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Erosion-control interventions associated with pond-catchment rehabilitation on the Borana plateaus, Southern Ethiopia

Abstract

Among the major problems of Borana pastoralists are scarcity of potable water inside dry season and gully erosion in a widespread on the Borana plateau. Gullies are the main pathway for sediment accumulation in community ponds, which reduces pond capacity. Ponds are therefore a critical source of water during dry seasons the Borana rangelands. However, most ponds rapidly fill with sediment from eroding catchments after rainfall events and hence, their water holding capacity gradually get reduced. Much work is then required each year from the communities to remove sediment manually. Erosion of pond catchments is the consequence of uncontrolled grazing that causes heavy grazing and trampling by livestock. Sediment movement in gullies can be substantially reduced by installation of sieve structures that slow down water flows and allow sediment to settle out of suspension. Sieves can be easily constructed from trees by community labour at low cost. Yabello researchers have demonstrated that a series of sieve structures down a secondary gully in Bunaka and Liban Jatani pond that effectively trap sediment. When gully head treatments are accompanied by a series of sieves in the main channel, gully erosion can be arrested, gully floor and walls re vegetated and sediment captured. *Overall, protection of grazing land from livestock reach for only one year led to a 55.45% increase in ground cover. Similarly, increases in cover tended to be greater (118.1 % more) at Liban Jatani pond that had less cover at the beginning when compared to Bunaka pond.* Protection from livestock grazing led to substantial increases in ground cover. Within the Liban Jatani pond enclosure, ground cover steadily increased at each sampling period by 7.1% in June 2019, 11.13% in November 2019.

Keywords: Erosion-control, interventions, pond-catchment, rehabilitation, Borana plateaus, Southern Ethiopia

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Introduction

One of the major problems of Borana pastoralists is scarcity of potable water for both human and livestock inside dry season in general and periodic drought wet season in particular. Ponds are therefore a critical source of water during dry seasons the Borana rangelands. Inside wet season, ponds capture run-off water that remains available in dry season. However, most ponds rapidly fill with sediment from eroding catchments after rainfall events and hence, their water holding capacity gradually get reduced and finally changed to green water. Erosion of pond catchments is the consequence of uncontrolled grazing that causes heavy grazing and trampling by livestock.[1] Much work is then required each year from the communities to remove sediment manually.[2] This participatory action research project should contribute to "improve the pond catchment vegetation cover, rehabilitate the gully erosion in the catchment and increase the pond water holding capacity to reduce water shortage during dry season for pastoralist communities in Borana Zone through community participation and locally available materials."

To this end, the following research objective has been defined: Apply, assess and generate knowledge on the effectiveness and sustainability of a combination of available technologies to:

a. rehabilitate pond catchment,

b. reduce siltation of ponds,

c. improve the water holding capacity and the water quality of the ponds,

d. increase the vegetation cover around the pond, continuously inform the development on effective technologies for improved practices and outcomes.

Methods and study site

The study was conducted in some selected districts of Borana Zone namely: Dillo, Dhas and Miyo in Figure 1.

Figure 1 Study site picture taken from Google map.

To achieve this, this participatory action research project adopted and assessed a three-pronged approach to alleviating the pond siltation problem:

i. Component 1: Fencing of catchment perimeters to protect direct access to livestock and human beings in order to restore vegetation in soil bank, so that sediments can be trapped before they can reach the ponds

ii. Component 2: Manually over sowing of highly degraded areas of the catchment parts;

iii. Component 3: Installing sieve dams to capture sediment in gullies before it can enter the pond and reducing erosion in the immediate vicinity of the pond.

*The participatory action research project was implemented in two demonstration ponds in Gayo Pastoral Associations (*Liban Jatani pond and Bunaka pond).

