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Full length Research Paper

Effect of locally available materials and temporal trends on gully rehabilitation in Borodo watershed, central Ethiopia

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Abstract: Erosion by water is the most serious form of land degradation process affecting the entire world of which gully erosion is the alarming and appalling stage as compared to other forms of erosion. Gully erosion is a highly visible form of soil erosion that affects soil productivity and restricts land use in Borodo watershed. Understanding the situation, the study was carried out with the aim of evaluating the potential of locally available materials to rehabilitate gullies. The potential of locally available materials to rehabilitate gully were observed on two gullies in the watershed. The total length of G1 and G2 were 105m and 56m. The study revealed that, the introduced practice had brought a vital morphological change over both gullies. Cross sectional area, depth, lip width, and base width of the gully was reduced from 1.44 m2 to 0.9m2 and 1.54m2 to 0.94m2, 0.36m to 0.31m and 0.36m to 0.34m, 5.42m to 4.62m and 5.33m to 3.87m, 2.75m to 1.16m and 3.6m to 1.57m over the period of 2021-2022 for G1 and G2 respectively. The volume of soil deposited across each section also ranges from 69.63 to 111.01 and 35.7 to 86.24 for G1 and G2 respectively. The Volume of deposited soil (V), cross sectional area and gully depth were highly correlated to each other. V is significantly correlated with CSA (r =1) and gully depth (r = 0.99) and (r = 0.95) for both G1 and G2 and respectively. Therefore, treating gullies using locally available material needs to be strengthened for gully bank rehabilitation in the watershed by participating stakeholders

Keywords: Gully Morphology; Soil loss; Gully temporal variability

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1. INTRODUCTION

Erosion, one of the symptoms of unsustainable land management, is an important degradation process affecting the soil resource in the entire world (Herweg and Stillhartd 1999). Erosion by water is the most serious form of land degradation process and accounts for 56% of the degraded soils in the world (Sohan and Lal, 2001; Elirehema, 2001). Roughly it is estimated that 75 billion tons of fertile topsoil is lost worldwide from agricultural systems every year (Pimentel, 2000) and nearly 10 million ha of cropland worldwide is abandoned every year because of problems associated with soil erosion alone (Pimentel, 2000).

Ethiopia has also been described as one of the countries in the world with the most serious soil erosion, with an estimated total annual soil loss ranged from 16 t ha^{-1} $year^{-1}$ (Gebreegziabher *et al*. 2008) to 179 t ha^{-1} $year^{-1}$ (Shiferaw and Holden 1999) in croplands. Soil erosion specifically, water erosion in Ethiopian Highlands degrades the soil resources on which agricultural production are based (Hurni, 1985, Nyssen, 2000).

The commonly recognized forms of water erosion are splash erosion, sheet erosion, rill erosion, gully erosion and stream bank erosion (FAO 1965; Dressing 2003), of which gully erosion is the alarming and appalling stage compared with sheet and rill erosion. Gully erosion is a highly visible form of soil erosion that affects soil productivity, restricts land use and can threaten roads, fences and buildings (Nyssen *et al*. 2004; Avni 2005; Carey 2006). Gullies are common features throughout the Ethiopian Highlands. The phenomenon of gully development is not restricted to Highlands of Ethiopia, but seems to be a phenomenon on sub-continental scale in Africa (Moeyersons, 2001).

Borodo watershed, the study site is one of the areas experiencing severe soil erosion and land degradation problem. Gully erosion is one of the most severe forms of soil erosion in vertisoil dominated Borodo watershed. Therefore, this study was designed with the aims; i) to evaluate the potential of locally available materials to rehabilitate gullies and ii) to demonstrate and aware the watershed communities about severity of gully erosion and its rehabilitation.

