POTENTIAL SOIL LOSS IN EARLY GULLY EROSION FORMATION IN UGEP, CROSS RIVER STATE

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Abstract
The objective of the study was to assess the potential soil loss in early gully formation in Ugep. Six composite soil samples were collected randomly from developing gullies in Ugep at depth of 0-30 cm and measurement of its height were investigated. Results from analysis using standard laboratory procedures show that, the soil texture was dominated by sandy loam. Sand fraction was higher than silt and clay. The pH was strongly acidic to slightly acid and other soil chemical properties were generally low. The potential soil loss (A) was highest in Ketabebe middle slope (234.7 Mg $ha^{-1}yr^{-1}$) belonging to category 5 of very high erosion potential and lowest in Kekomkolo (42.36 (Mg $ha^{-1}yr^{-1}$) belonging to category 4 of high erosion potential. Statistically, depth of gully decreases as potential soil loss, erodibility, K, silt and clay increases. Also showed, organic matter (OM), sodium adsorption ratio and total porosity increases, as depth of gully increases. Furthermore, there was a significant increase in sand and saturated hydraulic conductivity (K_{sat}) as the depth of gully increases. The study recommended that, vertiver grasses should be planted to control the runoff from the gully heads and prevent further under cutting of the gully heads and other management strategies such as construction of gutters and water diversion devices to control runoff of the area.
Key words: *Soil erosion, gulley erosion, potential soil loss*

Introduction

Soil erosion plays a pivoted role in land degradation and loss of top fertile soil (Eswaran *et al.*, 2001). In recent times, it has become a serious problem due to unhalted trends of unsustainable land use practices. Worldwide, soil erosion is one of the greatest environmental issues threatening human existence with its impact resting heavily on agricultural sustainability (Akpa *et al.*, 2024). Each year, about 10 million hectares of cropland are lost to soil erosion which has reduced the cropland available for food production. Reports show that soil erosion accounts for 85% of land quality deterioration and 17% decline in agricultural output and permanent degradation of the land (Singh, 2017). Similarly, it has been estimated that 80–85% of agricultural lands suffer soil erosion problems and six billion hectares of fertile land are being lost annually by soil erosion and other land degrading factors (Ganasri and Ramesh, 2016).

Gully erosion remains one of the most significant environmental issues, often triggered by the mismanagement of soil impacted by rainfall. Zegeye *et al.* (2010) established that gully erosion is a global phenomenon that exacerbates topographical instability. Gully erosion is caused by an accelerated process under which soil is physically displaced and transported away faster than it can be formed (Igbokwe *et al.,* 2008). Globally, gully erosion remains one of the most pressing environmental challenges. According to Ogbonna (2012), the menace emanating from gully erosion means approximately 90 percent of cropland is currently losing soil above the sustainable rate. Ofomata (2000) classified gully erosion as actual erosion, which is the physical manifestation of land loss due to erosive forces.

Gully erosion is a highly visible form of soil erosion that distresses geomorphological landscapes which limits land use and disrupt agricultural activities, roads, walls or fences, buildings and human life (Igwe *et al.,* 2017). It is one of the major shocking disasters that increase the speed

of soil erosion (Shit and Maiti, 2002). Gully erosion is defined by its channel depth which ranges from 0.5 to 30 m; *happens when runoff flows concentrate and cut a channel through the soil* to at least 0.3m deep *and this may reach depths of 10–15 m* (Soil Science Society of America, 2000).
In Southeastern Nigeria, gully erosion is the most serious problem that affect large population of urban and rural environments (Ezeigwe, 2015). According to Adekalu *et al.* (2007), gully site is one of the hazardous features that characterize the southeastern zone of Nigeria and its formation has become one of the greatest environmental disasters facing many towns and villages in southeastern Nigeria where, Cross River State is not exceptional.

According to Eze and Etu (2018) in Cross River State, the effects of gullying and its soil loss rates have been documented especially in the Calabar Metropolis. Ugep, a prominet city in Cross River State is experiencing gully formation especially in Ketabebe, Obioko and Kekomkolo, where gully erosion has inflicted harm to the people by reducing the sizes of their farmlands. This study was carried out to assess the potential soil loss via gulley formation with the view of recommending ways to curb the menace.