Treatments and check for component 1: fencing to protect/restore vegetation

In March 2019 we erected thorn-bush fences to enclose catchments surrounding the two demonstration ponds in Gayo Pastoral Associations. The fencing was realised just before the long rainy season. The originally enclosed areas ranged from 8 to 10 hectares (ha). However, in the Liban Jatani pond enclosures were extended with additional fencing in August-September 2019, at the start of the short rainy season. This extension was done by the pastoralists themselves after they have been seen impact changes of the treatments. *The purpose of the fence was to prevent unregulated livestock access and allow recovery of vegetation to trap sediment before it could reach the ponds.Livestock could still access the water, however, via a corridor leading to the pond edge. This controlled livestock movement should allow for vegetation recovery elsewhere in the catchment. An increase in the vegetative cover should intercept the overland flow of rainwater and trap suspended sediment before it could reach the ponds. In effect, the pond enclosures would resemble kalo (traditional fodder banks) that have been created by the Borana in recent decades to conserve forage elsewhere in the system. Kalo also are known to improve the forage base after one or two years of protection from grazing. The effects of protection from grazing in pond catchments should be much greater than those observed in kalo, however, simply because pond catchments are landscape sinks where water and nutrients accumulate.* On visiting the enclosures in May 2019, just two months after they were fenced, the ecological improvement inside the fences was already evident after one rainy season. *In June 2019 a baseline data sampling program was introduced to quantify ecological improvements evident after the first rainy season.*

Sampling methodology and data collection

To quantify the effects of fencing on vegetation, a baseline data sampling was implemented in June 2019 after the long rainy season and repeated in November 2019 after the short rainy season. Permanent 1m^2 quadrant plots were established in two zones within the enclosed areas of the ponds and in one zone outside the fences as a control. The zones are described in more detail below. At least 3-6 plots per zone were established and marked with wooden pins. In Liban Jatani control plots became protected from livestock after the enclosures were extended by the pastoralists in August/September 2019. The quadrants were sampled for ground cover (%), species richness, species diversity, relative density and herbaceous relative frequency.

Sampling zones: Within a pond enclosure, there sswere two sampling zones which corresponded to decreasing density of vegetation (Figure 2A).

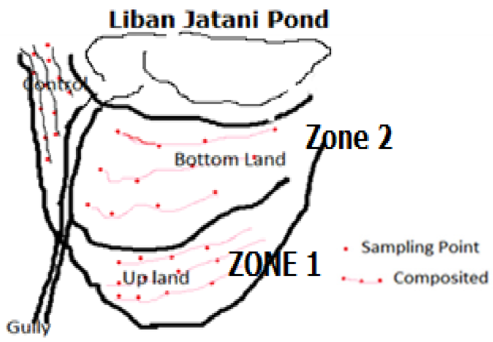

Figure 2A Layout of quadrant zones at Liban Jatani Pond based on homogeneity.

a. **Zone 1** was largely bare ground when the enclosure fence was established and matches the degraded control area outside the fence.

b. Zone 1 outside the fence was referred to as "Control", **Zone C**.

c. **Zone 2** was closer to the pond and had upland patches of partial but incomplete vegetation cover at the time the enclosure was established. By "upland", we mean parts of the land without depressions or small gullies where water flow is concentrated. It tends to be flatter land that is raised above the network of gullies and depressions.

d. A minimum of 3 to 6 plots in each zone data were recorded.

e. Establishment of sampling plots was done in concentric zones around the pond center. The outer zone inside is a treatment match for the control area in a zone immediately outside the fence. No attempt was made to find open-area controls for more vegetated zones close to the pond.

f. Four to six plots were located outside the enclosure boundary as a set of "controls." In Liban Jatani control plots became protected from livestock after the enclosures were extended. By "upland" areas or patches we mean parts of the land without depressions or small gullies where water flow is concentrated. They tend to be flatter land raised above the network of gullies and depressions. Based on observations at Liban Jatani pond, a "patch" is as small as 4m^2 or as large as 20-30m^2.

Sampling techniques

Upon the commencement of the participatory action resarch activity, attribute samples of grass and forbs species were collected from randomly drawn quadrants of 1m x 1m to determine the herbaceous species diversity, richness and ground cover of the study areas. Then, using a visible and permanent pin, each drawn quadrants purposively monitored for two sampling periods.