2. MATERIAL AND METHOD

2.1 Description of the study area

The study was conducted in Borodo Watershed in the central highlands of Ethiopia, covering an area of 374 ha. The watershed is part of Awash basin which is situated at an altitude of 2210 to 2720 m above sea level. It is located at 9o 01'54'' N to 9o 04'03'' N and 38o 09' 10" E to 38o 10' 40'' E. The area is characterised by three soil types, namely, Koticha (Vertisols), Abolsi Nitisols) and Dimile (Cambisols) based on colour, fertility level and workability. The watershed receives high annual rainfall (>1100 mm) mainly, concentrated in July and August. The farming system is a typical mixed crop-livestock system on a subsistence scale. The dominant crops grown in the watershed are wheat (Triticum sp.), Tef (Eragrostis tef) and chick pea (Cicer arietinum). Livestock including cattle, sheep and equines are also an important part of the farming system.

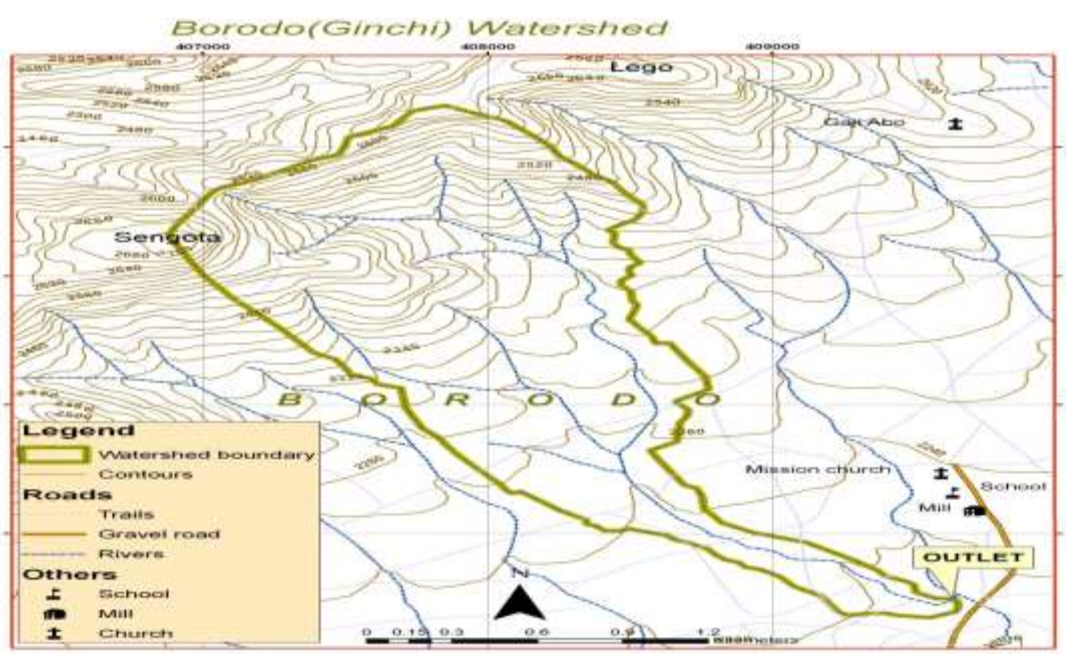


Fig 1: Map of Borodo Watershed (Demeke Nigussie, 2015)

2.2 Data Collection

Two gullies with different catchment area were treated by locally available materials; wood log chek dams and supported by biological soil and water conservation measures like vetiver grass and sesbania sesban. The length of each gully was 105m and 56m. The morphological data each gullies were being collected with the interval of two week. Width of the lip (WL in meter), Width of the base (WB in meter) and Depth (D in meter) of each gully were collected using 50m measuring tape, and pins.

