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SOCIAL-ECONOMIC THRESHOLD FACTORS FOR GULLY EROSION STABILIZATION IN SEMI-ARID ENVIRONMENT OF WANJOGA RIVER CATCHMENT, UPPER TANA BASIN, KENYA

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ABSTRACT
Gullies are a major environmental challenge in semi-arid areas, leading to expansion of semi-arid regions, triggering landslides, causing pollution, limiting agricultural activities and damaging infrastructure, which pose a threat to livelihoods. Despite massive threat posed by gully erosion, farmers lack capacity for designing appropriate rehabilitation structures. Thus, understanding conservation techniques adoptable by locals for conserving degraded ecosystem in semi-arid environments is necessary. The study examined social-economic threshold factors for gully stabilization in the semi-arid environment of Wanjoga Catchment. Objectives of study included; to evaluate perception of farmers on gully stabilization and conservation, and establish success levels of gully stabilization methods used by farmers. Landsat images were generated to predict gully venerability. Field surveys revealed total of 98 respondents whose farmlands had gullies of width and depth ≥ 0.5meters and interviewed. Paired t-test and chi-square, data revealed a positive significant relationship ($p = 0.001 < 0.05$), between preferred rehabilitation structures and topographical differentiation, with gabions indicating low levels of effectiveness; 12.1% of structures diverting threat or accelerating erosion down slope. Paired sample t-test p=0.000, revealed, gulley rehabilitation measures used by farmers have not healed a significant number of gullies.

Keywords: Gullies, Rehabilitation structures, Overland flow, Farmers.

1. INTRODUCTION
Gullies are considered one of the worst environmental problems, due to their ability modify river catchment dynamics, aggravating other environmental and land use sustainability. In long-term, the threat of gully erosion leads to initiation and expansion of semi-arid regions; a threat promoted by large soil loses and changes in land use (Arabameri *et al.,* 2019; Poesen *et al.*, 1998; Valentin *et al.,* 2005). In short-term, gully erosion can cause catastrophic flooding and pollution, triggers landslides, and damage infrastructure such as roads, bridges and buildings limiting agricultural activities, posing a threat to livelihood (Frankl *et al.*, 2016; Vandekerckhove *et al.,* 2000; Poesen *et al.,* 2003). Despite the threat posed by gully erosion, classical methods used for gully stabilization and conservation (stone barriers, gabions, reforesting, terracing and check dams), (Poesen and Valentin, 2004), are not effective (Dong *et al.*, 2011). Reclamation based on classical methods alone may be effective measure to other forms of erosion control, but inadequate in gully erosion control, more so in unstable environments such as semi-arid environments (Nyssen *et al.,* 2004; Canovas *et al.*, 2017). Therefore, a better understanding of

local factors which increase gully erosion and knowledge of conservation techniques adopted by locals, can help in designing and building more powerful strategies for conservation and rehabilitating degraded ecosystem in a semi-arid environment.

In most gully erosion prone areas, the willingness of a farmer to adopt and implement use of gully rehabilitation and conservation structures is often related to the perception of the danger posed by gullies (Johansson and Svensson, 2002; Mekuria *et al.*, 2007). Local communities prefer methods which are faster to implement, cheap, improves productivity of the natural resources (Deba, 2003), effective in-terms of an increase in land or labour productivity and often pegged upon incentives. However, most studies related to gully erosion conservation evaluate gully risk from a scientific perspective (Dobek *et al.*, 2011; Kartz *et al.*, 2013; Ghosh and Guchhaitsik, 2016; Costa and Bacellar, 2006; Zhao and Hou, 2019; Panagos *et al.*, 2015; Conoscenti, *et al.*, 2014). The practical challenge to scientific view on gully rehabilitation is that, many techniques suggested are rarely understood and/or adopted by farmers at larger scale since their introduction is costly and rarely associated with immediate benefit (Imwangana, *et al.*, 2014; Valentine *et al.*, 2005). The long-term methods to gully rehabilitation and conservation cannot be achieved without the participation of the society who must be convinced on importance of land restoration. Farmers tend to design and layout rehabilitation structures based on perceived short-term threat posed by the gullied channel, a main challenge in gully rehabilitation and conservation (Kumar *et al*, 2015; Sirvios and Rebeiro, 2004; Mekuria *et al.*, 2007). For effective adaptability and success to gully erosion control, suggested methods must be based on the view of the farmer, in relation to its ability to improve soil fertility, increase forage and fuel wood production. The study evaluated the farmers diverge views on causes and factors that increase gully erosion in order to effectively suggest gully rehabilitation methods effective for the local society. However, few studies are available on the perception of farmers risk gullies posed to livelihoods. Specifically, the study evaluated; the knowledge of local people on factors which increase gully erosion in the semi-arid area, accessed success of different gully stabilization methods used for controlling gully erosion in semi-arid environment and suggested best methods of conservation and rehabilitation to gully erosion based on local factors.

