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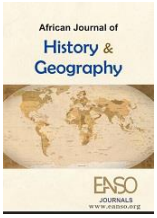

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Original Article

Effects of Land Use Land Cover Change on Gully Development in Lugari Sub Catchment, Kakamega County in Kenya

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ABSTRACT

Worldwide Gully erosion has been considered a severe agricultural and environmental problem. In Kenya, gully erosion is treated as a serious and common socio-economic and environmental problem of different catchments. Thus, the objective of this research was to assess the diversity and effect of gully erosion in Lugari sub-catchments in Kakamega County, Kenya. The objective of the study was achieved by analysis of the data from the images and data obtained from the field observation, field measurement, GPS, interviews and household survey. The result of the study indicates that gully erosion was initiated in the mountainous area following the 1990s and 2000s land cover changes and human cause factors. In addition, the steepness of the slopes and the soil characteristics have triggered gully erosion in the study area. Gully erosion affects the physical, economic and social effects on an area. According to the group discussion and interview, the social-economic impacts of the gully were the loss of life of a 65-year-old man death and injuries to livestock and reduced yield. The result from field measurements and field observation indicated that loss of soil (1,519,487) and loss of vegetation are the major physical impacts of gully erosion. In Lugari sub-catchments there are promising rehabilitation conditions and their conditions are, availabilities for the labour force, transport serves presence of civic societies, NEMA and the green economy policy of the county. Thus, the county and National government and local communities need to set, a work plan and use the existing opportunities.

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INTRODUCTION

soil erosion is one of the natural processes which have lasted since the agrarian revolution, natural soil erosion can take place without notice until the equilibrium changes due to the effect of human beings such as deforestation and land use land cover changes. Soil erosion is both sensitive to both human and natural factors and loss of soil is the most challenging worldwide environmental problem. Soil degradation via water accounts for up to two billion ha in the world. Among different forms of soil erosion gully erosion is an environmental threat. Gully erosion causes extensive social economic and environmental impact. Gully erosion reduces farmland, farm productivity and grazing land also the gully is a source of sediments (Poesen et al., 2003). The major causes of gully erosion are higher population growth, lack of vegetation cover in the area, overgrazing, inadequate rainfall and cultivation on steep slopes.

In Kenya, gully erosion is part of the landscape in semi-arid and arid areas. The estimated average soil loss rate in infertile cropland is 70 tons /ha/year and it can be greater than 300 tons/ha/year on steep slopes where vegetation is inadequate (Hurni, 1988). Kenya being agricultural-based economy and soil erosion problems have made water and soil erosion management an area of interest. Though water conservation and re-afforestation programmes and soil control were initiated long ago, the impact was far below expectation and land degradation is still a problem.

There are reasons why conservation has not succeeded in Kenya despite conservation efforts, such as the failure to balance land management intervention with dynamics of site-level gully erosion based on scientific and systematic ways before taking treatment measures. Because it gives a chance to design suitable and effective gully-controlling activities. Therefore the objective of this research was to assess the cause and effect of gully erosion in the Lugari sub-catchment in Kakamega County, Kenya.

Statement of the Research Problem

Lugari sub-catchment was covered with dense forest in the 1970s' this forested area was then deforested in 1990 as the population surged. The drought of 1984 led to stress and shock as the people lost their livelihoods such as animals and crops to deal with the impact of the drought they revised alternate ways of living including charcoal burning, maize growing and illegal logging which led to land subdivision due to increase of the population. The contour method of farming was dropped which led to increased soil susceptibility. The gullies in the catchment have caused injuries and death for both animal and human beings from falling into the gullies, the families have been separated and the agricultural land robbed by the gullies.

Justification for the Study

Many Sub-Sahara Africans depend on agriculture, and Kenya being a third-world country is not exceptional. Food security is threatened by land use and gully development in food production areas. According to the population (Censer Report, 2019) the population in the Lugari sub-catchments is growing at an alarming rate and this has led to the development of infrastructure such as road and social amenities, encroachment to fragile areas, brick marking, quarrying, deforestation among many other anthropogenic activities, these anthropogenic activities have resulted to change in the use of land and the cover. 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

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10% of the land degradation research. This is therefore call for more research on gully erosion. The extent and severity of gully erosion can vary significantly over time and space. Thus conducting a site-specific study on the development of gully erosion plays a vital role in finding specific site solutions.

The Objective of the Study

The objective of the study is to establish the effect and cause of gully erosion in the humid area of the Lugari sub-catchment in Kakamega County, Kenya.

Specific Objective

This study aims to achieve the listed specific objectives.

- To determine the effect of land use land cover change on gully erosion in Lugari sub-catchments between 1990 - 2024
- To find out the trend and Pattern of gully erosion in the Lugari sub-catchment between 1990 -2024
- To assess the relationship between high human population pressure and activities on land use, land cover change and land degradation in Lugari district.
- To propose appropriate strategies that can be deployed to control gully erosion.

Research questions

To achieve the above objective, the listed research questions are formulated:

- What are the effects of land use land cover change on gully erosion in the Lugari sub-catchment between 1990 to 2024?
- What are the trends and patterns of the gullies in the catchment between 1990-2024?
- Is there any relationship between land use change, rapid population and gully development?
- What is the appropriate strategy for gully erosion control?

LITERATURE REVIEW

Gully Development and Formation

Water erosion consists of gully, splash and rill erosion. Sheet erosion occurs when the runoff speed is about 0.3-0.6 meters per second. Rill erosion takes place when soil is removed from shallow channels. When the depth of the rill channel increases in depth more than 30 cm is referred to as the gully. Gully erosion is a severe land degradation and an important topic in research work. Gully development is rapid during the early stage and the head of the gully can be between $1.25\times10{-}4$ - 6 m yr-1. Gully development depends on various factors including land use, rainfall threshold anthropogenic factors and topography. Land use change that increases the amount of rainfall and accelerates the storm runoff is therefore of concern. When the runoff is more than the infiltration rate, gully development occurs. The national mitigation measure should be looking at the use of land and the seasonal and annual rainfall variability. Gully erosion and development occur when the head retreats, it dissects the farmland. Gullies are the source of sediments in the rivers and open water bodies. Therefore, protecting the surrounding land is important.

