

Community Gully Control and Rehabilitation

Field Guide for Development Agents

Imprint

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If not otherwise specified, all pictures are from Assefa Derebe Zegeye and NABU.

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1. Introduction

The Ethiopian government has been implementing a land restoration programme that aimed to restore degraded ecosystems and double agricultural productivity throughout the country since 2010. However, the success of the restoration programme has been limited due to the lack of integrating gully erosion control measures. Consequently, many reservoirs in Ethiopia and downstream riparian countries have lost their storage capacity due to sedimentation. Some studies demonstrated that gully erosion is one of the degradation hotspots within watersheds and it contributes a considerable proportion of the total sediment loads from a particular watershed (Daba et al., 2003; Tamene et al., 2006). Many of the recently constructed reservoirs will be filled with sediments already after a few years. For instance, the Gindae and Maidelle reservoirs in northern Ethiopia have lost their dead storage in less than a quarter of the expected life time (Tamene et al., 2006; Haregeweyn et al., 2013). Another example is Lake Alemaya, which was shrinked to 50% of its original size in 2003 mainly due to siltation (Daba et al., 2003), and currently does not exist.

Controlling gully erosion is more difficult and expensive than controlling sheet and rill erosion. Once formed, it requires large investments to be able to rehabilitate. It also requires extensive knowledge of the actual gully development processes in the targeted area. The gully rehabilitation practices, that do not try to deal with the actual gully formation mechanics, are inefficient. Another issue is a lack of maintenance of the installed erosion control structures (Zegeye et al., 2016). The Ethiopian landscape is a living example. Failed structures can be found in almost every gully where the treatments were attempted. Trees planted at the banks immediately collapse into the gullies. Thus, understanding patterns of gully complex development and its mitigation mechanisms in Ethiopian highlands is crucial both from a scientific perspective and for the land managers developing sustainable strategies.

Considering all mentioned above, this timely guideline aims to provide the basic knowledge, main characteristics and practical methods of gully formation. Specifically, our goals were (1) to control the channel gradient until it is stabilized by the vegetation; (2) to raise the channel base level; and (3) to stabilize channel banks in the context of overall watershed development and management.

This manual serves as practical tool for professionals and development agents working at different levels. It provides technical guidance to farmers in order to reduce the problems associated with gullies. Also, it introduces watershed managers to the actual biophysical gully treatment measures and promotes the application of effective measures for gully rehabilitation. Therefore, we kindly advice to use this manual as a guideline and learning tool that can be further developed and supplemented with growing field experiences considering the specific situation in a given area.

2. Factors controlling gully formation

Gullying is a threshold dependent process controlled by a wide range of factors (Valentin et al., 2005), including rainfall and flowing water, soil properties, and drainage area. Capra et al. (2009) and Campo et al. (2013) estimated that most of the gully erosion took place during heavy rainfall events (storms). Mechanic actions of the flowing water result in a rapid mass movement in the gullies by undercutting the banks (Figure 1) (Lanckriet et al., 2015). When the mechanic actions at the gully head exceed the cohesive strength of the soil, erosion proceeds upslope through a headword cutting gully (Munoz-Robels et al., 2010; Zegeye et al., 2016). Interactions between these processes are important because hydraulic erosion promotes bank collapse, which then modifies subsequent hydraulic erosion (Thorne, 1990; Avni, 2005). Similarly, gully formation is initiated with the occurrence of a convergent shallow subsurface flow that leads to seepage induced erosion of surface soils, gully heads and sidewalls (Figure 1f) (Vanmaercke et al., 2016; Tilahun et al., 2013a), and sliding (Figure 1d). Soil saturation by a rising water table decreases the soil shear strength (Poesen, 1993; Langendoen and Simon, 2008), and therefore destabilizes banks (Simon et al., 2000; Langendoen et al., 2013). Hence, active gully networks are predominantly found in the saturated valley bottomlands (Tebebu et al., 2010; Steenhuis et al., 2014). The largest and deepest gullies occur at the bottom of the watershed where the soil becomes saturated, starting in the middle and lasting until the end of the rain phase in (sub)humid and monsoonal climates (Tebebu et al., 2014).

Figure 1. Examples of gully expansion controlled by (a, b) bank geometry (height and slope); (c) tension cracks; (d) land slide; (e) soil pipes and (f) saturated vertisols (gully development on conservation ditches, narrow ditch upstream of gully headcut) in the sub-humid Lake Tana Basin, 2013 (Source: Assefa Derebe Zegeye)

Soil properties and soil types also play a role in gully formation and expansion. Vertisols for example, heavy clay soils with a high proportion of swelling clays (IUSS Working Group WRB, 2015), form deep cracks at the surface downward when they dry out and can develop the pipes, which later collapse and turn into large rills or gullies (Figure 1c-e) (Valentin et al., 2005; Frankl et al., 2014). This may be one of the reasons why most severe gully areas are often associated with vertisols (Valentin et al., 2005; Tebebu et al., 2014; Frankl et al., 2014). Therefore, understanding the controlling factors of gully head migration and lateral expansion is crucial for designing the appropriate gully control measures.

3. Gully development processes

It is difficult to plan the effective gully control or rehabilitation measures without a full understanding of the erosion processes and stages of gully development. Generally, a gully develops through three distinct stages: waterfall erosion, channel erosion along the gully bed and landslide erosion on gully banks. Effective gully control measures must be determined according to these development stages.