Materials and Method

Study Location, Field Data Collection and Laboratory Analysis

The study was carried out in Ugep, central Cross River State. The area lies between Latitude 05° 48' 05.9" N and Longitude 08° 05' 36.2" E and located in the humid tropical climate with distinct wet and dry seasons. Rainfall in the area ranges between 1800 and 2500 mm per annum, while relative humidity is between 80 and 90 percent. The mean annual temperature is between 22 and 31.8˚C. The underlying geological materials are of sandstone-shale intercalation with outcrops of dolerite found in patches, while alluvial deposits predominate low-lying poorly drained fadamas. The soils are Ultisols; they are deep, porous, and acidic with low organic matter content as a result of leaching causing high susceptibility of the soil to accelerated erosion and land degradation (Eyong and Akpa, 2018). The topography is characterized by gently and steeply sloping landscape of 0-9 % with the crest gradually sloping towards the valley bottom exhibiting moderate to high erosion conditions. The vegetation of the area is characterized by tropical rainforest. Common plant species in the areas include guinea grass *(Panicum maximum)*, elephant grass (*Pennisetum purpureum*), teak *(Tectona gradis)*, gmelina *(Gmelina arborea)*, pear *(Dacryadis edulis)* and timber trees. The major crops in the areas include rice (*Oryza sativa*) oil palm *(Elaeis guinensis)*, cassava *(Manihot spp.)*, plantain *(Musa paradisiaca); and* yam *(Dioscorea spp.)*. Six (6) composite soil samples were collected using soil auger by random sampling from 6 gully formations namely Ketabebe upper slope, Ketabebe middle, Katabebe lower slope, Ketabebe valley bottom, Obioko and Kekomkolo. A Garmin Global positioning system 12 was used to geo-reference the area of the sampling location; Katabebe (Lat 05˚ 48.319 Long 008˚ 05.402'), Obioko (Lat. 05˚ 48.222', Long 008˚ 04.675') and Kekomkolo (Lat 05˚ 48.199' Long 008˚ 04.650'). Thereafter, the depth of each gulley (Plates 1, 2 and 3) was taken with measuring tape. The samples collected were transported to the Soil Science Laboratory, University of Calabar for analysis. Particle size distribution was analyzed by Bouyoucos hydrometer method using calgon as dispersing agent (Gee and Or, 2002). The soil texture was determined using USDA soil textural triangle (SSS, 1999). Silt/clay ratio was determined from % silt and % clay of particle size analysis and calculated using the formula outlined by Igwe *et al.,* (1995):

$$SCR = \frac{\%Silt}{\%\text{Clay}} \quad (1)$$

The saturated hydraulic conductivity (Ksat) was determined by the constant head method. The transposed Darcy's equation as outlined by Youngs (2000) was used for computation of $K_{sat.}$

$$Ksat = \frac{QL}{\Delta \text{HAT}} \quad (2)$$

Bulk density was determined by the core method procedures outlined by Blake and Hartge (1986). Particle density was determined by the pycnometer method following the procedures outlined by Bowles (1992). Total porosity was obtained by calculation using the values of the ratio of bulk density (ℓ_b) and particle density (ℓ_p).

$$Ø = \left[1 - \frac{\ell b}{\ell p}\right] \times 100 \quad (3)$$

The soil structure was determined under field condition by size differentiation and grouped into classes; 1 = very fine granular; 2 = fine granular; 3 = medium or coarse granular; 4 = blocky, platy, or massive

Soil pH was determined in soil water ratio of 1:2.5 by a glass electrode pH meter standardized in buffered solution 4.0 and 6.85 (Udo *et al.,* 2009). Organic carbon was determined by the Walkley and Black method as outlined by Nelson and Sommers (1996). The percent organic matter was computed by multiplying the value of organic carbon by the Van Bemmelen factor of 1.724 and rated using FDALR (1990) and Landon (1991). Exchangeable potassium and sodium (K^+ and Na^+) were extracted in 1 N NH_4OAc at pH 7.0 method as outlined by Thomas (1982) and determined using flame photometer. Exchangeable calcium and magnesium (Ca^{2+}, Mg^{2+}) were determined by the complexometric titration method (Jackson, 1958). Exchangeable hydrogen and aluminum (H^+ and Al^{3+}) were extracted in 1 N KCl using the titrimetric method described by Mclean (1982). Cation exchange capacity (CEC) was extracted using 1 M NH_4OA_C at pH 7.0 following the method described by USDA-NRCS (SSS, 1996). Effective cation exchange capacity (ECEC) was evaluated by the summation of exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) and exchangeable acidity (H^+ and Al^{3+}) as outlined by USDA-NRCS (SSS, 1996). The base saturation (BS) was calculated by dividing the total exchangeable bases (TEB) (Ca^{2+}, Mg^{2+}, K^+ and Na^+) by effective cation exchange capacity (ECEC) and expressed as a percentage (Hazelton and Murphy, 2016).