Species diversity and richness

Species diversity and richness was determined for both enclosure and open grazing land of the study area. The species richness refers to the number of species in a particular area and species diversity refers to a combination of richness and relative abundance .There methods were utilized to comprehend more information about ground community composition and relative abundances of different species.

Ground covers (%) estimation

The proportion of bare ground and ground cover per unit areas for herbaceous species estimated from 1m x 1m quadrants. Surface

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ground cover of herbaceous species was estimated by dividing selected quadrants into halves and again dividing into eight. All grounds in the selected areas of 1 m² were further removed and transferred to eighth in order to facilitate visual estimation of living ground cover. The estimation of ground cover recorded for each quadrant to compare ground cover of enclosure and open grazing lands.

Data collection for component I

Data were collected for the following parameters: data collected for the various Participatory action research activities under different components includes, ground cover, species diversity, relative density, species richness and herbaceous relative frequency.

A. Data collected for ground cover

Permanent 1m² plots were sampled for both ground cover (%) and species richness at the time of sites study site establishment June 2019 at onset of long rainy season and data for the mentioned parameters were collected again in November 2019 as offset short rainy season. Within one zone or subzone, at least six quadrants were located in order to sample an area representative of the zone class. A thorough inspection of the area was reveal patches of upland that form a relatively homogeneous group, according to the criteria developed to define a zone or subzone. As the inherent variability of a class of patches increases, more than 6plots were desirable, up to 12 for the sake of efficiency. In the intervals between sieves dams (Zone S) there may not be sufficient area of homogenous features for the location of 6 quadrants. In such circumstances, reduced number of quadrants to 3 or 4 within a sieve dam interval was used. Foliage cover (%) data recording were principally performed as % of ground that is covered by foliage when the leaves in their natural position (natural "habit") are projected vertically onto the soil surface. For quadrants that were completely or mostly bare ground, most if not all of the 100cells won have no data entered. For cells that have leaves within the boundary, the area of the cell covered with foliage was visually estimated. If a ground is rooted within a box, an "R" is placed in that box. To complement the data record, photos were taken immediately above the 1x1 m plots and connected to the plot data form.

B. Data collected for species diversity

Cover, with the species identified, was estimated as identified referring, in the interspaces between structures, in initially bare areas with no grounds evident and in matching areas that are mostly bare ground but have scattered small grounds.

C. Data collected for species richness

Permanent 1m² plots were sampled for **species richness** at the time of establishment (June 2019), in November 2019 after the short rains. Within one zone or subzone, at least six quadrants were located in order to sample an area representative of the zone class. Exhaustive inspection of the area was revealed patches of upland that form a relatively homogeneous group, according to the criteria developed to define a zone or subzone. As the inherent variability of a class of patches increases, more than 6 plots were desirable, which extended up to 12 for the sake of efficiency. In the intervals between sieves dams (Zone S) there may not be sufficient area of homogenous features for the location of 6 quadrants. In such conditions, reduced number of quadrants to 3 or 4 within a sieve dam interval was used.

Data analyses for component I

In identifying the responses of pond catchment rehabilitation work regarding herbaceous species diversity and richness of the enclosure and open were analysed using PAST version 3.10, Paleontological Statistical software.[3] In addition, glm procedure of SAS version 9,[4] was used to identify the variation existed between before and after treatments and across locations. Sieve dam is a kind of soil and water conservation structure made of tree branches. Sediment movement in gullies can be substantially reduced by installation of sieve structures that slow down water flows and allow sediment to settle out of suspension. For these we measure with graduated stick ruler above the ground and marked it with wire at for its visibility (Figure 2B). We were try to use wood pin as mark for its visibility but most pins were wash by runoff and we choose sieve pole as a bench mark for permanent visibilities. Some gullies out enclosure were left without installing sieve dam structures and used as check for comparison.