Stages		**Description**
1. Waterfall erosion	1st phase	Sheet erosion develops into rills; the rills gain depth and reach the B-horizon of the soil.
	2nd phase	The gully reaches the C-horizon and the weak parent material is removed. A gully head is often developed where the flowing water plunges from the upstream segment to the bottom of the gully.
	3rd phase	The falling water from the gully head starts carving a hollow at the bottom of the gully by the direct action or splashing. When the excavation is too deep, the steep gully head wall collapses. This process is iterative, so consequently the gully head progresses backwards to the upper end of the watershed (so-called gully head advancement) (Figure 2e). New gully branches are developing as the gully head advances backwards and crosses lateral drainage ways caused by waterfall erosion. Branching of the gully may continue until a gully network or multiple gully systems cover the entire watershed.
2. Channel erosion along gully beds		Channel erosion along a gully bed is scouring the soil from the bottom and the sides of the gully by flowing water. The length of the gully channel increases as waterfall erosion causes the gully head to advance backwards. At the same time, the gully becomes deeper and wider because of the channel erosion. In some cases, a main gully channel may reach one kilometer in length.
3. Landslide erosion on gully banks		Channel erosion along gully beds is the main cause of landslides on gully banks (Figure 1d). During the rainy season, when the soil becomes saturated, and the gully banks are undermined and scoured by channel erosion, large soil blocks start sliding down the banks and are washed away through the gully channel. At this stage gullies become deeper, longer and wider.

Table 1. Three stages of gully development

Furthermore, bank failure occurs when the gravitational forces that tend to move soil downslope exceed the forces of friction, and cohesion resists the soil movement. Banks failure may be caused by four distinct mechanisms: (1) planar failures, (2) rotational failures, (3) cantilever failures and (4) piping and sapping failures (Figure 2) (Landendoen et al., 2014). Steep banks commonly fail along the planar failure surfaces, with the block sliding downward and outward into the channel (Figure 2b). Cantilevered or overhanging banks are generated when erosion of an erodible layer in a stratified bank leads to undermining of overlying and erosion resistant layers. Banks may also fail by seepage and internal erosion, known as piping and sapping (Figure 2) (Fox et al., 2007).

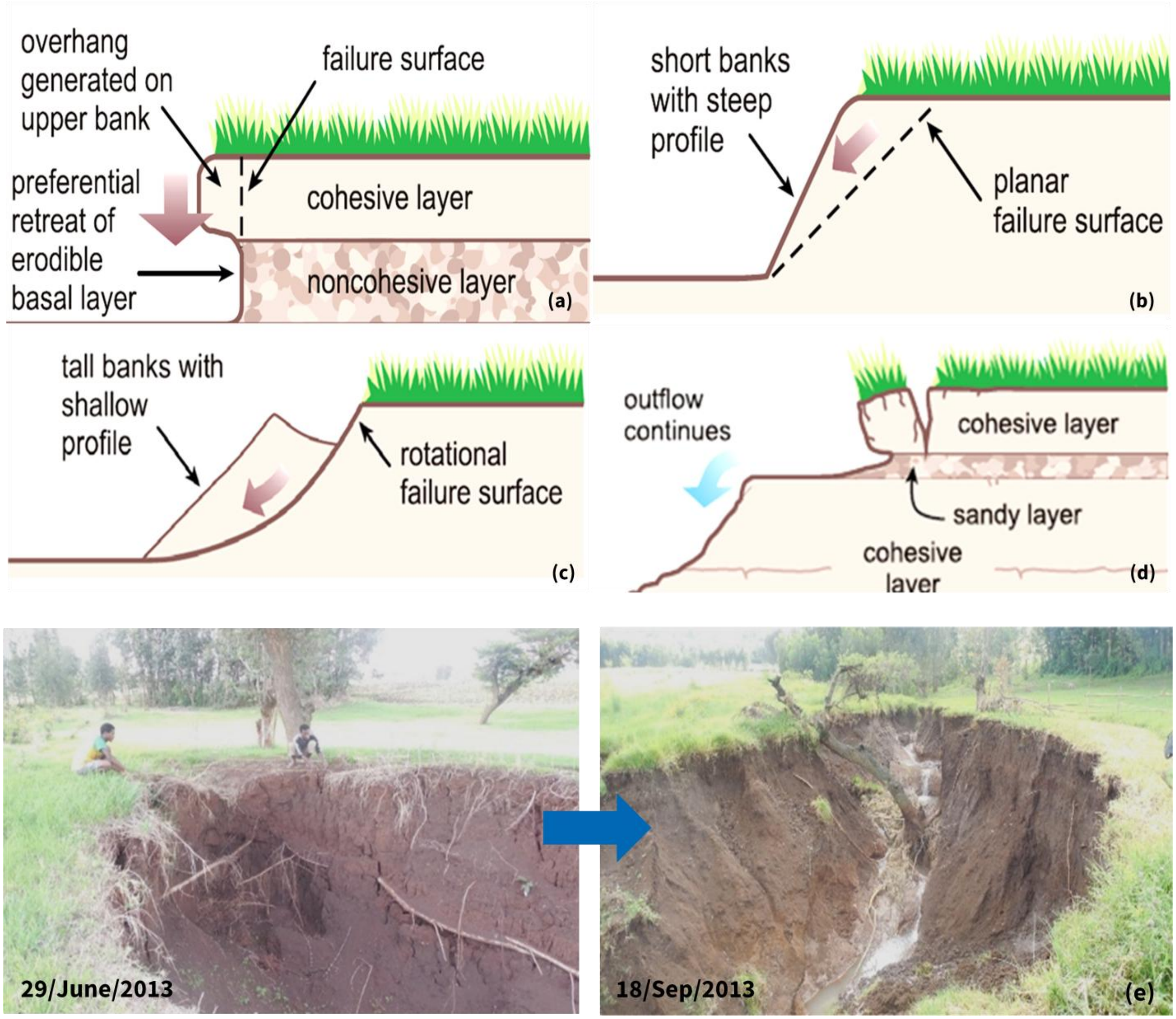


Figure 2. Bank failure mechanisms: (a) cantilever; (b) planar; (c) rotational; (d)piping or sapping ; (e) gully head advancement (increased by 25 m) (Source: Assefa Derebe Zegeye; Langendoen and Simon, 2008)

4. Classification of gullies

Gully classes based on size			Classes based on shape		Classes based on continuation	
Gully classes	*Depth (m)*	*Drainage (ha)*	*Gully classes*	*Description*	*Gully classes*	*Description*
Small gully	< 1	< 2	U-Shaped	Both, topsoil and subsoil, have the same resistance against erosion.	Continuous	A main gully channel and many mature or immature branch gullies.
Medium gully	1 to 5	2 to 20	V-Shaped	Subsoil has more resistance against ersosion than topsoil.	Discontinuous	The gully does not have a distinct junction with the main gully.The gully does not have a distinct junction with the main gully.
Large gully	> 5	> 20	Trapezoidal	The gully bottom is made of more resistant material than the topsoil.		