$$\%BS = \frac{\text{Total exchangeable bases}}{\text{Effective cation exchange capacity}} \times 100 \quad (4)$$

Sodium adsorption ratio (SAR) was calculated using the formular outlined by Michael (2005) as follows:

$$SAR = \frac{Na^+}{(Ca^{2+} + Mg^{2+})/2} \quad (5)$$

Where sodium, calcium and magnesium concentration are expressed is centimoles per kilogram

Calculation of Predicted Soil Loss (A)

The predicted soil loss (A) was calculated using the Universal Soil Loss Equation (USLE) model outlined by Wischmeier and Smith (1978) as follows:

$$A = RKLSCP \quad (6)$$

Calculation of Soil Erodibility Factor, K

The soil erodibility factor, K in the USLE model was calculated using the equation outlined by Wischmeier *et al.* (1971)

$$K = \frac{[2.1x\,10^{-4}(12 - a)\,M^{1.14} + 3.25(b - 2) + 3.3\,x\,10^{-3}(c - 3)]}{100} \quad (7)$$

Calculation of Erosivity, R

Erosivity, R was calculated using the equation as outlined by Kaltenrieder (2007).

$$R = 0.55x - 4.7 \quad (8)$$

Calculation of Slope Length and Steepness Factor, LS

The slope length and steepness factor (LS) in the USLE combined together were calculated using the equation outlined by Bizuwerk *et al.*, 2008:

$$LS = \left(\frac{\lambda}{22.1}\right)^m (0.065 + 0.0456s + 0.0065s^2) \quad (9)$$

Crop and cover management factor, C

The crop and cover management factor, C in the USLE was kept constant using value of 1. The value was adopted because the studied soils were not covered with any protective ground cover.

Conservation practice factor, P

The conservation practice factor, P in the USLE was kept constant using value of 1. The value was adopted because the soils were subjected to a slope with no conservation practices.

Classification of erosion potential (EP)

Erosion potential (Ep) was classified into 1, 2, 3, 4 and 5 according to the numerical range of the soil loss in t ha^{-1} y^{-1} of 0-2 (Very low), 2-10 (Low), 10-15 (Moderate), 15-50 (High) and >50 (Very high) as outlined by Tosic *et al.* (2011).

Data analysis

Data were subjected to correlation analysis to determine the height of the gully relationship with predicted soil loss and soil properties. All statistical analyses were conducted using IBM SPSS Statistics 27.0.1 Version.