2.MATERIALS AND METHODS

2.1 Study area

The Wanjoga River catchment (Figure 1) covers about 200.4km^2, located in Tana Basin, Embu County, Mbeere North Sub- County, between latitude 0°, 34’ 0.48” S and longitude 37°, 42’ 33.88” E. The geology of the area falls into four groups, the Archaean rocks eon (4.0 billion to 2,5 billion years) of the Neoproterozoic rock units include; the Embu Series, the Tertiary volcanic and superficial deposits of Pleistocene and Recent age (GOK, 1967). Neoproterozoic rock units consist wide variety of calcareous rocks, gneisses and schists with the Plagioclase amphibolites and hornblende gneisses most widely spread. Rocky outcrops of impermeable granitoid gneisses which resist weathering are common and form hills including the Kiang’ombe mountain, resulting in poorly developed soils (Bear, 1952). The intervening valleys and plains are composed of less resistant and more permeable biotite gneiss, migmatitic gneisses, and banded gneisses (Bear, 1952), forming arenosols, deep and well drained. Areas near Tana River (500m) under different basement system rocks, soils are stony loam sand to clay cambisols which are well drained.

Being a semi-arid environment, the river catchment experiences un-even rainfall distribution between days and months averaging at650mm/per annum. Rainfall patterns are bimodal with 60% of the total rainfall received between March and May which is the longer and more reliable season while 40% is received between October and December a shorter and less reliable season (Jaetzold and Schmidt, 1983). Temperatures of the area range between 20° to 32° with coldest month; July temperature averaging 15° (GOK, 2013). The nature of climate only encourages growth of drought resistant crops and livestock production (GOK, 2013). Hence, farmers grow drought resistant crops such as; cassava, maize, beans, cowpeas, pigeon peas, millet and khat-Catha edulis Forssk (Jaetzold and Schmidt, 1983), with more increased livestock production (Ngugi *et al.*, 2011). Despite unreliable rainfall, the catchment has an ever-increasing population (Olson, 2004). Rural-rural migration is evident from the neighbouring high potentials Counties and sub-counties (Embu east and Embu West Sub-Counties and Counties of Machakos, Tharaka Nithi and Kirinyaga), where high population density has pushed the landless people to the more marginal areas (GOK, 2013), in-turn increasing crop farming and cattle keeping (GOK, 2013). These increased agricultural practices are incompatible with unstable and fragile semi–arid environment affecting land productivity (Southgate and Hulme, 1996). Mbeere North Sub-County where the catchment lies has a total population 102,587 with a population density of 129 persons per km^2 (Gok, 2019) a rise from 2009 census with a total population of 86,186 density 111 persons per km^2 (GoK, 2019). Increases in population leads to increased demand for food, water and forage, roads, consequently, adding huge pressure on land exploitation and eventually leading to an increase in erosion rates. The objectives of the study was to evaluate social economic factors influencing gully rehabilitation and conservation and success level of structures used for rehabilitating and controlling against gully erosion for semi-arid environment, upon increasing anthropogenic activities.