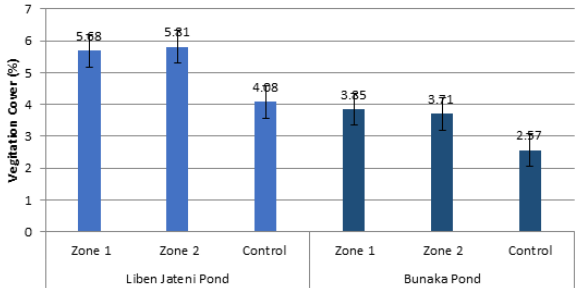

Figure 2B Ground cover % change at Liban Jatani and Bunaka pond catchment in different zone of Enclosure VS open grazing areas during Jun, 2019.

A "soft" gully intervention: sieve structures

The concept of a "sieve structure" is to slow down gully water flows, not stop them. When the speed of water is reduced, the heaviest suspended particles in the stream settle to the bottom. With further slowing of water flow, the next largest particles precipitate out of suspension and sink into sediment. Posts or 'stubs' cut from the main tree-stem are placed upright across the gully, buried into the gully floor and rising 50-150cm above it. Gaps of 10-15cm are left between the upright posts. Branches are then packed horizontally upstream against the row of posts. If sprigs of aloe grounds can be harvested from the neighbourhood, they should be grounded among the posts where they will grow. Similarly, if stubs from *Commiphora* trees are available to be incorporated into the row of posts, they too will sprout and together with aloe sprigs form a living sieve.

Monitoring protocols of sieve dam strictures

The sieve dams were inspected before and after the rainy seasons, and preferably after each major rainfall event, and observe their effectiveness in slowing down water flow in the gully. A scoring system was developed to monitor sieve dam effectiveness, with both descriptions and illustrations for each score unit. For example:

a. A 100% effective sieve dam will have slowed down water flow so that most of the suspended sediment is deposited on the upstream side of the dam.

b. A mature and fully effective sieve dam will have vegetation growing across the gully bottom on the upstream side of the dam, with some vegetation evident on the down-stream side as well.

c. A less effective sieve dam will show accumulation of branch and litter debris against the barrier, but water with suspended sediment is still flowing through or around the dam. Some sediment is being deposited on the downstream side.

d. An ineffective sieve dam will have openings at gully-bottom level that allow water and sediment to flow through easily.

The control zone for monitoring sieve dam effectiveness is an area outside the enclosure with matching gullies that have not received sieve dams. Monitor sediment accumulation behind sieve dam's vs sediment in control gullies. Among the essential components to managing the erosion problem: rehabilitating the landscape to control the source of soil loss, and reducing sediment flow through the gully system.

Data collection for component 3

Baseline data on soil erosion status during installation of sieve dam structures in reducing sedimentation were collected. The collected data were including the gully length between consecutive sieve structures, the mean width of the gully and depth of sediment. The intent was to compare the volume of sediment in a gully section before and after a rainy season. But soil erosion data after rainfall will be collected after coming rainfall season. However, we have been roughly seen while some others data collection works. In general, the sieves in the relatively short secondary gully had maintained their structure, serving to slow gully flows and capture sediment. The six sieves in the deep part of the main gully in Bunaka pond all failed. The packing branches had washed away and only some of the upright stubs remained (Figure 1). This is not a surprising result. No attempt was made to manage the head of the Bunaka pond main gully system near to control water flowing down its long straight length.

Results

Soil and climate characteristics

Soil physicochemical properties of the experimental site

Summary of analyzed soil physical and chemical properties of the experimental site is given in Table 1. Accordingly, sandy clay loam and sandy loam soil texture the most dominant soil in the area. The experimental site has 25.06% and 11.16% field capacity (FC) and permanent wilting point (PWP) respectively.

Overall, protection of grazing land from livestock reach for only one year led to a 55.45% increase in ground cover (Table 1). Similarly, increases in cover tended to be greater (118.1% more) at Liban Jatani pond that had less cover at the beginning when compared to Bunaka pond. In addition, protection from grazing improved ground biodiversity. Perennial grasses responded dramatically to protection, which enlightened the advantage of pond catchment rehabilitation technique in boosting dry matter availability. Given that the main stay of life in Borana predominantly depends on livestock and their products the result obtained indicated a paramount importance of pond rehabilitation work for the wellbeing of pastoralists.