Gullies Classification Based on Shape

Different types of gullies can be seen in different climatic conditions. In agriculture gullies that cannot be tilled by the agricultural implement are referred to as permeant gullies and they can range from 0.5-30cm deep (Poesen et al., 2003). Gullies that can be easily rehabilitated by agricultural implements and are small are referred to as Ephemeral gullies. When the top soil is more resistant than the bottom soil V (youth)-shaped gullies develop. The gullies that are still deepening and have its wall is steep is referred to as V-shaped gullies. When the bottom of the valley is made up of more resistant materials then it is called Trapezoidal gullies.

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A U-shaped gully has more sand content than silt and clay. Sand is about (over 50%), which promotes soil erodibility. A U-shaped gully is formed when the resistance of both subsoil and topsoil is the same. U shape is assigned to stable gullies. The bottom of the U-shaped gullies has a smaller content of clay soil compared to the V-shaped gullies. Gullies can be controlled by the use of vegetation and structure.

Factors Affecting Gully Development and Formation

Land Cover Change and Land Use

According to NEMA (2011), in Kenya, 80% of the land is semi-arid or arid (ASALs) 80-90% of the wildlife and livestock graze here. 20% of the remaining land is arable land and over 80%of people settle here. The area covered by the forest was 20% and it has been reduced to 1.7 % of its original area due to anthropogenic activities such as wood for building homes, settlements, farmlands, charcoal burning and infrastructure building. Forest cover in the Lugari sub-catchment is therefore lower than the 10% recommended threshold. These are an indicator of population pressure in Kenya.

Effect of Hill Slope Cultivation on Gully Erosion

Cultivation on slopes that are 10-30% steep is prone to soil erosion. Steep slope cultivation is widely practised in Kenya and these practices encourage soil erosion. A study conducted in the Sasumua catchment showed that farming on steep slope areas contributes to soil loss. On River Nyando observed the growing of new cash crops such as tea on the steep slope of the forested area, settlements into the forest reserve. Overstocking in the lowland areas leads to gully development. Waswa et al. (2000) in Taita Taveta, observed heavy rains, deforestation and inappropriate tillage practices.

Effect of Livestock Grazing on Gully Erosion

Keeping many animals on smaller pieces of land leads to depletion of the grass and shrubs and overgrazing affects rangeland health. Keeping animals in rangeland must be managed properly to maintain the cover at 60% or higher. 60% drop in cover has consequences such as a reduction of grass cover. A decrease in the cover facilitates surface runoff and reduces the infiltration in bare soils. Sheep keeping in Chile showed that they caused erosion that exceeded 190t/ ha/year which contributed to gully erosion (Valentin et al., 2005). Overstocking of animals reduces shrub and pasture and is therefore of concern among the Borana, Gabra, Buruji and Samburu communities in Northern Kenya.

Effect of Deforestation on Gully Erosion

Deforestation is a global menace, so they are in Lugari sub-catchments. The forest is linked to population growth. An increase in population leads to a demand for more land for cultivation. Higher demand for fuel wood, charcoal construction timbers and uncontrolled illegal logging. It is hard for the forest to regenerate because of browsing livestock and grazing within the forest.

In the Chinese loess plateau, the cultivated area was reduced by 46% and the area under forested and grassland increased by 42% resulting in a reduction in sedimentation by 31%. The sediment was also reduced by 80% on vegetated hill slopes and 49% on terraced hill slopes, these demonstrate that vegetation and terracing are effective in controlling erosion and its applicable in land use planning. In area around Lake Baringo showed runoff and water runoff has increased due the deforestation, Johansson et al. (2002) In Zambia, Luangwa Valley The rate of erosion is around 5 t/ha/yr in areas with plenty of grass and trees while areas with scanty vegetation and trees had an erosion rate of 100 t/ha/yr. The area under wooded and grassland change to area under cashew, orchards. The change in land use led to a reduction of natural vegetation in Southeast Tanzania (Kabanza et al., 2013).

Effect of Climate Variability and Climate Change on Gully Erosion

During drought, the land is left bare with no vegetation covering the areas. The soil is