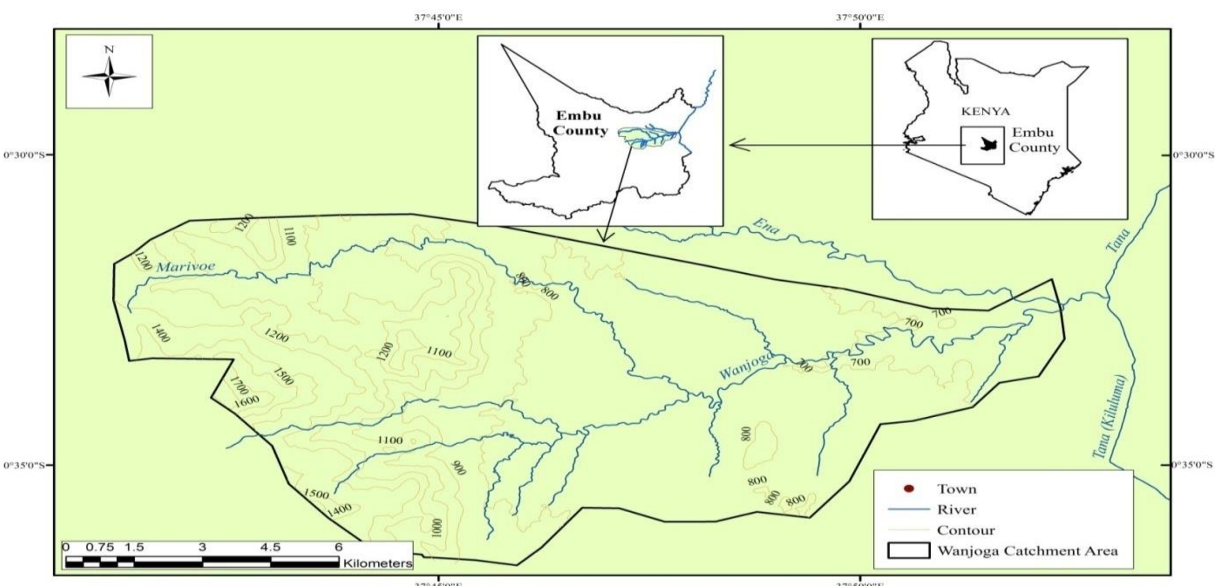

Figure 1 Wanjoga River catchment (Source: Survey of Kenya)

2.2 Research Methods

2.3 Sources of Data

Primary data was obtained from extensive and detailed field surveys along gullies and gullied areas by; taking GPS points and photographing sections of gullied and regions of stabilization and conservation structures, identifying and documenting geomorphic processes around the conservation structure establish the effectiveness of the conservation structure used based on the visible geomorphic process round the structure. Farmers whose land was affected by gully erosion were interviewed by use of an interview schedule to establish farmer's perception and social economic factors on gully rehabilitation and conservation. For gully susceptibility determination in Wanjoga river catchment, Landsat images mapped were digitized from September 2018 using Spot image 1.5m resolution made available by Google Earth and by use of GPS during the field visits. Successful susceptibility mapping permits for accurate identification and visualization of spatial distribution of gullied areas and areas of increased geomorphic processes that increase susceptibility to gully erosion, for better planning of conservation and rehabilitation of already gullied areas.

2.4 Data analysis

To determine the degree of association existing between farmer's social economic factors, rehabilitation structures and effectiveness of gully conservation methods, Paired sample t-test was performed to depict the relationship between the variables. Paired sample t-test is the best measure in a case-control study, to show effectiveness of used rehabilitation structures on gullied areas in relation to non-rehabilitated gullied areas. Two sets of hypotheses are set; the null hypothesis, which assumes that the mean of two paired samples is equal.

$$\mu_{gulley\ areas} = \mu_{healed\ gulley}$$

and the alternative hypothesis, which assumes that the means of two paired samples are not equal

$$\mu_{gulley\ areas} > \mu_{\ healed\ gulley}$$

After making the hypothesis, we choose the level of significance at 5% using (Goulden, (1959) formula.

$$t = \frac{\bar{d}\sqrt{n}}{s} \qquad (1)$$

t-statistic above follows *t-distribution with (n – 1) d.f.,*

$\bar{d}$ =mean of the differences

$$\bar{d} = \frac{\sum d}{n} \qquad (2)$$

d - difference between paired observations is the standard deviation of the differences and is given by:

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$$s = \sqrt{\frac{\sum\left(d - \bar{d}\right)^2}{n-1}} = \sqrt{\frac{\sum d^2 - n\left(\bar{d}\right)^2}{n-1}} \qquad (3)$$

and

n is the number of paired observations in the samples.