Table 1 Characteristics of the experimental soil (0–20cm, composite soil)

Soil parameters	%
Sand (%)	65.33
Silt (%)	9.33
Clay (%)	25.3
Texture Sandy clay loam Sandy loam	
Soil pH	7.24
Electrical conductivity (dS/m)	0.77
Organic matter (%)	0.9
Bulk density (g/cm3)	1.42
Field capacity vol. (%)	25.06
Permanent wilting point vol. (%)	11.16
TAW (mm/m)	139.1

The results of potential evapotranspiration were computed by using Penman-Monteith method (Tables 2&3)

Results of ground cover

Protection from livestock grazing led to substantial increases in ground cover (Table 1). Within the Jatani Liban pond enclosure, ground cover steadily increased at each sampling period. Mean ground cover was 7.1% in June 2019, 11.13% in November 2019. On average, ground cover increased nearly by 55.45% more cover in Nov 2019 as response to pond catchment rehabilitation that extended over 6 months period (between June 2019-Nov 2019).

Overall mean with standard error of various zones around both Liban Jatani and Bunaka pond enclosures is presented in Table 2. Experimental zones closest to the pond which is Zone 2 for Liban Jatani and Zone 1 for Bunaka ponds verified 42.4% and 49.8% more percent ground-cover than their respective control. The result obtained showed a significant ($p<0.05$) ground cover (%) because of closeness to pond at Liban Jatani pond and land feature (slope) at Bunaka pond. Comprehensively, the trend of ground cover found significant ($p<0.05$) ranging from 2.43.4% to 6.14% over two sampling periods respectively, in June 2019 and November 2019. The enclosure at Liban Jatani pond was extended outwards during August and September 2019 by the pastoralists themselves showing the extent of recognition intervention given by pastoral community regarding the importance of the intervention (Figure 2B).

Table 2 Mean monthly wind speed, relative humidity and sunshine hours

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
WS (m/s)	1.39	1.63	1.74	1.44	1.05	1.01	1.04	1.21	1.44	1.22	1.22	1.18
RH (%)	35.38	36.87	42.01	60.01	64.65	60.74	57.78	52.99	51.29	58.75	58.38	44.21
SH (hrs)	8.76	8.38	7.74	5.73	5.06	4.04	2.63	3.69	4.92	4.79	6.14	7.93

Note: WS-wind speed; RH-relative humidity; SH-sunshine hours

Results of ground species diversity

Altogether, 19 species were recorded inside the drawn the quadrants. Both species diversity and species richness, expressed as the average number of species per study site, showing steadily increments through time: 7 species in the first sampling period rose to 12 species in November 2019 showing 58.33% increments in response to employed intervention. Due to only enclosing, the control quadrants showed an increase in average species number ranging from 5.5 to 11.5 species over the two sites on the 2 sampling dates. The increase in the species diversity of control plots, however, is partly attributable to the enclosure extensions in August-September 2019 that brought many control quadrants inside the protective fencing. The most widespread species in each of the two enclosures were perennial grasses such as *Sporobolus pellucidus* (Tables 3&4). The most common non-grass species were *Barleria spinisepala*, and *Lippia carviodora* sp. There is great floristic variation across the Liban Jatani pond enclosures; some species appeared in only 1 or 2 enclosures while some species occurred more frequently in one zone rather than the other. Henceforth, significant changes have been observed between enclosure with treated pond catchments and open pond catchment without treatments, among many herbaceous species richness were seen (Table 2).