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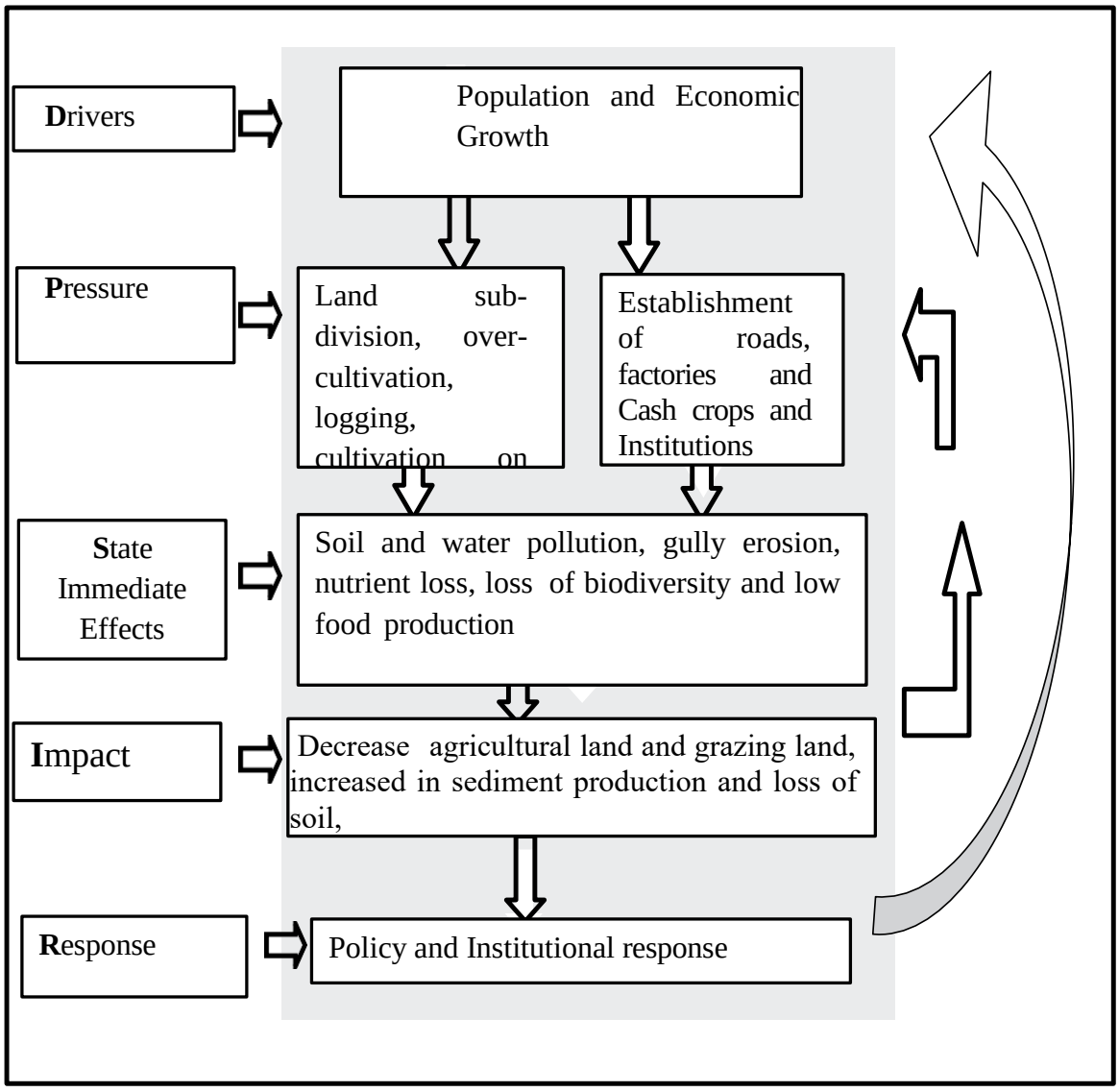
unprotected from the impact of rain and the speed of surface runoff can lead to gully development at drainage release sites on the roads and steep slopes. In a study on river Gucha, it is observed that when agricultural and residential lands expand and the forest reduced water in the rivers increases. So, there is a relationship between climate change and land use. **Frankl A. (2012)**

Conceptual Framework

DPSIR Framework is a framework used to describe the relationship between the environment and the society. DPSIR framework assesses and analyses environmental issues by bringing together political classes, stakeholders and environmental managers to solve the environmental problems. Indicators here are classified into the drives, pressure, state and impact that lead to various responses that can maintain or recover the system from the impact.

Figure 1: Conceptual Framework



METHODOLOGY

Area of Study

The study will be conducted in Kakamega County in Kenya. The study area is located between longitudes 34º 28' and between 0º 25' and 1º north of the equator and the total area is about 10km2. The area is undulating dynamic and fragile with several hills which make it susceptible to erosion.

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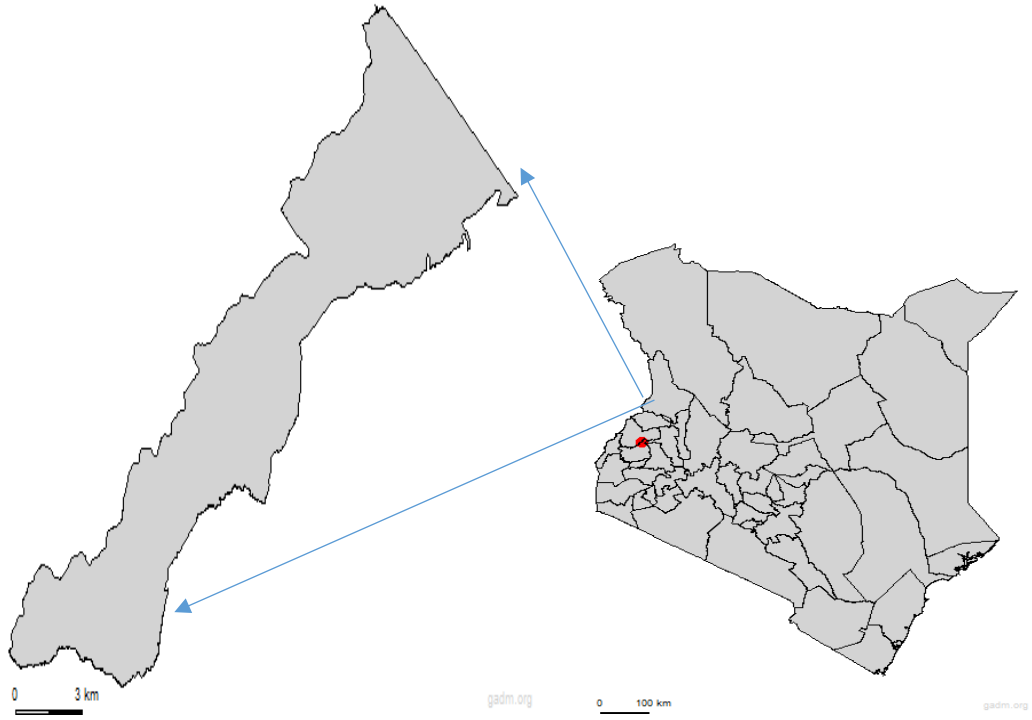
Figure 2: Map of Lugari District Showing the Original Administrative Division Boundaries



(Source: Central Bureau of Statistics, 2002)