If the computed value of p-value associated with the computed value of 't' is> 0.05 (5% significance level), the null hypothesis is accepted, otherwise rejected.

For gully susceptibility map analysis, Weighted Overlay Tool in ArcGIS was used. Two gully influencing factors (land cover/land use and slope) were assigned a weight in comparison with one another. After weighting of the conditioning factors, an overlay of factors was carried out in ArcGIS version 10.4 to come up with final susceptibility map showing level of susceptibility to gully erosion.

3 RESULTS AND DISCUSSIONS

3.1Social economic factors for gully erosion stabilization and conservation

Effectiveness of gully stabilization methods used in a semi-arid environment depend upon a thorough understanding of local mechanics of erosion processes. This involves a proper understanding of both natural and human factors which increase geomorphic processes, increased channelization resulting in increased density and widening of already formed channels. Therefore, it's necessary to evaluate farmers understanding on factors which increase susceptibility to gully erosion to effectively design structures for rehabilitating against gully erosion. Based on results depicted on Table 1, respondents were aware that slope played a major role in gully development since it leads to extreme runoff concentration. Responses on perceived role of slope on gully erosion indicate, out of 156 analysed gullied sections, 90 (56.7%) were perceived to occur on steep slopes, 46 gullies (29.5%) on medium slopes while 20 (12.8%) sections occurred on gentle slope regions.

Table 1 Farmers perception influence of slope to gully occurrence

Steepness	Gully count	percentage
Steep slopes	90	56.7
Medium slopes	46	29.5
Gentle slopes	20	12.8
Total	156	100

Source: Field data 2021

Perception to risk posed by gully erosion on farmlands is dependent on frequency of gullies per farm holding as summarized on Table 2. The findings indicated; most farms had between 1-5 gullies (86%) while 31.4% of farms had more than ≥4 gullied areas.

Table 2 Gully frequency on farmland

Gully number	Respondents	Percentage
1-3	68	68.7
4-5	27	27.3
Above 5	4	4
Total	99	100

Considering majority of respondents had more than one gully channels on their respective farms, the results indicated most farmers were at high risk of gully development in their farmlands.

3.2 Farmers perception to threat posed by gully erosion

Perception of farmers on threat posed by gully erosion was determined by use or lack of use of gully rehabilitation and conservation structures and/or frequency of conservation structures per gullied area. Since gullies act as channelization point, increased gully discharge dictates for frequent and more elaborate planned structures for effective rehabilitation and gully initiation control. 7.1% of farmers view gullies on grazing land as a threat to their livelihood. The low perception to threat by gullies on grazing land could be attributed to land used as community grazing land thus no farmers had direct responsibility for gully rehabilitation. 73.5% viewed gullies on cultivated land posing the greatest threat to their livelihood while 15.3% threat was perceived on road side gullies (Table 3)

Table 3 Perception to threat to gully erosion

	Frequency	**Percentage**
Grazing land	7	7.1
Cultivation land	72	73.3
Roadsides	15	15.3
forest	4	4.1
Total	98	100

Source: Field data 2021

Despite a high frequency of gullied areas on grazing land (Table 4), only 24.4% of conservation structures were cited on landscapes (>10 acres) posing a higher risk to gully formation.

Table 4 Frequency of rehabilitation structures on farmland

Frequency		Gully count	Conservation Structures frequency	Percent
> 5 acres	22	24	20	83.3
5-10 acres	61	46	17	37
>10 acres	16	86	21	24.4
Total	99	156	58	28.8

Source: Field data 2021

Small land holders (<5acres) were more concerned on rehabilitating gullied areas with 83.3% of conservation structures designed and cited compared to medium land holders (5-10 acres) accounting for 37% of applied conservation structures. Low conservation uptake of gully rehabilitation structures (28.8%) in the semi-arid region indicated a higher risk to gully erosion.

3.3 Gully rehabilitation and conservation methods

The principle of gully control and rehabilitation used by farmers in the study area was mainly to create new conditions since most farmers viewed gullies as originated from extreme overland flow brought by increased slope and road construction. Farmers took effective approach of slope reduction in a bid to rehabilitate gullied areas on farmlands while road side gullies used the second principal of gully restoration by use of 'filling' and gabions approach, which restores the original hydraulic balance and protected the gullied scar areas. The results as indicated on Table 5, shows, vegetation and filling with stones/stone barriers were the single most preferred method of rehabilitation at 19% and 22.4% respectively while filling with soil (1.3%) was least preferred. 13.8% of gullied section had gabions designed and applied on them.