Table 3 Potential evapotranspiration calculated using FAO Penman-Monteith method

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann.
MMMxT	28.36	29.14	28.24	26.04	24.89	24.69	24	25.03	26.25	25.58	25.93	26.79	
MMMiT	12.65	14.18	15.65	16.16	15.53	14.68	14.13	14.18	14.94	15.63	14.38	13.06	
WS (km/d)	135	158	170	140	102	98	101	118	140	118	118	115	
RH (%)	35.38	36.87	42.01	60.01	64.65	60.74	57.78	52.99	51.29	58.75	58.38	44.21	
SH (hrs)	9.9	9.4	8.7	6.4	5.7	4.5	3	4.2	5.5	5.4	6.9	8.9	
SR	23	23.3	23	19.2	17.5	15.3	13.3	15.5	17.8	17.3	18.7	21.1	
Eto (mm/d)	4.99	5.44	5.53	4.31	3.67	3.36	3.12	3.65	4.24	3.85	3.96	4.36	1533.58

Note: MMMxT-Mean monthly maximum temperature (°C); MMMiT-Mean monthly minimum temperature (°C); WS-wind speed; RH-relative humidity; SH-sunshine hours; SR-solar radiation ($MJ/m^2/d$) and Eto-Evapotranspiration (mm/d)

Table 4 Means of ground % cover in associated with ponds at two locations as offset of long and short rainy season

Factors	N	Ground Cover % (Mean±SE)
Location	48	***
Liban Jateni Pond	30	12.54±0.26[a]
Bunaka Pond	18	5.75±0.15[b]
Season	48	***
Main rainy (Jun. 2019)	33	7.16±0.15[b]
Short Rainy (Nov. 2019)	15	11.13±0.27[a]

[1]Means with different letters are significantly different

[2]P<0.001=***

Table 5 Means of ground % cover in associated with sampling zones at two locations as offset of long and short rainy season

Factors	N	Ground Cover % (Mean ± SE)
Location	66	***
Liban Jateni Pond Zone 1	15	5.68±0.17[a]
Liban Jateni Pond Zone 2	15	5.81±0.17[a]
Control	15	4.08±0.17[b]
Bunaka Pond Zone 1	7	3.85±0.27[b]
Bunaka Pond Zone 2	7	3.71±0.27[b]
Control	7	2.57±0.27[c]
Season	66	***
Main rainy (Jun. 2019)	42	2.43±0.10[b]
Short Rainy (Nov. 2019)	24	6.14±0.17[a]

[1]Means with different letters are significantly different

[2]P<0.001=***

The analysis at both pond catchments also revealed that pond perimeter enclosure with different treatment is high herbaceous species diversity than open pond catchments (Figures 3&4). Nineteen grass species were recorded across the two enclosures, of which 18 were perennials. As noted above, three of these were common species, and altogether they gave the vegetation a characteristic "grassy appearance." At the first sample, only 8 perennial grasses were found in the quadrants. By the second sample that number had risen to 15 species, and another 3 perennial grasses were observed in June 2019. Eleven species were recorded for the first time in November 2019 in Liban Jatani pond closure (Table 4). In contrast, only 8 species recorded in June 2019 were not evident in the following November sample.

Comparing pond catchments mid-term results of treatment and without treatments have substantial variance in terms of ground cover (Table 1). However, these parameters are the very important for soil microbial activity found in the soil that in turn results regeneration of herbaceous found in the soil seed banks. Ground cover is directly proportional with that of soil erosion and soil compaction means increase when soil erosion and soil compaction decreases and vice versa due sieve dam structures installed (Figure 5). As reported by Demisachew and Mihret,[5] integrated catchment management improves soil fertility which results soil infiltration capacities.

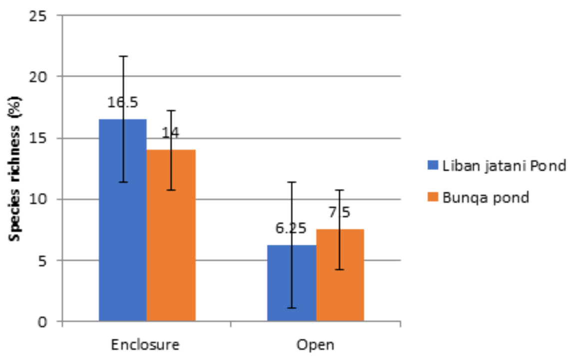

Figure 3 Mean value of herbaceous species richness at Liban Jatani and Bunaka pond catchment VS open grazing areas during Jun, 2019.