The objective formulated was addressed with primary sources such as household surveys, interview aerial photos filed measurement, filed observation and satellite image analysis. Also, the unpublished documents and statistical abstracts were used as secondary sources of data. In this research, a mixed approach was deployed to collect the data (quantitative and qualitative) and a simple sampling technique. Data for gully initiation, incision period and volume loss were obtained from analysis of the satellite images, group discussion aerial photos and interviews. Whereas, data on the impact of the gully and drivers of the gully opportunity for rehabilitation was obtained from household surveys, field observation and interviews. Identification of the gully age was obtained from monitoring the event calendar and time approach, in this regard the chief, elders and leaders were selected to give the major event which served to guess the age of the gully and were purposefully identified and interviewed on the gully dynamics and trend and impact. The aim of the key informant interview is to document historical events such as El Nino, deforestation and drought**.**

Sample size was determined by using Cochran's (1977) procedure and random sampling was used to identify households.

$$n_0 = \frac{PQZ^2}{d^2} = \frac{0.5x0.5x1.96^2}{0.05^2} = 384$$

Eq.1

n_0 = target sample size at 95% confidence level

Q = The proportion estimate of the attribute available in the population, in this case, 0.5 will be used

Z = is the stardard normal deviance of 1.96

d= level of precision, 0.05 will be adopted

Lugari sub-catchment has a total of 3636 households, Census Report (2019). If the required sample exceeds 5 % of the total population, then an adjustment is needed using the formula in Eq.2

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$n = \frac{n_0}{1+n_0/population}$ $= \frac{384}{1+384/3636}$ x110 =382 Eq.2

The volume of soil loss in the study area was estimated by use of equation number 3 and 4.

V = $Lx\frac{(w_t+w_h)}{2}x$Df Eq.3

V =the displaced volume of soil in m^2

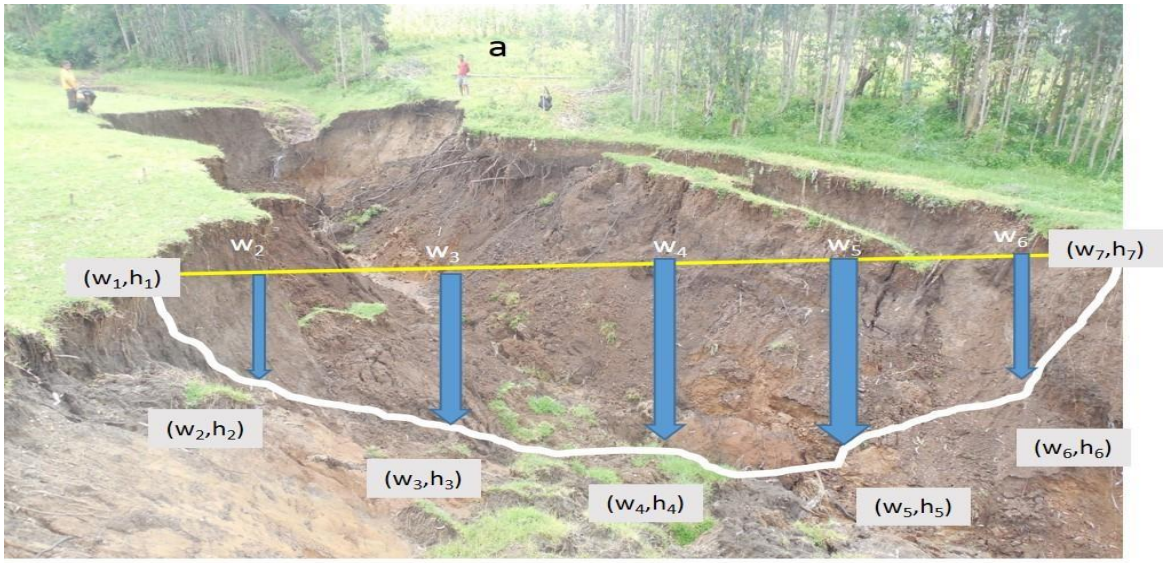
~Length of gully in meters

w_t=top width of the gully in meters

$w_{h=}$ Bottom width of the gully in meters

Df =the average depth measured in meters

Plate 1: **Gully Erosion Cross-Section in Turbo Forest**



To covert the volume of soil loss to the weight of soil loss over time (tonne per year) equation 4 was used

E= [(VxW/1000)/Y] x N eq 4

Where E =the soil loss in tonnes per year

V= the volume of soil calculated in equation 3

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

1000= the weight in kilogram per tone

Y =the number of years the gully has been active

N= the number of similar classic gullies.

According to Abdurrahman (2012), the average soil density of the watershed is 0.97g/cm3.and it ranges from 0.90 to 1.06g/cm3.

Data Analysis and Interpretation

Data collection and analysis was done with different methods. GIS was used to analyse the cause and effect of gully erosion. Data analysis was done and analysed with different methods. GIS was used to analyse the data for drivers and the impact of gully erosion, topographical maps for 1990 aerial for 2000 and spot images for 2023 were used. A topographical map of a scale of 1:50,000 was used as a base for georeferenced satellite images and aerial photos.

To perform analysis of the distribution and pattern of the gully Topographical and aerial photos were bought from surveyors of Kenya scanned and then converted from analogue to digital format this map was geo-referenced into two types of images, to map registration by inserting the coordinates manually for the topographical maps. The second registration was applied to the satellite image by using the map as the reference. This method was also applied to aerial photos and satellite image was used as the base. Both image registrations were done using ENVI 4.3.

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Then digitization was done in ARC GIS 9 and Arc Map version 9.3. This step is important to map gullies from satellite images and scanned aerial maps, finally, the digitized gullies were exported as graphics so as to be included in results and discussions.