Table 5 Gully rehabilitation in Wanjoga catchment

Conservation structures	**Upper segment**	**Mid-segment**	**Lower segment**	**Conservation structures count**	**%**
Filling with stone/stone barrier	5	8	-	13	22.4
Filling with soil	1	1	-	2	1.3
Use of Vegetation	3	6	2	11	19
Gabions	3	3	2	8	13.8
Vegetation and use of stone barriers	5	9	-	14	24.1

Gabions and filling with soil	3	4	3	10	17.2
Non-conserved gullies	70(77.8%)	15(32.6%)	13(65%)	-	62.0
Total	90	46	20	156	100

Source: Field data 2021

Several farmers used a combination of methods to effectively rehabilitate gullied areas with combined gabions and filling with soil accounted for 17.2% while use of stone barriers and vegetation accounted for 17.2%. However, a high proportion of farmers (62.0%), did not perceive gullies as a threat to livelihood since no form of rehabilitation or conservation structure was designed and cited across and/or above gullied areas. Based on elevation, the highest number of gullies with no form of rehabilitation structure were at upper segment (77.8%), an indication that farmers ignored the threat posed by small gullies on sediment removal. In mid and lower region, sections with no form of conservation structure accounted for 32.6% and 65% respectively. A chi-squire test was used to evaluate preference of conservation structures used by farmers. The results indicate a positive significant relationship ($p= 0.001 < 0.05$), between preferred rehabilitation structure and topographical differentiation. For instance, stone barriers are most preferred form of rehabilitation at upper segments compared to the mid-segment and lower segments where gabions and use of vegetation were preferred.

3.4 Effectiveness of gully rehabilitation and conservation methods

Based on interview responses and intensive field observations, the study revealed most conservation structures designed and cited by farmers did not work to heal or limit increased geomorphic processes down slope after conservation structure was cited. Only 36.9% of observed rehabilitated gullied sections showed healing processes or were completely healed by the applied structure while 63.1% had more instances of erosion down slope after conservation structure was sited (Table 6). Single most preferred method for rehabilitation; filling with stones and use of vegetation, were not effective in controlling gully erosion since structures did not work to limit erosion down slope after citing of the structure. Only 5.2% of gully channels rehabilitated by filling with stones and 7% of those used vegetation had limited erosion down slope

Table 6 Effectiveness of applied rehabilitation structures on gullied areas

Rehabilitation structure	Healing process	%	Non healing gullies	%	Total gullies	%
Filling with stones/stone barrier	3	5.2	10	17.2	13	22.4
Filling with soil	1	1.7	1	1.7	2	1.3
Use of Vegetation	4	7	7	12.1	11	19

Gabions	1	1.7	7	12.1	8	13.8
Vegetation and stone barriers	8	13.9	6	10.3	14	24
Gabions and filling with soil	7	12.1	3	5.2	10	17.2
Total Conservation structures	24	36.9	41	63.1	58	

Source: Field data 2021

However, use of combination of structures on gullied areas proved most effective in gully rehabilitation, with gabions and filling with soil structures (12.1%), and use of vegetation and stone barriers (13.9%) showing limited erosion down slope after application of conservation structures. The most preferred rehabilitation method on road sides gullies; use of gabions, showed low levels of effectiveness in limiting erosion down slope with only 1.7% of rehabilitated gully sections showing decreased erosion down slope while 12.1% sections had instances of accelerated erosion on the lower section and/or the diverted side. In most instance, road side sections of gully systems rehabilitated by use of gabions evolving down slope causing further growth in all directions, affecting ruggedness of the landscape (Figure 2).

Figure 2 Excessive erosion down slope over rehabilitation structure (source: researcher 2020)

This scenario can be aggravated by introduction of rehabilitation structures by farmers with insufficient knowledge on factors responsible to gully erosion at local environment. Despite huge responsibility on farmers to design and cite rehabilitation structures, 84% of respondents' choice for citing rehabilitation structure was based on areas viewed most affected by excessive soil loss, ignoring threat created by potential increased discharge brought about by increased drainage area. 12% placed the structures randomly while 1% sought advice from agricultural extensional officers (Table 7).