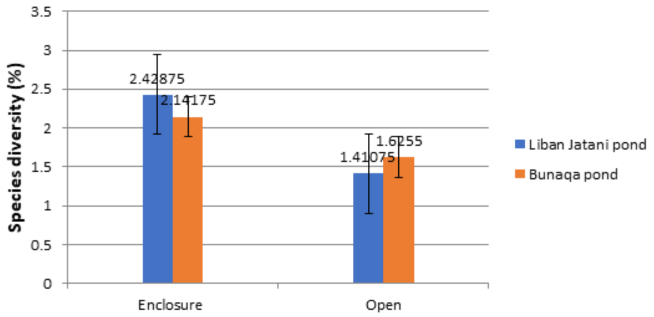

Figure 4 Mean value of herbaceous species diversity at Liban Jatani and Bunaka pond catchment VS open.

Figure 5 Change of ground cover due to sieve structure installed in the gully.

Table 6 Means Relative frequency and density of herbaceous species collected from both Liban Jatani and Bunaqa pond in Jun 2019 and November 2019

Scientific name	Vernacular name	Growth from	Relative frequency June 2019	Relative density June 2019	Relative frequency Nov 2019	Relative density Nov 2019
Sporobolus pellucidus	Salaqoo	G	22.22	43.86	14.81	22.58
Digitaria naghellensis	Ilmoogorii	G	16.67	12.28	11.11	6.45
Athroisma boranense	Gurbii	NG	5.56	3.51	11.11	6.45
Barleria spinisepala	Qilxiphe	NG	16.67	12.28	11.11	9.68
Solanum somalense	Idii	NG	5.56	3.51	3.7	1.61
Lippia carviodora	Urgoo	NG	16.67	14.04	18.52	22.58
Chrysopogon aucheri	Alaloo	G	5.56	3.51	11.11	14.52
Dactyloctenium aegyptium	Ardaa	G	11.11	7.02	7.41	9.68
Cissus aphyllantha	Cophii soodduu	NG	n.a	n.a	3.7	1.61
Pennisetum glaucifolium	Ogoonichoo	G	n.a	n.a	3.7	1.61
Macroculia species		G	n.a	n.a	3.7	3.23

Reaction of the community (result of participatory monitoring and evaluation)

The pastoralists report that the increased cover has reduced pond sedimentation and improved water quality. The enclosure of Liban Jatani was extended outwards during August and September 2019 by the pastoralists themselves. It provided evidence that the people appreciated the effects of the intervention. There was an organized field day for the pastoralist living nearby woredas and PA to visit the Liban Jatani pond showed their interesting and asked for copping or replicating pond catchment rehabilitation works for the pond found in their areas (Figure 6).

Figure 6 Photo taken during field day.

Scientific conclusions and recommendations

General observations from these data overall include that:

i. Protection from livestock grazing can cause dramatic increases in vegetation cover within a relatively short period of period.

ii. The trend of increasing ground cover under protection had not reached its potential after 12 months; and

iii. Areas that initially had very low ground cover can experience substantial increases in cover once protected.

I. The simple act of fencing an area to exclude livestock here for about one year caused both ground cover and ground species diversity to more than double.

II. This is a conservative conclusion based on a data record that was initiated well after the improvement process had begun.

III. The data collected so far show that the positive ecological changes are relatively greater on sites that are in a poorer condition to begin with.

IV. These results offer promise to those who dream of restoring the degraded rangelands of Borana to their positive change.

V. SWC for pond catchment rehabilitation bring positive impact decreasing degradation but meanwhile user community concluded as it has an effect on water filling it need further research investigation.[6]

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Conflicts of interest

The author declares there is no conflict of interest.

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