Table 2. Classification of gullies (Lakew and Belayneh, 2012)

5. Criteria for the selection of gully control measures

For a continuous gully, the main criteria for selecting structural control measures are based on the size of the gully catchment area, the gradient and the length of the gully channel. The various portions of the main gully channel and branch gullies are stabilized by brush fills, earth plugs, brushwood, log and loose stone check dams. The lower parts are treated with loose stones or boulder check dams. At a stable spot in the lowest section of the main gully channel (e.g. outcrop), a gabion or cement masonry check dam should be constructed. If no stable spot is available, a counter dam (gabion or cement masonry) must be constructed in front of the first check dam. The spots for the other check dams should be determined according to the compensation gradient of the gully channel and the effective height of the check dams.

General standards for selecting control measures for each portion of a continuous gully are presented in Table 3. There, the required structural measures for each portion of a main gully channel are shown in the last column. The given criteria used for selecting gully control measures should be applied for continuous gullies, gully networks or multiple gully systems located in deteriorated mountain watersheds.

Length of main gully channel portions (m)	Gradient of main gully channel portions (%)	Catchment area of gully portions (ha)	Required structural measures for each portion of a main gully channel
-	-	2 or less	*Above gully head:* Diversion ditches or channel.
100 or less (from gully head)	Various	2 or less	*Max. 100 m from gully head:* Brush fills, earth plugs, woven wire, brushwood, log and loose stone check dams. These measures can also be constructed in branch gullies.
900	70 or less	2 to 20	*Between 100^{th} to 1000^{th} m:* Boulder check dams, retaining walls between check dams. If necessary, first, one gabion or cement masonry check dam may be constructed, instead of a boulder check dam.

Table 3. Criteria for the selection of control measures for continuous gullies

6. Principles of gully prevention and rehabilitation measures

Controlling gully erosion can be an elusive process. Crucial are the planning, design and techniques employed. The ultimate success depends on a proper diagnosis of the problem, steps taken to eliminate the problem causes and drastic changes in land use to stabilize the ecosystem. The cost-benefit ratio of gully control must be carefully assessed. Some gully control measures are extremely expensive, making them unaffordable for farmers with limited resources. Therefore, gully preventive control measures must produce short term benefits by increasing land availability for cultivation and reliable crop yields through soil water usage improvements. In fact, expensive measures of gully control and/or restoration have rarely been successful. General, accurate gully control rules are difficult to establish, as gullies significantly vary, even in the same area. Therefore, reliable judgments, based on experience, are essential. Generally, placing a loose brushwood, hay, tree branches, stones, etc. in gullies does not stop erosion. Refilling large to very large gullies with soil, without diversion of the water flow, is not recommended either. Mostly, the refilled soils are less compressed than natural soils and prone to erode again. Side sloping of very large gullies does not appear to be economically efficient, as the gully sides will get naturally slanted after some years.

In gully control, the sequence of the following three methods must be applied:

(1) Improvement of gully catchments to reduce and regulate the run-off rates (peak flows);

(2) Diversion of surface water above the gully area;

(3) Stabilization of gullies by structural measures and accompanying re-vegetation.

Under a temperate climate, small or incipient gullies may be stabilized after water diversion. Hence, the third step can be skipped. However, in tropical and subtropical countries prone to heavy rains, the sequence of all three methods should be applied.

7. Gully treatment measures

7.2. Prevention of gully formation

The control of gullies is an important step in watershed rehabilitation. Fixing the valley bottom at a certain base level, by stabilizing the ground through sediment accumulation in the gully channel, reduces sediment deposition in river streambeds and, therefore, enhances the quality of water supplies. Benefits of a gully control programme accrue to both on-site and downstream users alike.

For effective gully control, the main causes and characteristics of the gully need to be intensively studied. Rehabilitation of the gully should be participatory and must include vegetative measures. Furthermore, the procedure largely depends on the treatment of the upper parts of the watershed. Gullies can contribute to enhanced local productivity by converting wastelands into productive units. They have a great potential to turn into most fertile and fruitful areas due to sediment deposits and water harvesting effects, generated by a combination of the measures within and above the gully.

The prevention of gully development in the first place is often economically more profitable, as the costs of gully control and repair are rather high compared to the value of the land. While small gullies at initial stages can still be controlled relatively easy, without stabilizing interventions they become longer, larger and deeper.

In many cases, the simplest, cheapest and safest gully control method is to divert run-off before it enters the gully (Figure 3). This practice is particularly useful on forested land and grassland, but less effective on cultivated land. Diversions constructed above the gully area redirect run-off away from the gully heads and discharge it either into natural waterways or vegetated watercourses, or onto rock outcrops and stable areas not susceptible to erosion.

The basic aim of diversions is to reduce the surface water entering the gully through the gully heads and along gully edges, and to protect critical planted areas from being washed away. Small diversion ditches, constructed either alone or with other structures such as earth plugs and check dams, are commonly used in gully control (Figure 3).

To prevent scouring along the diversion channel, the gradient of small diversion ditches must be less than 1%, preferably 0,5%. However, if there is a permanent plant cover in the channel, the gradient may be as high as 2-3%. The protective vegetation must be maintained during the entire rainy season, or the steeper gradients will cause channel erosion.