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Table 7 Conservation structures placement

	Frequency	Percent	Structure frequency	
			1 structure	More than 1 structure
Randomly	12	12.2	83.3	16.7
Use of agriculture extension officer	2	2.1	100	0
Areas of increased erosion	84	84.7	94.1	5.9
100		100.0		

Source: Field data 2021

Increased erosion down slope can also be aggravated by use of limited number of conservation structures to control increased gully discharge. Most farmers used single rehabilitation structure per gullied area irrespective of length and channel density, thus, the structures did not work to limit and/or prevent downslope gully development. 83.3% used 1 (one) conservation structures randomly per gullied area, while 94.1% used one structures on areas of excessive erosion. Farmers assumed a single structure was effective enough to reduce threat posed by the surface overland flow over the affected area. Use of one structure (gabion or stone barrier) per gullied area to control overland flow concentrated over a large drainage area resulted in increased geomorphic processes; scouring, side slope failures and undercutting on the lower section and/or on the diverted direction. Moreover, all farmers cited a challenge in gully rehabilitation due to lack of government participation in gully rehabilitation (Table 8), since local authorities view the biggest threat of gullies as those occurring on the main roads, since they posed a threat to transport and communication.

Table 8 Challenges to gully rehabilitation

Challenge	**Frequency**	**Percentage**
Lack of technical know how	4	4.1
Lack of equipment	16	16.3
Lack of Capital	36	36.7
Materials to use	18	18.4
None	24	24.5
Total	98	100

Following the diverging results on gully rehabilitation, paired t-test was used to establish the effectiveness of the different rehabilitation structures and computed on Table 9. A 2-tailed significance observed $p=0.000$, <0.05 hence accepting the null hypothesis and concluding, gulley prevention measures used have not healed a significant number of gullies across all segments.

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Table 9 Paired t- test statistics for three segments

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Gully count healing gully	20.859	22.412	1.794	17.314	24.404	11.624	155	.000

Source: Field data 2021

Use of numerous in-appropriate and poorly constructed gully erosion rehabilitation structure have encouraged gully channels to by-pass the threat area and cut a new channel at low gradient direction. Therefore, for the study area, the most effective rehabilitation methods would be those designed to reduce slope, manage upland drainage area and properly maintain vegetation cover to reduce runoff (Figure 3). Such structures may take a longer time to achieve and sometimes costly to install, but minimize overland flow and aim at reducing the erosive power of concentrated runoff.

Figure3. Degraded non-rehabilitated lands versus conserved land in Wanjoga Catchment. (a and b) a degraded hillslope with gullies in Kathera and Kirie, (c and d) Improved land area by different varieties of grass and gabions **(**Source: Researcher 2021)

In areas with increased concentrated overland flow, infiltration can be increased by ensuring good vegetative cover and if proving a challenge since the areas is a semi-arid, increasing alternate beams of stone cover.

4. DISCUSSIONS

Effectiveness to gully stabilization in an area depend upon a thorough understanding of local mechanics of the erosion processes. Farmers took effective approach of slope reduction in a bid to rehabilitate gullied areas with vegetation and filling with stones/stone barriers being the single most preferred method of gully rehabilitation. However, a high proportion of farmers did not perceive gullies as a threat since there were no designed and cited rehabilitation structures across gullied areas, increasing gully erosion in the semi-arid region, as showed by Imwangana, *et al.*, (2014). The most preferred rehabilitation method on road sides gullies; use of gabions, showed low levels of effective in limiting erosion, since there was instances of accelerated erosion on the lower section and/or the diverted region which affected ruggedness of the landscape. Thus, in introducing certain rehabilitation structures, care must be taken, since additional coarse materials can ensure incision cut round the introduced structure and scouring by movement of added materials down slope. This finding concur with those of Kirkby and Brecken, (2009), that, course materials can discourage flows by passing the treated areas to other regions, cutting a new channel at areas which had no original threat.