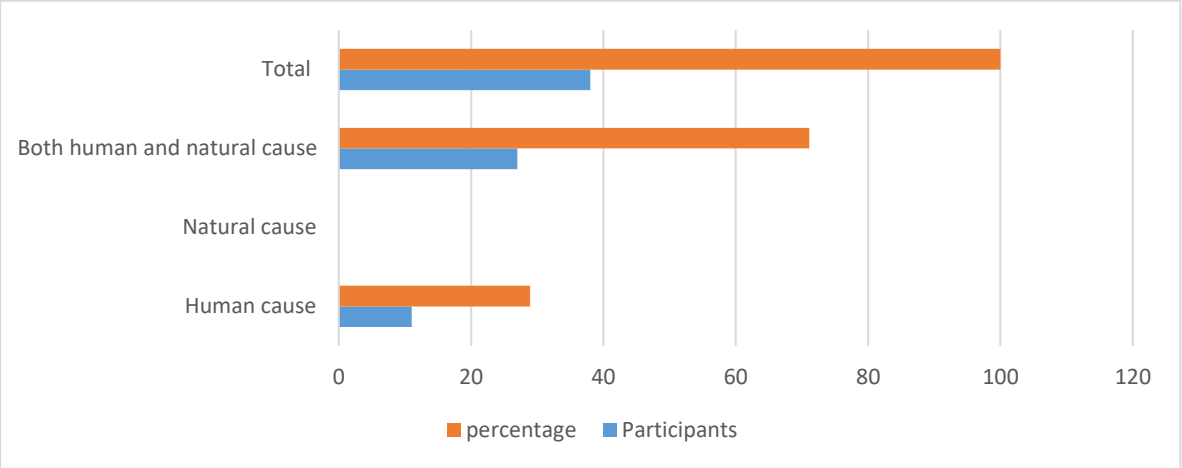
Content analysis was done on the data obtained from group discussion, field observation and secondary sources. Data obtained from the quantitative technique was analysed through descriptive statistics using Statistical Package for Social Science (SPSS) version 20.

RESULT AND DISCUSSION

Drivers of Gully Erosion

The data on the cause of the gully was obtained from field observation and household survey (see Figure 3)

Figure 3: Household Respondent Opinion on the Cause of Gully Erosion



Source: Household Respondent

According to Figure 3 from a household survey about 28.9% responded that the human factor is the cause of gully erosion in their farms (71.1 %) of the participants responded that the cause of the gully erosion is a result of both human and natural causes. This finding is in line with (Konana et al., 2017).

Plate 2: Sand Harvesting on the Floor of the Gully

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Plate 3: Brick Layering in the Catchment

Human Cause of Gully Erosion

The cause of the gully erosion in the Lugari catchment was us result of high population, social-political factors and human activities. Some of the activities include deforestation, expansion of farmland, overgrazing and cultivation on steep slopes. See plates 3 and 4.

Plate 3: The Forest Land has changed from Forest to Shrubs

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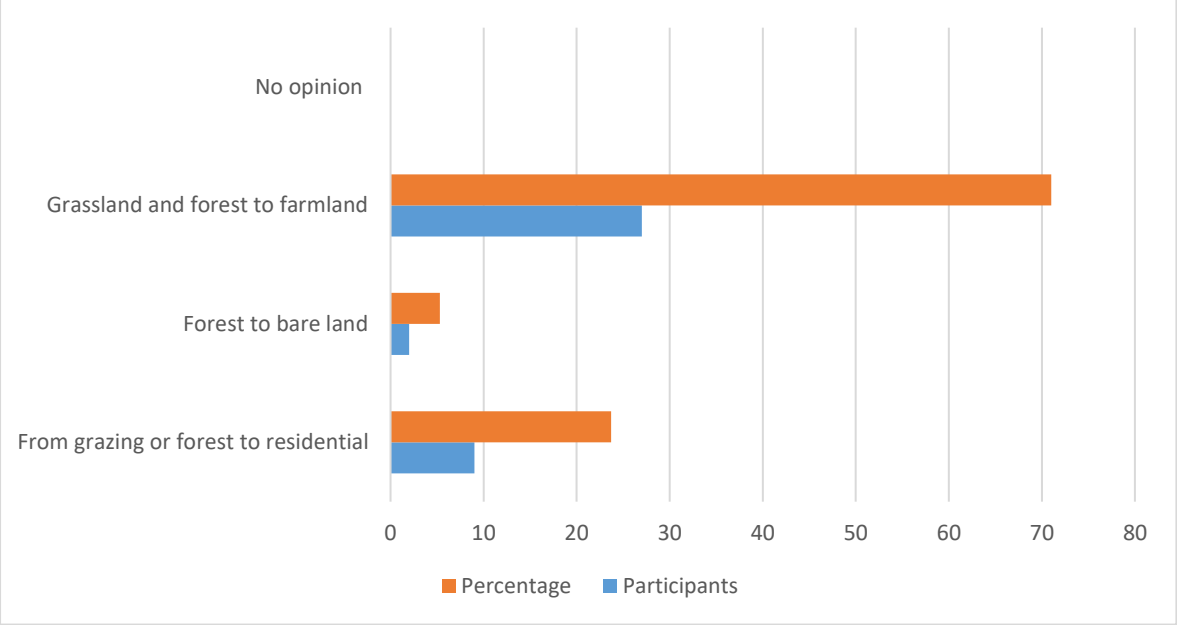
Plate 4 Overgrazing

In Figure 3, the total respondents 71% indicate that the land cover has changed from forest and grass to farmland since the 1990s. In the watershed mixed farming accounts for about 86% of the economic activities. Therefore, these economic activities combined with agricultural activities initiate gully erosion.

Figure 4: Land Use Change Awareness by the Participants



(**Source:** Household Survey)

During the field observation the researcher observed the animals grazing on the gully floor, these activities reduce the possibility of natural rehabilitation and sudden collapse of the gully banks that may cause injuries to animals and human life. Which is in agreement with (Waswa et al., 2002; Valentin et al., 2005).