Diversion ditches should be large enough to carry all the water that is discharged from the gully catchment area during the periods of maximum run-off. In regions with particularly heavy rains, a series of check dams must be constructed along the gully channels in addition to diversions established above the gullied area.

Figure 3. The diverted flow initiated a new gully in the Debre Mawi watershed, Ethiopia, 2013 (Source: Assefa Derebe Zegeye)

When diverting water, the outlet point must be stable against erosion, to prevent the formation of a new gully (Figure 3). When the catchment area is too large, water flows can be diverted to several waterways. The design and construction of a diversion channel involves the following steps:

1. Calculate the catchment area contributing to the discharge of the gully.
2. Calculate the peak run-off rate expected from the catchment.
3. Estimate the maximum permissible velocity considering the type of soil and vegetation.
4. Estimate the gradient, size and cross section of the diversion channel.
5. Identify suitable outlet(s) for discharging water.
6. Assess the erosion conditions in the outlet drain(s) or existing gully.
7. Use the above information/analysis from steps 1 to 6 and take appropriate measures to stabilize the outlet drains or gullies.

7.3. Gully treatment with stabilization structures

Small gullies can be stabilized by reshaping them through cutting and filling. Rills and incipient branch gullies can be filled by a spade or plow. Extension can also be prevented by filling the gullies with tightly packed litter or soil covered with sods, or alternatively with loose stones. Planting grasses resistant to soil erosion is very important. However, in regions with heavy rains, filling, shaping and diversions alone will not be sufficient for gully control. Additional gully control and slope stabilization measures, such as woven wire, brushwood, logs, loose stones and boulder check dams, should be undertaken to facilitate the growth of permanent vegetative cover.

Check dams should be constructed across the gully bed to stop channel and lateral erosion. By reducing the original gradient of the gully channel, check dams diminish the velocity of water flow and the erosive power of run-off. Run-off during a peak flow can be conveyed safely by the check dams. Temporary check dams with a life span of three to eight years collect and hold soil and moisture in the bottom of the gully. Tree seedlings, as well as shrub and grass cuttings, planted in gullies can grow without being washed away by flowing water. Thus, a permanent vegetative cover can be established in a short time.

(a) (b) (c)

Figure 4. Gully headcut treatment in the Debre Mawi watershed (Lake Tana Basin) (Zegeye et al., 2017). Column (a) shows frequent discussions and trainings implemented in a watershed community for reaching a consensus on gully protection and rehabilitation; column (b) shows gully head treatment measures; column (c) shows the improvements and challenges of gully treatment (Source: Assefa Derebe Zegeye)

Gully heads are usually stabilized by building suitable check dams in front of them. The type of the check dam depends on the water falling distance from the gully head and availability of construction material. Figure 4 shows the steps of involving the local community and development agents into the process of large gully head advancement in the Debre Mawi watershed, Lake Tana Basin. Figure 4a demonstrates the first discussions in the local community, supporting the development of a sense of ownership, with tremendous benefits for sustaining the gully control interventions. Figure 4b shows the gully headcut and sidewalls reshaped to 45°, to decrease the slope and hence the bank failure. Finally, plant species such as elephant grass (*Pennisetum purpureum*) and *Sesbania sesban* planted at the banks is illustrated in Figure 4c. In addition, to dissipate the flowing energy, gabion check dams underneath the headcut and other consecutive check dams were installed downstream.

8. Design of check dams

8.1. Hydraulic requirements

The proper design of erosion control structures is of great importance for successful gully treatment. While overdesign results in extra expenditures, underdesign of one check dam can cause damage to all other installations upstream. Such damage may accelerate erosion worse than that from untreated gullies. By designing check dams, the highest expected peak flow for the period of treatment should be considered. A check dam should be keyed into solid gully banks and the channel bottom to prevent failing (as shown in Figure 5a). Since falling water endangers the channel bottom below a dam, an apron is necessary to dissipate the energy of the water reaching the bottom (Figure 5b-c). Insufficient length or quality of an apron may disrupt the installation.

(a) (b) (c)

Figure 5. (a) A gabion check dam which was not keyed properly into the solid gully banks; (b, c) A check dam constructed out of varying supplies and designed with an apron (Source: Assefa Derebe Zegeye; Lakew and Belayneh, 2012)

8.2. Calculating spacing and the number of check dams

The spaces between check dams can be determined according to the compensation gradient and the effective height for the check dams. The gradient between the top of the lower check dam and the bottom of the upper one is called "compensation gradient", which is the final gradient of the gully channel. It is formed as material carried by flowing water fills the check dams to spillway level. Field experience has demonstrated that the compensation gradient of gullies is less than 3%. Therefore, some formulas work with little practical value to compute the compensation gradient.

The first check dam should be constructed on a stable point in the gully, such as a rock outcrop. If there is no such stable point, a counter dam must be constructed. The distance between the first dam and the counter dam must be at least two times the effective height of the first check dam.

Proper placement of the check dams is determined according to the compensation gradient and the effective height of the check dams. Figure 6 shows the correct use of a clinometer, a clinometer stand, and a target in order to find the second check dam point in a gully bed. At the second point, the effective height of the second check dam is marked at the edge of the gully by taking into account the depth of the gully, the depth of the spillway, and the maximum height of the check dam.

