage structure of Agulae river bridge almost one hectare of farming land is lost since 1996 due to erosion in the downstream of the bridge as shown in the Figure 5.

Land and soil lost due to gully erosion

size of gully's and area of land lost were surveyed in 7 culverts of Wukiro/Kehen, 3 culverts in Edagahamus, 4 culverts in Gantafeshum/Betehaweriat and 2 culverts in Laelay Wukiro; 3 bridges and 1 Km side channel the detail survey data is in Appendix A. The average width, average depth and total length up to the tail of gully was measured using plastic tape and GPS; and take average to estimate the area of farming land and volume of soil lost. Using the total farming land lost from the 16 culverts is estimated 33,669.52 m^2 or 3.39 Hectare and 196,509.99 M^3 soil was lost. From 3 surveyed bridges 23,320 m^2 or 2.33 hectare land and 98244 m^3 soil was lost. In 1 km long side channel surveyed in Laelay Wukiro 2128. 76 m^2 or 0.21 hectare land and 6075.59 m^3 soil were lost (estimated using lower, intermediate, and upper depths of the gully computing with area).

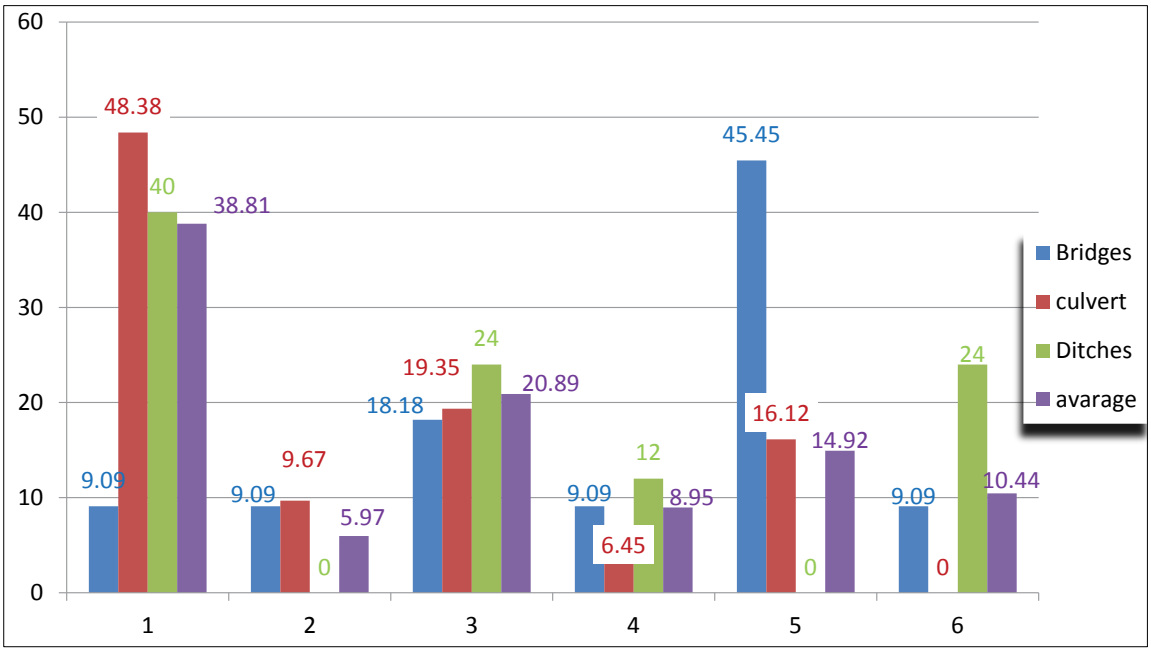

Figure 4: Response analysis of causes of highway outlet erosion in% (from experts interview and observation).

Causes	Respondents	Yes %	No %	No answer	Amount of land Lost/ha
Cultivable land loss	60	75	15	10	12[A]
Non cultivable land loss	60	38.33	48.33	13.33	14[B]
Loss of crops	60	15	61.67	23.33	-
Sedimentation	60	18.33	38.33	43.33	-

Table 2: Impact of highway drainage on the cultivable and non-cultivable land; response of farmers;. [A] estimation from the interview farmers; [B] estimation of loss of uncaltivable land from farmers interview.

$$V = D^{*}A \quad (1)$$

Where: V = volume of soil lost, M^3

D = average depth of gully in m

A = area of gully lost in m^2

Due to the major crops grown in the study area are Tef, maize, wheat and barley (interview); and current the average production per hectare of Tef -25 Quintal, maize-45 quintal, wheat-35 quintal and barely -35 quintal (from WoARD, 2014 report). So from 5.91 ha of eroded farming land we have lost around 147.8 qtl Tef, 266 qtl Maize, 206.91 qtl wheat and barley yearly from measured gullies only, And 300, 540, and 420 qtls respectively yearly are lost due to gully's (from the interview) Table 3.