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Plate 5:G1, Sudden Gully Wall Collapse

Natural Cause of Gully Erosion

The natural cause of gully is mainly rain, higher temperatures and steep slopes. Mohamed MA, et al,(2020) the data from the field survey, field observation and interview confirmed this. According to the participants, the cause of the gully erosion in the study area is a steep slope, loss of vegetation cover, rainfall, and droughts. This agrees with (Waswa et al., 2002).

Origin, Pattern, and Period of Gully Erosion

Based on the satellite image and aerial photos of 2024, twelve gullies were identified and assigned G1, G2, G3, G4, G5 up to G12 (gully 12). In 1990 and 2000 aerial photos and satellite images of only (7) gullies were identified, which are G2, G3, G4, G8, G9, G10 and G11 image analysis of Table 4 depicts a similar pattern of gully pattern.

Plate 6: Gully 2

Plate 6: Gully 3

Plate 6: Gully 4

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Plate 6: Gully 5

Plate 8: Gully 7

Plate 7: Gully 6

Table 1: **Gully Length, and Width from 1990-2024**

YEARs	1990		2000		2024		Field measurement		
Gully id	Length (m)	Width (m)	Length (m)	Width (m)	Length (m)	Width (m)	Length (m)	Width (m)	Depth (m)
G1	NG	NG	NG	11	235	10	240	253	12	9
G2	291	8	300	10	1502	23	1495	1500	25	14
G3	225	5	225	6.5	300	11	319	340	10	11
G4	334	6	380	6	432	16	401	420	17	8
G5	NG	NG	NG	12	1402	12	1489	1501	13	11
G6	NG	NG	NG	8	372	12	496	530	10	7
G7	NG	NG	NG	13	702	14	695	700	15	12
G8	280	6	300	9	560	19	573	600	18	8
G9	289	9	330	10.5	860	21	876	1040	22	9
G10	402	9	470	9	960	10	980	1020	11	11
G11	241	6	300	7.5	800	9	848	850	11	8
G12	NG	NG	NG	9	466	11	480	500	10	6

Source: Aerial Photos, Satellite Image and Field Measurements

NG means no Gully was formed.

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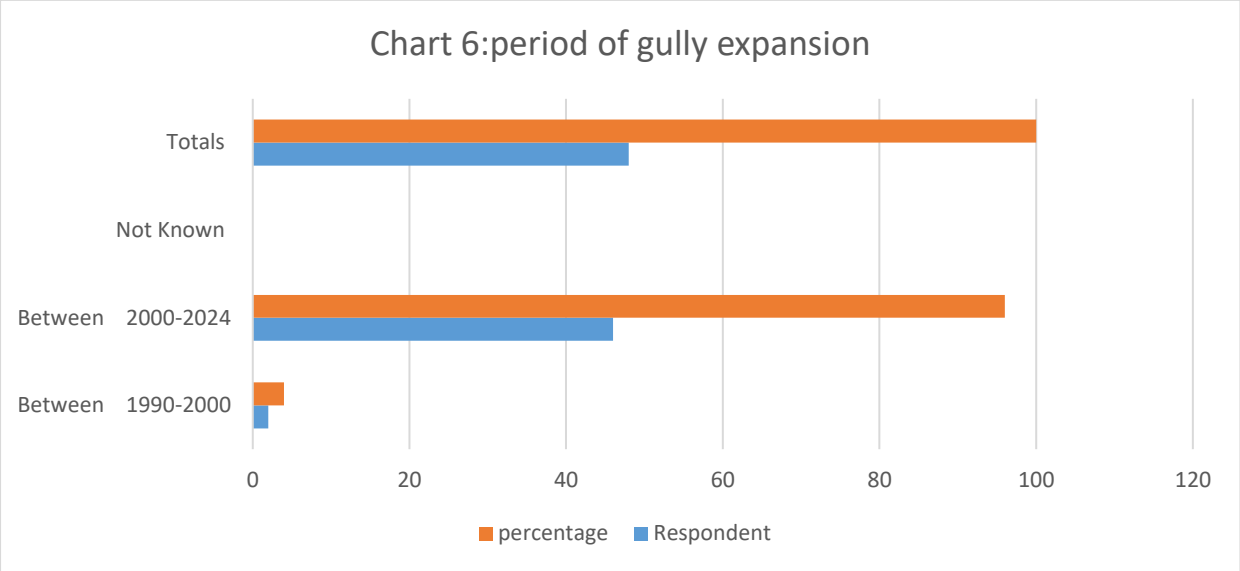
Figure 5: Period of Gully Expansion



Source: Household Respondents

Figure 5 shows the increment in gully size between 2000 and 2024, and to check the cause of the increments in the gully size data was collected from chief and village elders and household surveys. In Figure 3, 96% % of total respondents believed that the year 2000's to 2024's was a critical gully development period. This period was considered as a year of serious land cover change characterized by deforestation (see plate 8).

Plate 8: Animal Grazing in Government Gazetted Forest Turbo

Plate 9: Deforested Part of the Forest

Gully morphology knowledge is important to carry out effective stabilization of gullies and to explain the reason for current erosion (Pathak et al., 2005). The gully morphology such as the size, volume of soil loss and width were presented in Table 2.