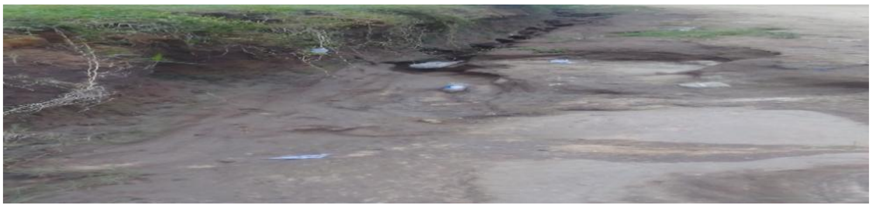

Plate 1: Ketabebe gully formation

Plate 2: Obioko gully formation

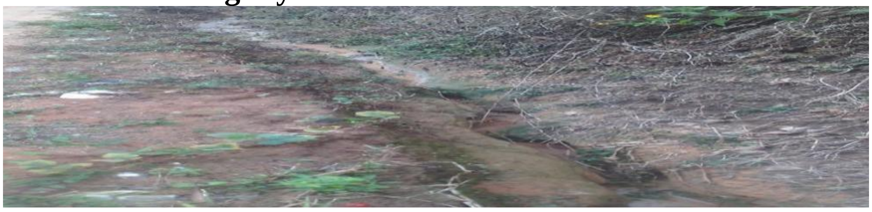

Plate 3: Kekonkolo gully formation

Results and Discussion

Particle Size Distribution

The particle size distribution is presented in Table 1. The result revealed that, sand fraction predominant over other fractions with the highest value recorded in Obioko (810 g/kg) and lowest in Ketebebe middle slope (550 g/kg). The texture was dominated by sandy loam. Blanco and Lal (2008) reported that sand tends to be less erodible than silt, very fine sand and clay soils implying how easily it can be detached and transported by water. The sandiness of the soil could be associated with the coarse texture from which the soil was formed coupled with heavy rainfall and high temperature. Osujieke *et al.*, 2017 and Obasi *et al.*, 2016 reported that parent material influences soil texture. The silt content was low and recorded highest in Ketabebe middle slope (440 g/kg) and lowest in Obioko (170 g/kg). Madueke *et al.* (2012) reported that low silt could be attributed to a high degree and intense weathering. The clay was highest in Ketabebe upper slope (30 g/kg) and lowest in Ketabebe middle slope (10 g/kg), indicating the rate of fine particle deposition by erosion. The saturated hydraulic conductivity (K_{sat}) was generally moderate to rapid with mean values ranging from 50 – 150 cm/h. The result is in line with the report of Park and Smucker (2005) who observed that high movement of water in soils result to condition of moderate to rapid saturated hydraulic conductivity due to their macroaggregate condition. The bulk density (ℓ_b) was low with values ranging from 1.42 to 1.49. Bulk density values less than 1.49 g cm^{-3} generally indicate porous soil condition which leads to soil erosion. Mckenzie, *et al.* 2004 reported critical values of bulk density for encouraging erosion and restricting root growth varies with soil type but bulk densities less than 1.8 g cm^{-3} encourage soil erosion and greater than 1.8 g cm^{-3} generally tend to restrict root growth. The particle density (ℓ_p) was lower than the value of 2.65 g cm^{-3} recommended for tropical soils by Stutter *et al.* (2004). Akpa *et al.* (2020) reported similar value of 2.55 g cm^{-3} in coastal plain soils of southeastern Nigeria, attributing the values to the spatial variability of soil properties. The total porosity (ϕ) varied from highly porous (35-40%) to extremely porous (40-60%) values (Udom and Anozie, 2018). This indicates fairly aerated soils (Akpa *et al.,* 2020). The highest value was obtained in Obioko (63.1%) and lowest in Ketabebe middle slope (36%). Similar values within the range of 46-56% were reported by Ogban and Utin (2015). The soil structure under field condition showed fine granular (Katabebe upper slope), blocky, platy, or massive (Ketabebe middle slope), medium or coarse granular (Ketabebe lower slope and Katabebe valley bottom) and fine granular (Obioko and Kekomkolo)**.** Blanco and Lal (2008) reported that fine granular structure are more detachable, unstable and susceptible to compaction, thereby having low water infiltration and high runoff rates.

Chemical Properties

The soil pH (H_2O) had range of 5.5-6.4. The pH was strongly acid to slightly acid on the scale of FAO (2004), indicating that the soils are weathered and acidic in nature due to the high rainfall occurring in these areas. Akpan–Idiok (2012) reported that the acidic conditions of soils might be due to the high rainfall exceeding 3500 mm which could leach out basic cations from the soil solum in the areas. The organic matter (OM) varied from 0.75 to 2.34%. The OM was generally low to medium on the scale of FDALR (1990) and Landon (1991). Blanco-Canqui *et al.* (2006) reported that low to medium organic matter contents lead to soil erosion because the soil is bare and exposed to raindrop impact. The exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) were generally low to medium on the scale of FDALR (1990) and Landon (1991). Bulktrade (1989) reported low to medium Mg^{2+} content in surface and sub – surface soils of South Eastern, Nigeria. The exchangeable K^+ was generally below 0.1 cmol kg^{-1} and rated low. Such low values are attributed to the low cation exchange, sandy textural class and high rainfall causing the leaching of exchangeable bases in the areas. Exchangeable Na^+ was below the limit of 0.3 cmol kg^{-1}). The low values might be attributed to the high rainfall which leaches the exchangeable sodium down the soil profile. The exchangeable acidity (H^+ and Al^{3+}) was constituted mostly of exchangeable Al^{3+}. Exchangeable Al^{3+} ranged from 0.0 to 0.88 cmol kg^{-1}. The exchangeable Al^{3+} is the most abundant elements in these soils but generally low on the scale of FDALR (1990) and Landon (1991). The cation exchange capacity (CEC) recorded highest value of 11.6 cmol kg^{-1} in Ketabebe valley bottom and lowest value of 6.3 cmol kg^{-1} in Ketabebe valley bottom. The CEC was generally low as values were found to be below (< 15 cmol kg^{-1}) on the rating scale of FDALR (1990) and Landon (1991). Fashina *et al.* (2003) reported low CEC being attributed to chemical weathering of the soil that leaches the soil and expose it to acidity. The base saturation (BS) ranged from 49.8% in Ketabebe valley bottom and 68.2% in Ketabebe middle slope. Base saturation (BS) was generally low on the rating scale of FDALR (1990) and Landon (1991). The sodium adsorption ratio (SAR) was generally less than 9 and rated as low on the scale of Rollins (2007). Brady and Weil (2008) reported that monovalent ions like potassium do not promote soil structure aggregation against erosion.