The measured data's were used to calculate cross sectional area and amount of soil deposited (V in m^3) following the procedure of (Stocking and Murnghan, 2000). Soil loss (SL in t) was calculated multiplying bulk density of the soil with gully volume. The bulk density used was 1.7g/cm^3 for Vertisoil dominated borodo watershed.

$$CSA = (LW_{av} + BW_{av})/2 * D_{av} \quad (1)$$

$$V (m^3) = CSA * Length \quad (2)$$

$$V (m^3/m^2) = V (m3) / Catchment\ area \quad (3)$$

$$V (t/ha) = V (m^3) * Bd (t/m^3) * 10{,}000 \quad (4)$$

2.3 Statistical analysis

Spearman's rank correlation coefficient and regression analysis were used to examine the relationship among gully parameters. Descriptive statistics such as minimum, maximum, mean, median, and standard deviation were used to summarize gully morphological parameters. The analysis was performed using Statistics 10 and Microsoft Excel software.

3. Result and Discussion

3.1 Rainfall distribution of the study area

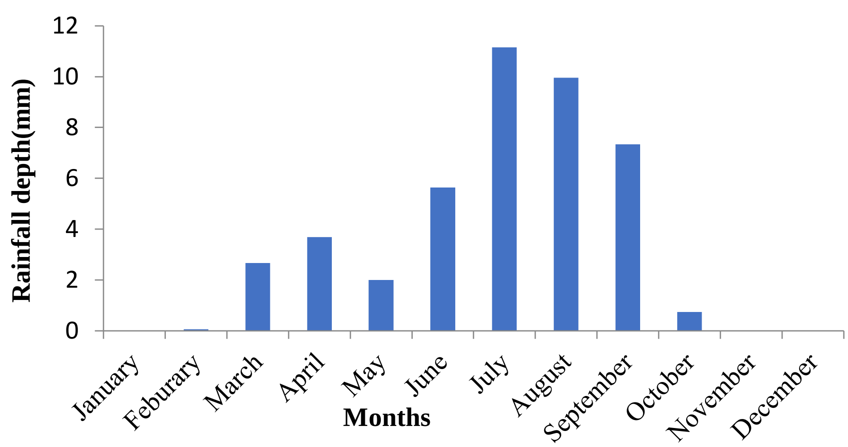


Fig. 2: Rainfall distribution of the study area

3.2 Current estimates of gully morphologies at Borodo watershed

Different morphological parameters were collected to estimate current extent of gullies. The average width of the lip, base width, and gully depth ranges from 4.6m to 4.63m, 1.1m to 1.17m, 0.23m to 0.37m and where, the mean and median values are 4.62m and 4.63m, 1.16m and 1.17, 0.31 and 0.33m respectively, where the Standard deviation of LW, BW, and gully depth was 0.015, 0.022, and 0.038m which show less variability of each parameter across the cross section for G1 (Table 1). The volume of soil deposited across each section ranges from 69.63 to 111.01 where, its standard deviation value is 11.57 which showed slight variation of soil deposition across check dams due to intervention of locally available materials.

The average width of the lip, base width, and gully depth ranges from 3.85m to 3.95m, 1.25m to 3.85m, 0.25m to 0.4m and where, the mean and median values are 3.87m and 3.85m, 1.57m and 1.3, 0.34 and 0.35m respectively where the Standard deviation of LW, BW, and gully depth was 0.035, 0.85, and 0.058m which show less variability of each parameter across the cross section of the G2. The volume of soil deposited across each section ranges from 35.7 to 86.24 with the standard deviation value of 14.66 which showed slight variation of soil deposition due to intervention of locally available materials.

The result of both gullies coincides with the gully cross sectional values for North western Ethiopia. The morphological parameters of gullies observed in this study are within the range of values reported from semi-arid part of northern Ethiopia (LW =0.35–31.90 m, BW = 0.10–19.50 m, D = 0.20–12.77 m, and CSA =0.15–236.5 m2, Frankl *et al*. 2013b, Adugna *et al*, 2017).