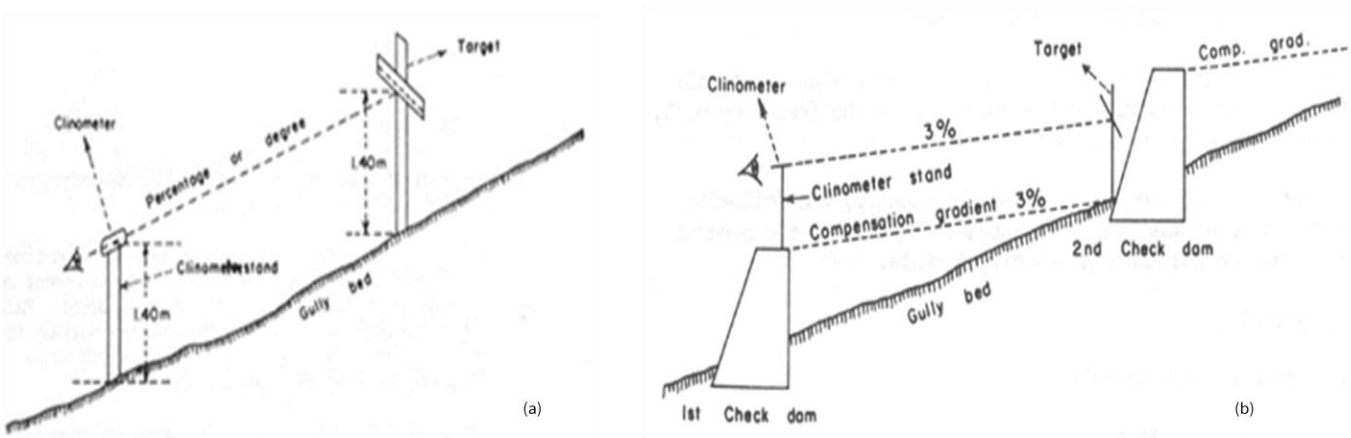


Figure 6. (a) Measuring the gradient of the gully bed; (b) measuring the compensation gradient between check dams (Source: FAO, 1991)

The stand at the second point should be marked at the edge of the gully, or another position at the same level as the marked one. As the compensation gradient measures 3%, the construction site for the third check dam has been determined. The remaining check dam points should be demarcated following the same logic.

After surveying the longitudinal profile of the gully with simple field instruments, such as clinometer (0-90°) and 50 m measuring tape, the **number of check dams** (N.O.C.D.) for each portion of the main gully channel can be calculated by using the following equation

$$N.O.C.D. = \frac{a-b}{H}$$

, where **a** is the total vertical distance and calculated according to the average gully channel gradient and the horizontal distance between the first and last check dam in that portion of the gully bed; **b** is the total vertical distance and calculated according to the compensation gradient and horizontal distance between the first and last check dam in that portion of the gully bed; and **H** is the average effective height of the check dams, excluding foundation, to be constructed in that portion of the gully bed.

Example: Let a 150 m gully channel have three approximately uniform segments (named as a, b and c having ground distances of 40, 50 & 45 m and vertical angles of 10, 20 & 15°, respectively). What are the horizontal and vertical distances of these three segments if the average effective height (H) is 1.5 m?

Solution:

HD_{10} = GD*cos 10 = 40 * 0.9848 = **39.4 m**

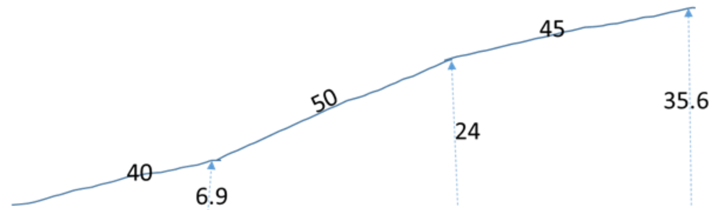
VD_{10} = GD * sin 10 = 40 * 0.1736 = **6.9 m**

HD_{20} = GD*cos 20 = 50 * 0.94 = **47.0 m**

VD_{20} = GD * sin 20 = 50 * 0.342 = **17.1 m**

HD_{15} = GD*cos 15 = 45 * 0.9659 = **43.5 m**

VD_{15} = GD * sin 15 = 45 * 0.2588 = **11.6 m**



segments	a	b	c
Horizontal distance (HD)	39.4	47.0	43.5
Total HD		130 m	
Vertical distance (VD)	6.9	17.1	11.6
Total VD		35.6	
Ave gradient		22%	
N.O.C.D.		$\frac{a-b}{H} = \frac{130 * 0.22 \ - 35.6 * 0.22}{1.5} = 21$	

Figure 7. Longitudinal profile of a gully; the calculation shows that a total of 21 check dams are required in all segments (Source:)

8.3. Estimation of maximum discharge and spillway dimensions

Estimate the maximum discharge (Q_{max}) of the gully catchment area by using the following run-off formulas:

Rational formula $Q_{max} = \frac{CIA}{3.6}$

, where $\mathbf{Q_{max}}$ is the maximum discharge of the catchment at the check dam site, expressed in cubic meters per second (cms). **C** is a coefficient that varies from 0.20 to 0.50, depending on the type of land use and topography; **I** stands for the rainfall intensity, based on the concentration time of the flowing water from the limit of the catchment to the site where the check dam might be constructed (Rainfall intensity is calculated according to the maximum (one hour) rainfall intensity (I, mm/hour), which has a frequency of 5 to 10 years for that area.); and **A** indicates the catchment area of the gully above the proposed check dam, expressed in square kilometers. **3.6** is a constant.

The rational formula can only be used when a rainfall intensity (I, mm/hour) map of the country with the frequency of 5, 10, 25, 50 and 100 years is available.

If this is not the case, discharge formulas (**Kresnik formula**) must be used:

Main Kresnik formula $Q_{max} = \frac{a\ 32\ A}{0.5+\sqrt{A}}$

Simple Kresnik formula $Q_{max} = 25\ A^{1/2}$

, where $\mathbf{Q_{max}}$ is the maximum discharge of the gully catchment at the proposed check dam site, expressed in cms. **A** represents the catchment area of the gully above the proposed check dam, expressed in square kilometers, while **a** is a coefficient that varies from 0.6 to 2.0, depending on the land use type. The simple Kresnik formula gives more suitable results for gullies with catchment areas less than 20 ha. It can also be used in torrent control (catchment 300 ha maximum). The main Kresnik formula gives better results for torrents with catchment areas greater than 300 ha.