Since gullies act as channelization point, increased gully discharge dictates for frequent and more elaborate planned structures for effective rehabilitation and initiation control. However, farmers used only one structures randomly or at sections perceived of increased soil loss irrespective of size and length of the gully channels. Assumption that a single structure was effective to reduce threat posed by surface overland flow over a large drainage area, work to increase geomorphic processes (Kirkby and Brecken, 2009) on the lower section and/or on the diverted direction. However, use of combination of structures was the most effective for gully rehabilitation, with conserved sections showing limited erosion down slope after application of the structure which act to reduce discharge (Q) into the gully system (Kartz *et al*., 2013).

5. CONCLUSION

Since most gully development is by human induced activities; land cover changes and increased grazing, gully rehabilitation can be carried out by minimizing drainage into the gully by constructing a stone barrier or terracing at the edge of a gully. In the upstream region of the gully, a stone burrier and/or terracing should be constructed and after, plant fast growing grass on the upstream direction (Figure 3c). This introduced rehabilitation structures at upstream edge of the gully is effective to reduce drainage area which increase discharge (Q) into the gully system. Subsequently, more rehabilitation and conservation structures should be designed and constructed to reduce slope which wound eventually reduce overland flow as predicted on Figure 4.

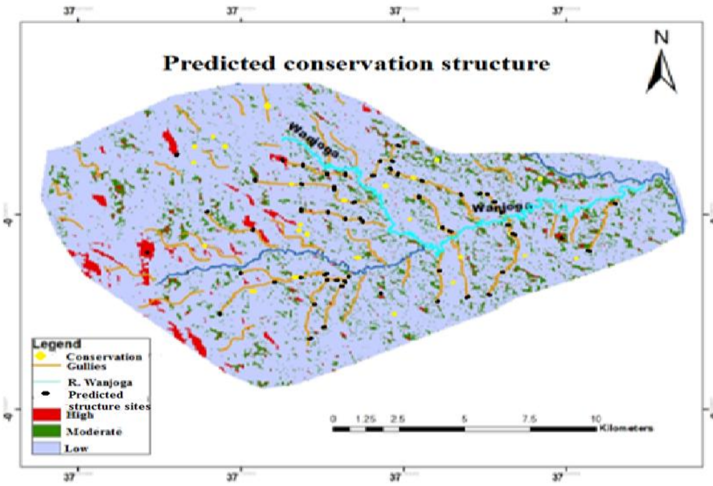

Figure 4. Predicted areas for gully rehabilitation

Increased rehabilitation structures across gullied channels and landscapes, would reduce flow velocity by reduced slope and increased ground roughness. Vanwalleghem*et al*. (2008) showed that in Belgium, reducing slope gradients of the soil surface is the most important factor in controlling occurrence of permanent gullies. Small gullies can be rehabilitated by minimizing human activities round the gully channel since natural vegetation growth within the gully has the potential for continual natural regeneration. Although use of combination of structures such as gabion and filling with soil and/or stone barriers and vegetation may take longer time to achieve and sometimes costly to install, they prove a useful tool to minimize overland flow, aimed at reducing the erosive power of concentrated runoff eventually. In areas with increased concentrated overland flow, infiltration can be increased by ensuring good vegetative cover. Ultimately, farmers and road planners should be careful in land cover changes not to influence gully development by increasing slope gradients.

This study was concluded by use of already established conservation structures by farmers to determine their effectiveness to gully rehabilitation. Thus, further studies can be conducted by designing and citing conservation structures at different regions and sections of gullied channels and/or at upstream edge of the gully, and conservation structures observed over time, to establish their effectiveness to gully conservation. Further the study suggests use prediction of areas susceptible to gully erosion in semi-arid environment which act as a guide increase conservation structures.

5. RECOMMENDATIONS

The study recommends that areas with deep cuts gullies should be stabilized by the farmers using combination of effective stabilization measures with locally available materials; gabions and filling with stones, strip farming, stone barriers and use of vegetation, trenches and vegetation cover, that would provide stability on soil movement and impact on gully erosion control. Most urgently, government should put in place early warning systems that guide against gully erosion. The evaluation would help identify areas with visible indicators of soil loss due to gully erosion.

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Author contribution

Cecilia Ireri; conceptualization of the research topic, data collection and investigation and wrote the draft manuscript; George Krhoda reviewed the manuscript and helped in forming of the model and the paper while Stella Murkhovi assisted in GIS issues of the paper.

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Conflicts of interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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