Table 1; Summary of current (2022) gully morphologies (n=18)

Gully	Parameters	Min.	Max.	Mean	Median	SD.
G1	Lip Width av.(m)	4.6	4.63	4.62	4.63	0.015
G1	Base Width av.(m)	1.1	1.17	1.16	1.17	0.022
G1	Gully Depth av.(m)	0.23	0.37	0.313	0.33	0.038
G1	Cross sectional area(m^2)	0.66	1.05	0.90	0.96	0.11
G1	Volume of soil deposited (m^3)	69.63	111.01	94.97	100.43	11.57
G2	Lip Width av.(m)	3.85	3.95	3.87	3.85	0.035
G2	Base Width av.(m)	1.25	3.85	1.57	1.3	0.85
G2	Gully Depth av.(m)	0.25	0.4	0.34	0.35	0.058
G2	Cross sectional area (m^2)	0.64	1.54	0.94	0.90	0.26
G2	Volume of soil deposited (m^3)	35.7	86.24	52.87	50.47	14.66

G1= First Gully (code), G2= Second gully (Code), Min. = Minimum, Max. = Maximum, SD= Standard deviation

Fig 3: Gullies at Borodo watershed (Photo taken by authors, 2022)

3.3. Relationship among Gully Morphologies

3.3.1 Gully depth and Lip width

Spearman rank correlation coefficient was used to see the relationship between gully morphologies. Gully depth and Lip width showed weak relationship on both gullies implying both parameters are controlled by different runoff process and soil types (fig.3 and 4). This study coincides with (Li *et.al*, (2017), Yibeltal, 2019a,) which showed no significant relationship between gully depth and lip widths. The relationship of Gully depth and lip width reflects environmental setting like climate, topography, vegetation, runoff discharge and Physical properties of sub and subsurface soil (Frankl *et al*, (2013a), Li *et.al*, (2017).

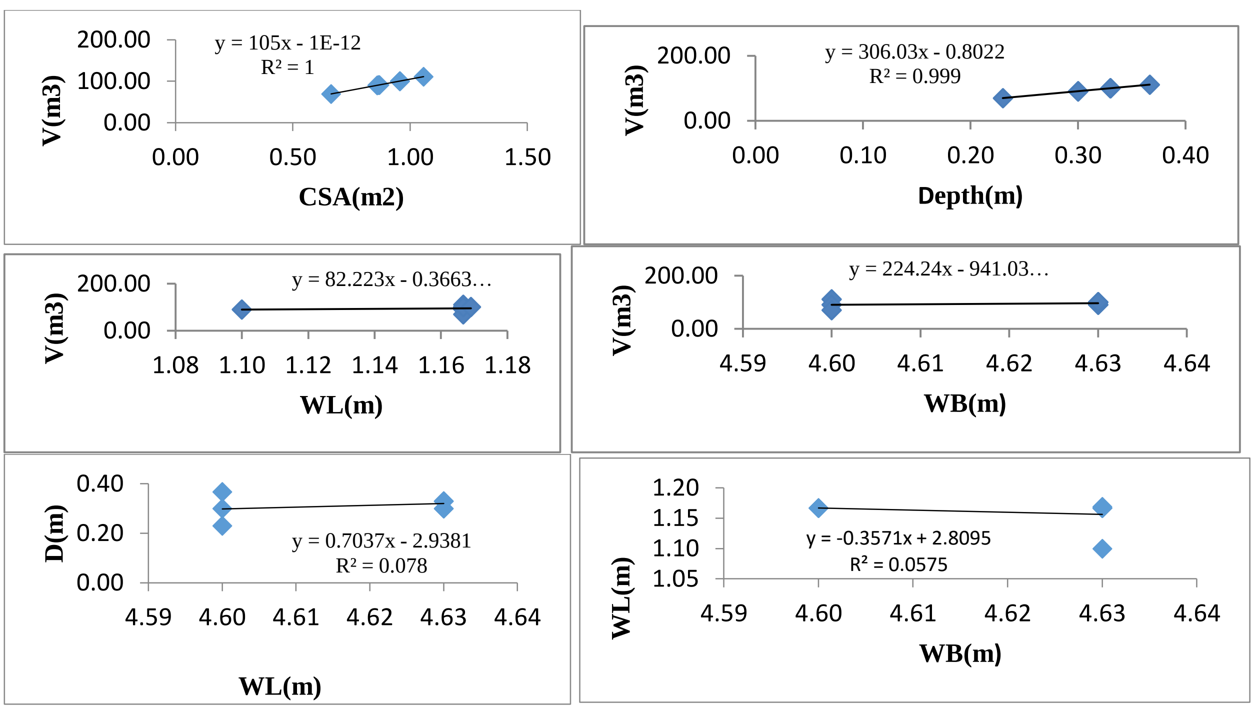
3.3.2 Gully Cross sectional area, depth and Volume of soil loss