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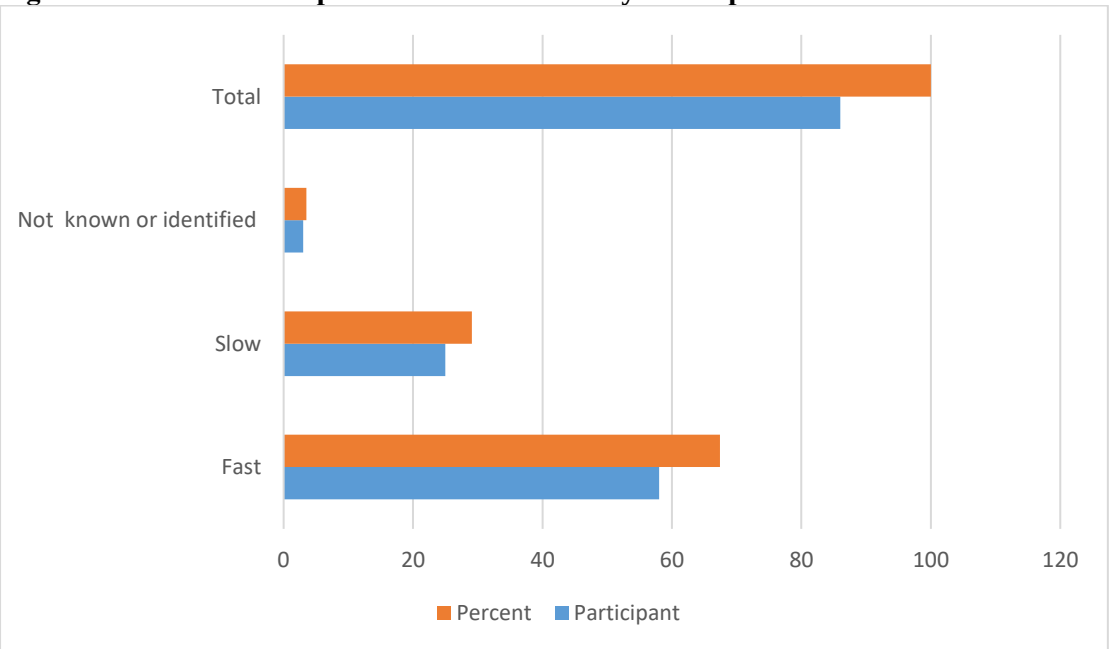
Table 2: Field Measurement Result on Gully Erosion

Name of watersheds	Gully id	Length (m)	Width (m)	Depth (m)	W/D ratio	Volume of soil lost (m3)	Age of the gulley
Lugari sub-	G1	253	12	9	1.3	27,324	17
	G2	1500	25	14	1.8	525,000	50
	G3	340	10	11	0.9	37,400	48
	G4	420	17	8	2.1	57,120	48
	G5	1501	13	11	1.2	214,643	35
	G6	530	10	7	1.4	22,260	20
	G7	700	15	12	1.3	126,000	24
	G8	600	18	8	2.0	76,800	49
	G9	1040	22	9	2.3	205,920	50
	G10	1020	11	11	1.0	123,420	49
	G11	850	11	8	1.4	74,800	48
	G12	500	10	6	1.7	28,800	18
Total soil loss						**1,519,487**	

Source: Field measurement

To obtain data on gully length and width field measurement was done in all 12 gullies. According to Table 7, the length of gullies is 9234m. Therefore the annual average growth rate of the gully width, length and height are 21m/yr, 0.28m/yr and 0.275m/yr respectively. A Gully that has a growth rate of greater than 10m/yr is referred to as a catastrophic gully. Data was collected from household surveys to cross-check the people's perception of morphology and gully development rate.

Figure 6: Farmer's Perception of the Rate of Gully Development



(**Source:** Household Respondent)

According to Figure 6, 67.4% believed that gully development in the area is fast, the result from the housed hold on gully development is in agreement with the data obtained from field measurement. In this study, the amount of soil loss is estimated by $V = L\,x\,\frac{(w_t+w_h)}{2}\,x\mathrm{Df}$, the total volume of soil

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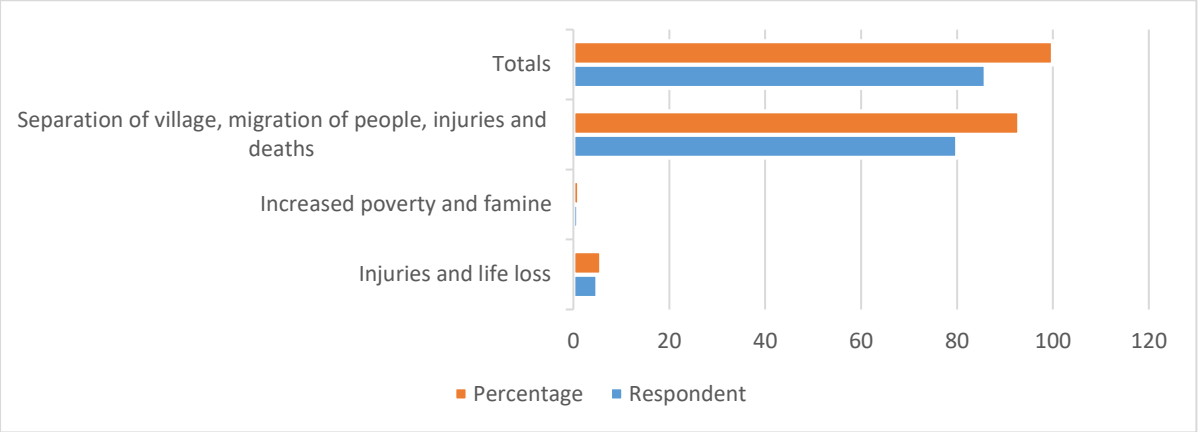
loss in Lugari Sub catchments is **1,519,487** and the average soil loss is 6 **tons/ha/year**.

Effect of Gully Erosion

Gully erosion has several effects on the social-economic and physical environment. The results from the household, field observation and field measurement show that the major impact of gully erosion is listed in Figure 7.

Figure 7: Social Effect of Gully Erosion



(**Source:** Household Survey)

Social Impact of Gully Erosion

Gully erosion has negative impacts such as displacement of people, reduced farmland, causing death of animals and human beings, injuries and risk of flooding. Data were collected from household surveys to assess the impact of gullies. (See Figure 7). According to Figure 7, 80% of the participants argue that the social effects of the gullies in the watershed are increased famine and poverty, injuries and loss of life, separation of villages and migration of people. The participant indicates that 60 yrs old woman died in the gully and 12 goats and sheep were washed away.