Table 1: Soil properties of the study location

Physical properties	Sampling location					
	Ketabebe upper slope	**Ketabebe middle slope**	**Ketabebe lower slope**	**Ketabebe valley bottom**	**Obioko**	**Kekomkolo**
Depth of gully (cm)	30	33	40	35	42	45
Sand (g/kg)	580	550	650	620	810	800
Silt (g/kg)	260	440	340	360	170	180
Clay (g/kg)	30	10	10	20	20	20
TC	SL	SL	SL	SL	LS	LS
Silt-clay ratio	8.7	44	34	18	8.5	9
SHC (mm/h)	58.56	73.73	96.09	101.42	127.68	118.46
Bulk density (g cm^{-3})	1.49	1.49	1.46	1.35	1.42	1.45
Particle density (g cm^{-3})	2.50	2.39	2.35	2.61	2.25	2.51
Total porosity (%)	38.8	36	38	48.3	63.1	57.8
Structure	fine granular	blocky, plastic or massive	medium/coarse granular	medium/coarse granular	Fine granular	Fine granular
Chemical Properties						
pH	6.4	6.2	6.2	5.9	5.7	5.5
Org. matter (%)	0.76	0.75	1.18	1.89	2.34	2.31
Ca^{2+} (cmol kg^{-1})	4.2	18.4	10.2	17.0	8.0	8.2
Mg^{2+} (cmol kg^{-1})	1.4	5.4	5.2	5.2	1.4	0.8
K^{+} (cmol kg^{-1})	0.1	0.1	0.1	0.1	0.2	0.2
Na^{+} (cmol kg^{-1})	0.10	0.12	0.10	0.09	0.14	0.15
H^{+} (cmol kg^{-1})	0.0	0.0	0.0	0.0	0.0	0.0
Al^{3+} (cmol kg^{-1})	0.50	0.48	0.52	0.88	0.0	0.0
CEC (cmol kg^{-1})	3.23	16.7	10.1	11.6	6.28	5.32
ECEC (cmol kg^{-1})	6.3	24.5	16.12	23.3	9.74	9.35
BS (%)	51.3	68.2	62.7	49.8	64.5	56.9
SAR	6.0	5.5	3.6	2.9	6.5	7.1

Erodibility (K) erosivity (R) and topographic factor (LS) and potential soil loss

The result is presented in Table 2. The soil erodibility (K) had range of 0.10 – 0.19 Mg ha^{-1} MJ mm^{-1} and rated low, whereas 0.20 – 0.29 Mg ha^{-1} MJ mm^{-1} is rated medium, indicating high erodibility of the soils to erosion (Landon, 1991). Brady and Weil (2008) reported that more easily eroded soils are associated with low infiltration rates that have K factors of 0.04 or higher. The (R) was 1186.6 MJ mmh^{-1} ha^{-1} yr^{-1} showing extreme vulnerability class (> 600 MJ mmh^{-1} ha^{-1} yr^{-1}), indicating very high vulnerability on the scale of Beskow *et al.* (2009). Brady and Weil (2008) reported that the higher the rate of rainfall, the more runoff occurs providing the means to transport detached particles. The (LS) values were highest in Ketabebe middle slope (5.933) and lowest in Obioko (2.373). Brady and Weil (2008) elucidated that, the longer the slope, the greater the opportunity for concentration of runoff water. The potential soil loss A, was highest in Ketabebe middle slope (234.7 Mg $ha^{-1}yr^{-1}$) belonging to category 5 of very high erosion potential and lowest in Kekomkolo (42.36 (Mg $ha^{-1}yr^{-1}$) belonging to category 4 of high erosion potential.