Spearman correlation and coefficient of determination revealed strong relationship between Volume of soil deposited, Cross sectional area and depth of G1 and G2 (Table 3 and Table 4). The volume of soil deposited (V) is significantly correlated with CSA (r =1) for both G1 and G2 and also V is significantly correlated with gully depth of (r = 0.99) and (r = 0.95) for G1 and G2 respectively (Fig 1 and Fig. 2).

As the value of V is calculated from CSA and D, the higher volume of soil loss was associated with large cross sectional area and depth of the gully as shown on (Table 3 and Table 4). The result obtained from this study coincides with (Belay and Bewket (2012), Li *et al*, (2017), Yibeltal et al. (2019a) the research results.

Table 3: Spearman rank correlation coefficient of 'G1' morphologies

	$LW_{av.}$	$BW_{av.}$	$Dep._{av}$	CSA	Volume
$LW_{av.}$(m)	1				
$BW_{av.}$(m)	0	1			
$Dep._{av(m)}$	0.19^{ns}	0.34^{ns}	1		
CSA(m^2)	0.18^{ns}	0.56^{ns}	0.96^{**}	1	
Volume(m^3)	0.19^{ns}	0.56^{ns}	0.96**	1	1

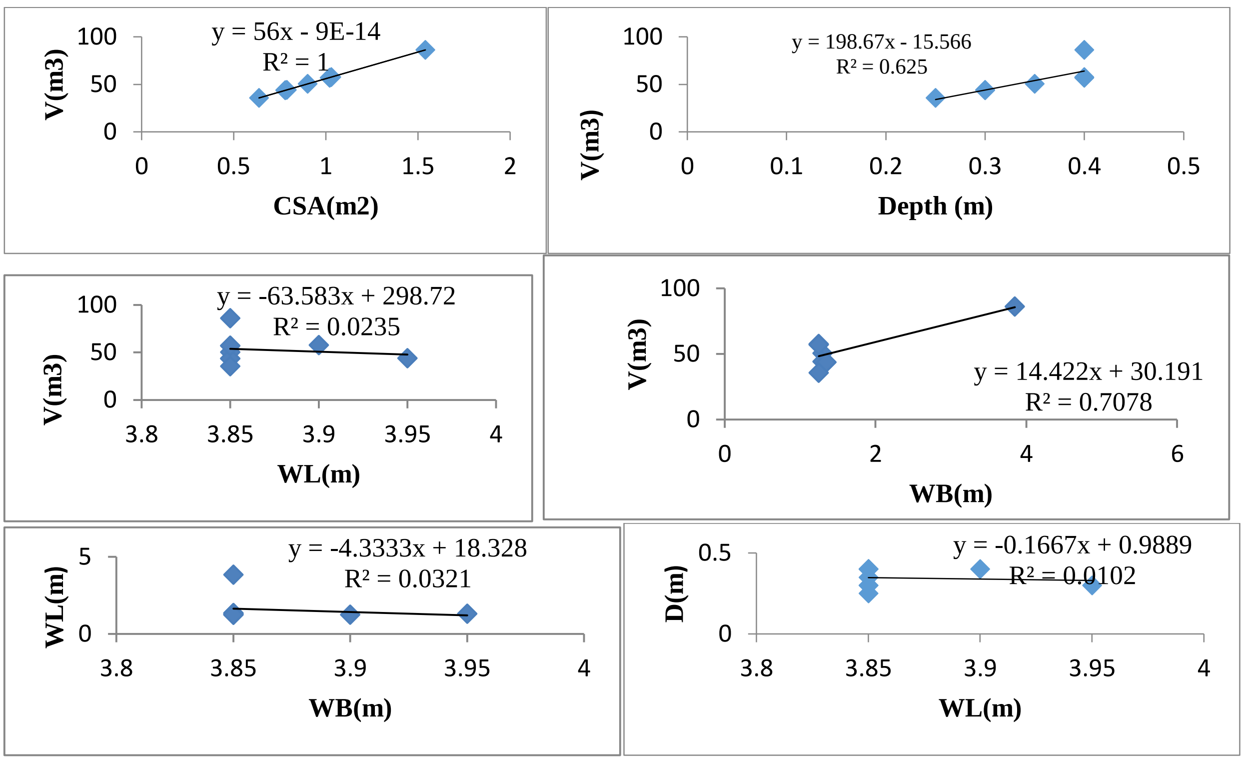


*LW_{av}= average width of the lip, BW_{av} = average width of the base, Dep_{av}= average depth, CSA = cross sectional area, V= volume of soil los, ** and ns are significant at p< 0.01*

Fig.4: Linear regression curves of 'G1' morphologies

Table 4: Pearson correlation coefficient of ‘G2’ morphologies

	$LW_{av.}$	$BW_{av.}$	$Dep._{av}$	CSA	Volume
$LW_{av.}$(m)	1				
$BW_{av.}$(m)	0.18^{ns}	1			
$Dep._{av(m)}$	0	0.18^{ns}	1		
CSA(m^2)	0.16^{ns}	0.035^{ns}	0.95^{**}	1	
Volume(m^3)	0.16^{ns}	0.035^{ns}	0.95^{**}	1	1



*LW_{av}= average width of the lip, BW_{av} = average width of the base, Dep_{av}= average depth, CSA = cross sectional area, V= volume of soil loss, ** and ns are significant at p< 0.01*