Government attention after construction

Among the total interviewed and assessed road drainage structures the government has rehabilitates 3 Bridges, 10 culverts, and 30 Km length of paved side channels or ditches. Using gabion check dam for bridges, maintain their downstream and conservation works on their upstream drainage and some naturally vegetated channels. But when we take the whole study area the government intention in protecting and re-habitation of highway out let erosion is very low. Governments rehabilitate; Culvert downstream and upstream protection/elephant grass in Betehaweriat area; and side channel protection using Scour Checks ("Raised") Kehen.

Remedial measures

From the assessment possible remedial measures have been assessed for the gully formations and erosions due to highway drainage outlets; from 21 respondents (experts and DAs) the summarized possible controlling mechanisms are as shown in Table 4. Of the described controlling mechanisms are grassing, scour check and stone lining are best for side channels; vegetation cover, check dams, water harvest and design for culverts, and vegetation cover, check dams and design for bridges

Conclusion and Recommendation

Conclusion

The following conclusions were drawn from the results of the investigation:

1. Splash and sheet, rill and gulley erosions are common in the study area but most of the erosions are gully erosion and cause for loss of cultivable and non-cultivable land;
2. Road drainage outlet erosions are high in culverts, from the total culverts 44.39% are affected by gully erosion.
3. Erosions and land degradations due to highway drainages have great impact on the farmers' economy, total of 5.91 ha farming land lost after construction.

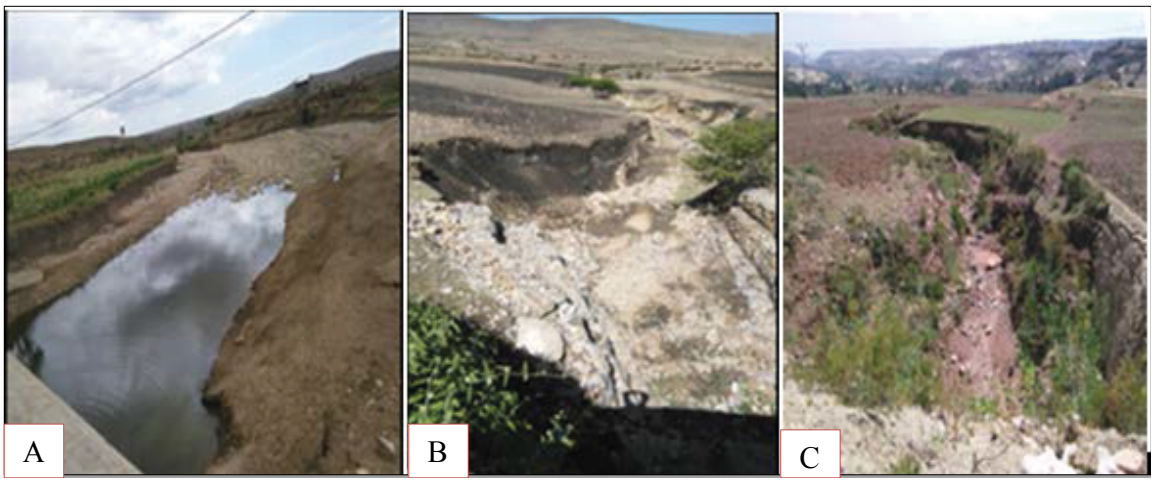

Figure 5: Example of impact of road drainage on farming land in A) Agulae, B) Kehen and C) Betehaweriat; April, 2015.

	No structure	No of eroded structures	no of surveyed structures	Area(m^2) gully	Volume(m^3)[C] of soil lost due to gulley
Culvert	196	87[A]	16	33,669.52	196,509.99
Bridge	22	4	3	23,320	98,244.53
Ditch in Km	116[B]	3Km	1km	2128. 76	6705.59
Total				59118.28	300830.12

Table 3: Land lost due to road drainage erosion and gully formation. Where, [A]87 culverts are sever by gully erosion; [B] estimated ditch or side channel length of the study area; [C] volume of gully computed from Lower, Intermediate and top gully depth measuring and multiplying by Area.

Drainage structure	Grassing	Stone lining	Scour check	Vegetation cover	Diversion ditch	Check dams	Water harvest	Design properly[1]
Ditches	13	9	8	nn	nn	nn	14	nn
Culverts	nn	nn	nn	16	7	10	15	11
Bridges	nn	nn	nn	16	nn	15	nn	10

Table 4: Possible controlling mechanisms for erosion due to highway drainage outlet. Where: nn- not necessary; and design properly: for culverts side walls, wing wall and aprons, and for bridges ripraps and side walls.

4. The major cause of highway drainage outlet erosion which analyzed from experts interview indicates; 38.81% lack of conservation works upstream and downstream of the road; 20.90% improper land use practice 14.92% design and maintenance problem;

Recommendation

The following recommendations were drawn from this study

1. The mathematical modeling of soil erosion and sediment yield processes sedimentation problems in many areas due to road drainage structures does not look flow data collection is also required to estimate the exact amount of sediment deposition around the structures;
2. There are forming a lot of gully's due to road crossing and side channel construction in many places; so researchers have to do a lot of works in this topic;
3. There should be detail study on favorable conservation works for the study area based on its land use characteristics type of soil with the help of soil chemistry. Detail study should be carried out including gully head characteristics, land use and cover as well as impact of slope on the erosion;

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