Spillway formula $Q = CLD^{3/2}$

, where **Q** is the maximum discharge of the gully catchment at the proposed check dam point in cms. **C** is a coefficient with the value 3.0 for loose rock, boulder log and brushwood check dams, and 1.8 for gabion and cement masonry check dams; **L** is the average length of the spillway in meter; **D** is the depth of the spillway in meter.

Example

The catchment area of a gully (continuous gully) is 15 ha above the point where a boulder check dam would be built. What are the dimensions of the check dam's spillway?

By using the simple Kresnik formula, the maximum discharge can be estimated as follows:

$Q_{max} = 25\ A^{1/2}$, with $A = 0.15\ km^2$, you will get $Q_{max} = 9.675$ cms

Consequently, the spillway dimensions can be calculated with the spillway formula as follows:

$Q = CLD^{3/2}$

Using the simple Kresnik formula, and taking Q = 9.675 cms, C = 3 (coefficient for rock and brush structures), D = 0.8 for depth of spillway (varies from 0.5 to 1.5 m in general), leads to L= 4.6 m, if the depth of the spillway is accepted as 0.8 m.

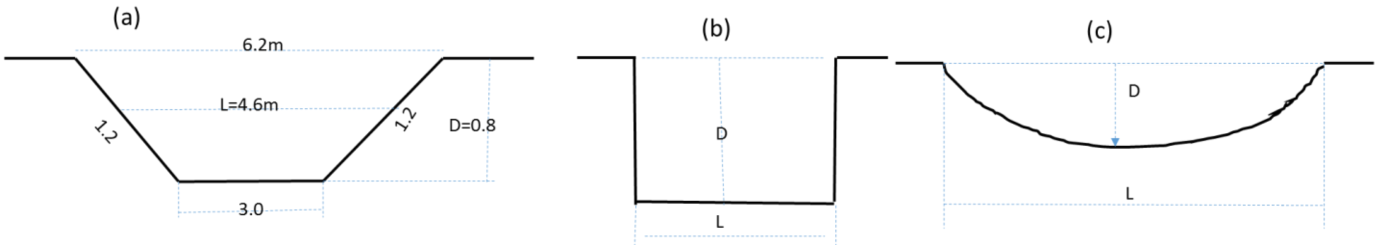


Figure 8. Common spillway forms used for check dams. (a) Trapezoidal spillway for loose stone, boulder, gabion and cement masonry check dams; (b) rectangular spillway for brushwood, log (pole), gabion and cement masonry check dams; (c) concave spillway for brushwood and loose stone check dams (Source:)

The length of the foundation always has to be longer than the length of the spillway, to prevent scouring and undermining by falling water.

8.4. Specific treatment measures

8.4.1. Loose stone check dams

Figure 9 shows loose stone check dams, made of relatively small rocks, placed across the gully. The main objectives for these dams are to control channel erosion along the gully bed and to stop waterfall erosion by stabilizing gully heads.

Loose stone check dams are used to stabilize incipient and small gullies as well as branch gullies of a continuous gully or gully network. The length of the gully channel shall not exceed 100 m, the catchment area shall stretch over 2 ha maximum. Loose stone check dams can be used in all regions.

The maximum effective height of the dam is 1.0 m, its foundation depth at least 0.5 m. The thickness of the dam at spillway level is 0.5 to 0.7 m, and the inclination of its downstream face amounts 20%. The thickness of the base is computed accordingly. The upstream face of the dam is generally vertical.

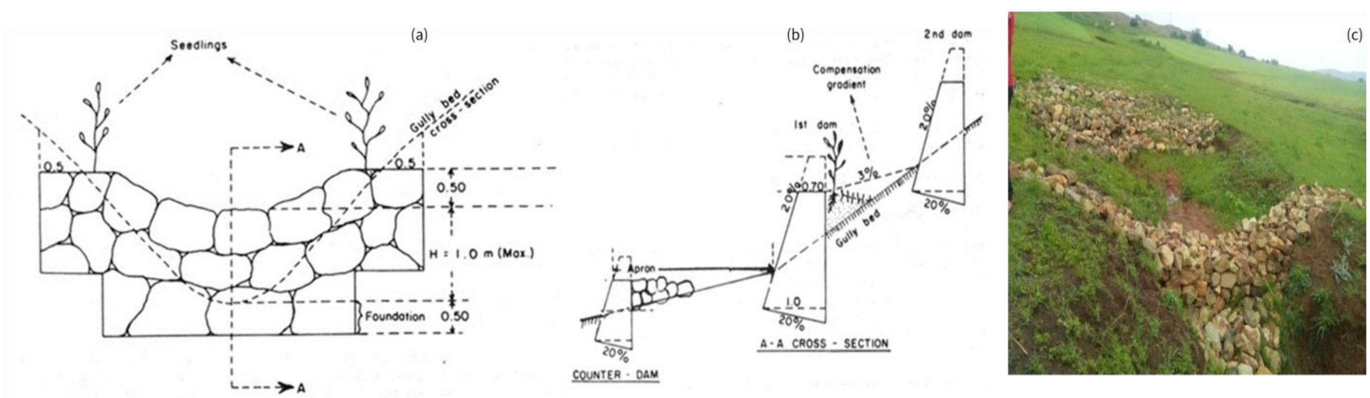


Figure 9. (a) Front view of the first loose stone check dam; (b) cross section of the first loose stone check dam and counter dam; (c) loose stone check dam constructed in a small gully head (Source: NABU;)

Further specifications for loose stone check dams:

- The dam shall be longer than the spillway. Its wings should enter each side of the gully for at least 50 cm.
- Crest and middle part must be constructed using bigger rocks than for the rest of the dam.
- The wings of the dam should be protected against flash water by the wing walls. The angle between the wing wall and the wing is 30 to 45°. The wing wall's height must be equal to the depth of the spillway. The space behind the wing walls should be filled with soil.
- Also, the spaces behind the dam should be filled with soil excavated from the gully bed, to reach spillway level.
- The spillway must be concave shaped.