Economic Effect of the Gully Erosion

The economic impact of the gully can be analysed on-site on the plot where erosion is taking place and off-site is downstream**.** The data from HHS indicate that the major effects of gully erosion are a decline in income and food**,** property loss, and change in livelihood. The participant indicates that before the 1990s the foodstuffs were fruits, cereals-maize, beans and cash crops such as sugarcane. But today most of the crops are less productive and some are completely not growing because of land use land cover change and gully erosion. During the group discussion, the elder indicated that before the 1990s the common food crops were wild fruit was common food. The result from the discussion and interview showed there are economic impacts as a result of gully formation in the catchment.

Environmental Effect of Gully Erosion

Gully erosion causes the loss of soil forever and affects the land making it unworkable and inhabitable (Stout, B.A, 1965)

Plate 10: Overgrazing of Animals in Turbo Forest and Gully Showing Complete Loss of Vegetation

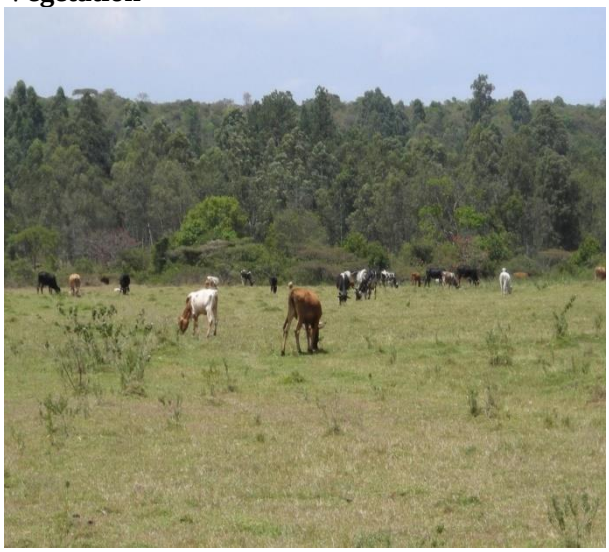


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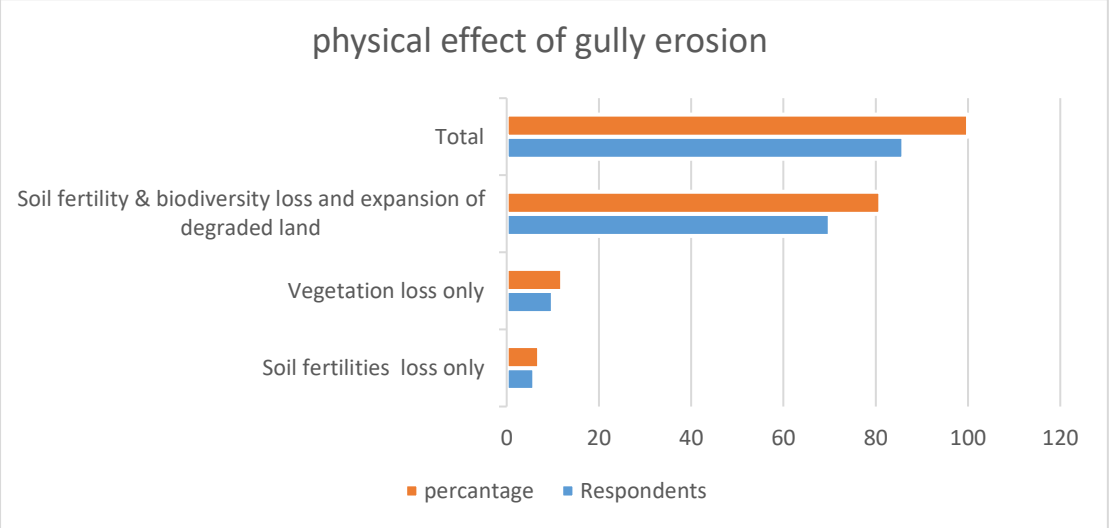
Plate 11: Gully Showing Complete Loss of Soil

According to Figure 8, about 81% of the households due to the increment of gully expansion the area has experienced increased land use land cover change, shortage of grazing and farmland, fertility loss, biodiversity loss, root crop and wild fruits.

Figure 8: Physical EDC Effect of Gully Erosion



(Source: Household respondent)

CONCLUSIONS AND RECOMMENDATION

Conclusions

The knowledge on gully erosion is vital for successful erosion control measures (Pathak et al., 2005). In these regards, the assessment of the cause driver and effect of gully erosion in Lugari sub-catchments was carried out. For valid and correct data to be collected different methods and tools such as satellite image analysis, interview, group discussion, field observations, field measurement and household survey were deployed. The result of the study indicated that in the 1990s and 2000, the gully erosion dominated the steep slopes. But between 2000 to 2010 the gully erosion expanded to the middle and lower area of the catchments.

Based on the primary and secondary data obtained the main cause of the gully erosion in the catchments is associated with anthropogenic activities and natural causes. Some of the causes of gully erosion are land use land cover change, expansion of farmland, increase in population, steep slope, heavy rainfall and drought.

The effects of the gully erosion observed in the catchments were fatal falls, death and injuries for both animal and human beings, village separation, soil fertility loss, loss of wild fruits and expansion of degraded land. The result from this study will

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be useful for gully conservation and rehabilitation for gullies.

Recommendation

- Gully is very expensive to rehabilitate once formed therefore prevention is cheaper than gully stabilization.
- A lot of effect is needed in the conservation of the remaining resources.
- Campaigns on the consequences of gully and deforestation should be initiated by county and national governments.
- The higher human exploitation of natural resources should be controlled by local authorities.
- Civic societies should be supported in conservation efforts by local authorities and communities.
- Gully erosion in the study area is gaining speed, the stakeholders should practice sustainable natural management.

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