Fig. 5: Linear regression curves of gully ‘G2’ morphologies

3.4 Temporal Variability of gully morphologies

Treating gullies with locally available materials had brought significant change on gully morphologies over years. Wood log check dam, vetiver grass and sesbania sesban are of the materials used to treat both gullies. The intervened locally available materials had reduced the Lip width and Base width by 17.3% and 137.07% for G1 and 37.73 % and 129.3 % for G2 over year respectively. The volume of soil loss was also reduced by 59.42% and 68.15% for G1 and G2 which is highly related with the cross sectional area and gully depth parameters. Similarly, this result is consistent with the report of Adugna *et, al*, 2017, in North western part of Ethiopia.

Hailu et al, 2015, has also reported the potential of locally available materials with vegetative materials on reduction of soil loss and stabilizing gully from further enlargement in North western part of Ethiopia.

Table 5: Temporal trends of gully morphologies due to interventions

Gully	Parameters	Years		2021 – 2022	
		2021	2022	unit	(%)
G1	Lip Width av.(m)	5.42	4.62	0.8	-17.32
G1	Base Width av.(m)	2.75	1.16	1.59	-137.07
G1	Gully Depth av.(m)	0.35	0.31	0.04	-12.90
G1	Cross sectional area (m^2)	1.44	0.9	0.54	-60.00
G1	Volume of soil loss (m^3)	151.4	94.97	56.43	-59.42
G2	Lip Width av.(m)	5.33	3.87	1.46	-37.73
G2	Base Width av.(m)	3.6	1.57	2.03	-129.30
G2	Gully Depth av.(m)	0.36	0.34	0.02	-5.88
G2	Cross sectional area (m2)	1.59	0.94	0.65	-69.15
G2	Volume of soil loss (m3)	88.9	52.87	36.03	-68.15

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