8.4.2. Boulder check dams

Boulder check dams placed across the gully are mainly used to control channel erosion and to stabilize gully heads. In a gully system, or multiple gully system, all the main gully channels of continuous gullies (each continuous gully has a catchment area of 20 ha or less, and a length of about 900 m) can be stabilized by boulder check dams. These dams can be used in all regions.

The maximum total height of the dam is 2 m. The foundation depth must be at least half of the effective height. The thickness of the dam at spillway level is 0.7 to 1.0 m (average 0.85 m), and the inclination of its downstream face is 30% (1:0.3 ratio). The thickness of the base is calculated accordingly. The upstream face of the dam is usually vertical. The form of the spillway is generally trapezoidal.

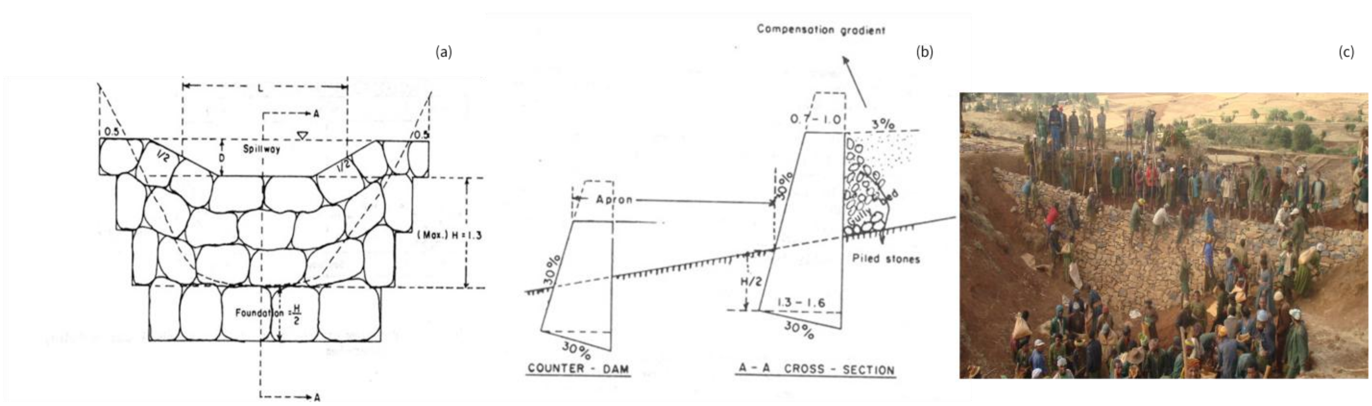


Figure 10. (a) Front view of the first boulder check dam; (b) cross section of the first boulder check dam and counter dam; (c) a boulder check dam under construction in East Gojjam (Source: Assefa Derebe Zegeye; FAO, 1991; Lakew and Belayneh, 2012)

8.4.3. Gabion check dams

In a gully network or multiple gully system, continuous gullies can be treated with structural measures (check dams, earth plugs, etc.). If the catchment area of a gully is 20 ha or less, and the length of the gully is about 1000 m, channel erosion will be controlled by boulder check dams. Still, the first check dam, and its counter dam, should be constructed as gabions. If the gully crosses a road, gabion check dams may be built above and below the road at the junction points. In addition, gabion check dams combined with gabion retaining walls can be used to stabilize landslides in the upper portions of the gully. Generally, it is neither necessary nor economical to build a series of gabion check dams to control channel erosion along the gully beds.

For dams 3 m high or less (effective height plus foundation depth)	**For dams 3 - 5 m high (effective height plus foundation depth)**
Box gabions with dimensions 1 x 1 x 2 m; 0.85 x 0.85 x 2 m; 0.75 x 1.5 x 3 m. Thickness of crest and base of a dam computations can be omitted. Box gabion stabilizes the dams against overturning, collapsing, sliding and breaking. Therefore, computations according to principles or empirical formulas are not necessary. Figure 11 shows a gabion check dam constructed by using the box gabions of 0.85 x 0.85 x 2 m.	The thicknesses of crest and base are calculated using the following formulas: *k = 0.4 H* and *d = 0.6 H, where* *k* - thickness of the dam's crest at spillway level, *d* - thickness of the dam's base, *H* - total height of the dam including foundation. These formulas provide stability against overturning, collapsing, sliding and breaking.

Table 4. Determining the dimensions of gabion check dams (see Figure 11)

The depth of the foundation is equal to one half of the effective height of the dam, which means that the foundation depth is one third of the dam's total height. The foundation is longer than the spillway. After digging the foundation, a layer of box gabions are placed vertically. The vertical sides of the box gabions are tied with binding wire of the same diameter.