Table 2: Erodibility (K), erosivity (R), and topographic factor (LS) and potential soil loss (A)

Sampling location	K (Mg ha^{-1} MJ mm^{-1})	R (MJ mmh^{-1} ha^{-1})	LS	C	P	A (Mg ha^{-1}yr^{-1}.)	Category	Erosion potential (EP)
Ketabebe upper slope	0.20	1186.6	2.535	1	1	50.13	5	Very high
Ketabebe middle slope	0.40	1186.6	5.933	1	1	234.7	5	Very high
Ketabebe lower slope	0.24	1186.6	3.689	1	1	87.55	5	Very high
Ketabebe valley bottom	0.20	1186.6	2.868	1	1	56.72	5	Very high
Obioko	0.21	1186.6	2.373	1	1	49.28	4	High
Kekomkolo	0.15	1186.6	2.856	1	1	42.36	4	High

K-erodibilty, R-erosivity, LS-topography factor, C-crop and cover management factor, P-conservation practice factor, A-predicted soil loss.

Relationship between soil depth, predicted soil loss and soil properties

The result of the relationship between soil depth, predicted soil loss and soil properties is presented in Table 3. It shows that, potential soil loss, A, was highly positively correlated with erodibility (K) (r = 0.979** at p<0.05), silt (r=0.771) but negatively with organic matter (OM) (r = -0.597), sodium adsorption ratio (r = -0.081), sand (r = -0.581), clay (r = -0.664), saturated hydraulic conductivity (Ksat) (r = -0.439), total porosity (r = -0.582) and height (r= -0.382). Erodibility, K correlated positively with silt (r = 0.776) and negatively with organic matter (OM) (r = -0.634), sodium adsorption ratio (r=-0.138) sand (r = -0.613), clay (r = -0.634), saturated hydraulic conductivity (Ksat) (r = -0.463), total porosity (r = -0.597) and depth of gully (r= -0.453). The correlation matrix shows that, a decrease in depth of the gully led to an increase in the potential soil loss, erodibility, K, silt and clay. Also, it was found that, organic matter (OM), sodium adsorption ratio and total porosity increases as the depth of the gully increases.

Table 3: Matrix of coefficient of correlation among gully depth and predicted soil loss

	PSL	Erodibility K	OM	SAR	Sand	Silt	Clay	K_{sat}	Total P	Gully depth
PSL	1									
Erodibility K	.979**	1								
OM	-0.597	-0.634	1							
SAR	-0.081	-0.138	0.23	1						
Sand	-0.581	-0.613	.894*	0.506	1					
Silt	0.771	0.776	-0.683	-0.657	-.855*	1				
Clay	-0.664	-0.634	0.133	0.346	0.115	-0.567	1			
K_{sat}	-0.439	-0.463	.945**	0.159	.900*	-0.578	-0.155	1		
Total P	-0.582	-0.597	.954**	0.454	.922**	-0.802	0.276	.879*	1	
Gully depth	-0.382	-0.453	0.802	0.303	.905*	-0.606	-0.254	.900*	0.73	1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Conclusion and Recommendation

Gully erosion is one of the greatest challenges that most states in southeastern Nigeria States face and Ugep located in Central Cross State is no exception. The potential soil loss (PSL)

(A), was generally high especially in Ketabebe. The gully depth decreases as the potential soil loss increases. It is worthy of note that, gully formations develop in stages providing warning signs at the early stage but can be arrested with proper measures, especially if community effort is put to control the runoff from the gully heads to prevent further under cutting of the gully heads using vertiver grass for bank stabilization and catchment areas protection. Soil conservation measures such as terracing to reduce the velocity of rain especially at undulating areas and other engineering measures such as surface drainage structures (culvert or gutter) to channel water away are recommended to be carried out.

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