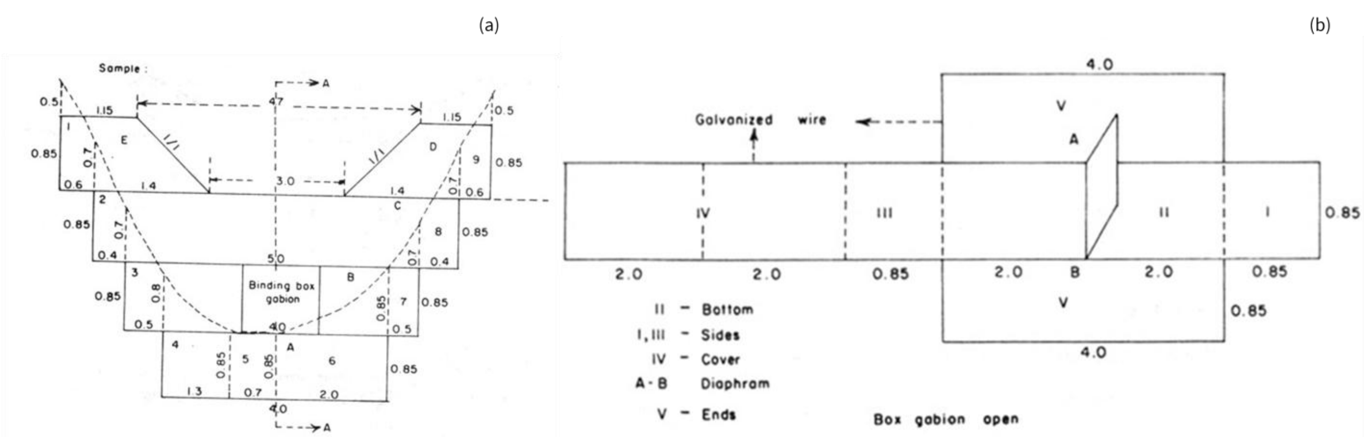


Figure 11. (a) Front view of the first gabion check dam; (b) assembly of a box gabion with a central diaphragm (Source: FAO, 1991)

The stones should be packed inside the boxes and be hard enough to withstand an abrasion, not disintegrate and resist erosion. The bigger stones should be placed along the sides of the box gabions, while the smaller stones should fill the middle sections.

2 m long box gabions should be fixed with five parallel ties between the inner and outer sides when they are one third full. Five extra ties should be placed as soon as the boxes are two thirds full. Four corner ties should be placed as indicated in Figure 11. Counter gabion dams should be constructed in the same manner as main gabion check dams.

8.5. Vegetation establishment in gully control work

All structural measures used in gully control must be accompanied by vegetation fortification for stable results.

Figure 12. (a) Planting on the reshaped part of a gully headcut; (b) gabion check dam filled with soil (top and bottom plates), and its effect after one year (Source: Lakew and Belayneh, 2012)

General principles:

- All structural measures should be completed in the dry season and accompanied with vegetative measures undertaken during the following rainy season.
- Suitable tree seedlings and cuttings must be planted in close proximity of the structural elements.
- Shrubs and grasses must be planted between the structural elements.
- Tree and grass seeds should be sown between the structural elements, in the bare gentle slopes, with a sufficient amount of soil.
- Gentle slopes do not need any structural measures and should be planted with tree seedlings, grasses and cut shrubs.

9. Maintenance and management

Maintenance of gully control structures is very important and worth to be emphasized. Treated gullies should be checked regularly and the healing process should be monitored closely to determine the needs for further installations or repairs. Structures built in the gully for stabilization purposes should be observed for damage, especially during rainy seasons and after heavy storms. Damaged check dams should be repaired immediately to avoid further damage and the eventual collapse. Collapse of one check dam will sooner or later affect other structures through the headward erosion. When repair is postponed, the damage will be larger and repairing will be more expensive. Delayed maintenance may result in a total collapse of all gully structures. Therefore, gully control should always be carried out in order to safeguard future maintenance.

10. Utilization of a rehabilitated gully

The use of a gully will depend on whether it has been established as a protected waterway, or the water has been diverted and the gully was stabilized for other uses. When the water is discharged through the gully, after the necessary stabilization activities, the gully can be used for grass or fodder planting, even for growing horticultural crops such as banana or other fruit trees. Wide gullies can maintain trees planted on the side slopes, provided they are not too steep.

The other important issue for a sustainable gully rehabilitation scheme is the identification of users and the development of a use concept or management plan. In most cases, gullies are crossing private lands with different land owners. Therefore, before gully treatment, the users should be identified, and the boundaries should be clearly demarcated. The gully rehabilitation process should be objective, and responsibilities of owners should be elaborated and agreed upon concerning the management, maintenance, and utilization of the gully and its produces.

Practical experience has shown that most of the gully rehabilitation efforts are made accidentally, without having clear purposes. As a result, it is common to see gullies with a large, non-harvested single species biomass (*Sesbania sesban* or elephant grass), with unknown land users. This has forced the community members into conflict and further destruction of the whole endeavor.

Considering all mentioned above, the identification of gully owners and demarcation of their boundaries should come before any treatment effort. Further preliminary efforts are the development of a management plan and formulation of user agreements on maintenance and proper utilization of the gully. It is crucial, before making decisions about gully control measures, to plan the gully after-treatment purposes and to undertake measures relevant for the future strategy.

11. Checklist for gully control development

This checklist aims to help development agents, or other practitioners, to guide the future gully control. We recommend using this checklist to mitigate and rehabilitate gullies, and gradually transform them into productive lands. However, this checklist should not become the only ultimate guideline. We also encourage the user to refer to other documents for future practices.

No	Title		Yes	No	Remark
1	Is the gully system continuous or discontinuous?				
2	Have you estimated the size of the gully?				
3	Have you determined the critical locations in the gully system?				
4	Have you determined the controlling factors of gully erosion?				
5	Which bank failure mechanism(s) is/are observed?	Cantilever?			
		Planar?			
		Piping or sapping?			
		Rotational?			
6	Have you discussed the gully history, and ideas how to control it, with the local community?				
7	Have you estimated the highest expected storm run-off for the structural treatment period?				
8	Have you estimated the highest expected peak flow at all structural sites?				
9	Does your design structure accommodate this flow?				
10	Have you controlled gully headcuts (applied for discontinuous gully only)?				
11	Have you lowered the channel segments with structures near the gully mouth?				
12	Have you started structural treatment at the gully mouth (applied for continuous gully only)?				
13	Have you placed the strongest check dam at the gully mouth?				
14	Have you installed structures below headcuts located in the channel bottom?				
15	Have you treated critical locations of a gully, such as sharp curves in meandering gullies or gully headcut?				
16	Did you not deflect the flow towards the channel bank?				
17	Have you selected suitable plant species for different parts of the gully (channel, edge, bank side)?				
18	To reduce the amount of soil movement/bank failure, have you re-graded the sharp bank?				
19	Have you inspected the treated gully periodically, to determine needs for maintenance and further control measures?				

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