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Effect of rangeland rehabilitation on the herbaceous species composition and diversity in Suswa catchment, Narok County, Kenya

N. J. Ombega[1,2*], S. M. Mureithi[1], O. K. Koech[1], A. N. Karuma[1] and C. K. K. Gachene[1,2]

Abstract

Introduction: Land degradation is a serious environmental problem of our time. In Kenya, it is estimated that 30% of the total land mass is severely degraded. Suswa catchment within Narok County is a good example with gullies of over 25 m deep and 30 m wide. In response to the increasing land degradation in the area, the Sustainable Land Management (SLM) project rehabilitated the catchment through establishment of soil and water conservation structures such as cutoff drains, semicircular bunds, and water retention ditches. Despite the various rehabilitation approaches carried out, little research has been done to ascertain their effect on successful vegetation recovery. This coupled with the fact that many restoration approaches have failed in East Africa and Kenya in particular gave drive to the study. The objective of this study was to determine the effects of rangeland rehabilitation on herbaceous species composition and diversity in a severely degraded rangeland.

Methods: To assess the diversity of aboveground herbaceous layer in the rehabilitated and degraded areas along a slope (upper, middle, and lower), line transect and quadrat count methods were used. Within each slope position, three 100-m-long transects were placed across the hill parallel to one another 30 m apart using a tape. The species hit, the closest species to the hit, and hits on bare ground were recorded. Along the same transects, 1-m^2 quadrats were placed 25 m apart and aboveground biomass determined by the use of the destructive method. In the determination of species richness, diversity, relative abundance, percentage cover, and species composition, the Shannon-Wiener diversity index was used. Data collected on vegetation attributes was subjected to analysis of variance (ANOVA) using Genstat and Tukey's HSD post hoc used in means separation where *F* values were significant.

Results: The results showed that percent cover (74.67%), aboveground biomass (1459 kg/ha), relative abundance, richness, composition, and diversity of perennial grasses significantly ($P \leq 0.05$) increased downslope and were higher in the rehabilitated area than in the degraded area. On the contrary, forbs and annual grasses were significantly ($P \leq 0.05$) higher within the degraded area compared to the rehabilitated area and increased upslope.

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* Correspondence: joseph.ombega@gmail.com
[1]Department of Land Resource Management and Agricultural Technology (LARMAT), University of Nairobi, P.O Box 29053, Nairobi 00625, Kenya
[2]Sustainable Land Management (SLM) Agro-Pastoral Project Kenya, Nairobi, Kenya

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Conclusions: In general, herbaceous species diversity, species richness, relative abundance, percent composition, biomass production, and percent cover of perennial grasses significantly increased downslope and were higher in the rehabilitated area compared to the degraded area. On the contrary, the same attributes for forbs and annual grasses were higher in the degraded area and increased upslope. The study concluded that effective rangeland rehabilitation has the potential to enhance vegetation regeneration and hence forage productivity.

Keywords: Rehabilitation, Land degradation, Slope, Herbaceous layer, Biodiversity

Introduction

Land degradation is a serious environmental problem of our time. An estimated 20% of rangelands in the world are currently experiencing land degradation (Hassan et al. 2005). The effects of land degradation on plant biodiversity are profound and negative since it disturbs the floristic composition, spatial distribution, and diversity of the herbaceous layer (Landsberg et al. 2003; Metzger et al. 2005; Brooks et al. 2006). Land degradation significantly reduces primary productivity of palatable species, hence reducing community resilience (Kinyua et al. 2010).

The alteration in species composition affects soil fertility due to changes in belowground biomass and organic matter content, thus reducing soil carbon sequestration (Scholes 1990; Klumpp et al. 2009). Further, land degradation leads to a reduction in resilience of host species, reduction of vegetation cover, decreased species diversity, and reduced herbaceous biomass production (Kairis et al. 2015; Belgacem et al. 2013). Nonetheless, disturbances such as overgrazing favors establishment of invader species, survival, and dominance of short-lived, unpreferred annual plant species rather than the palatable perennial species (Byers 2002). Ultimately, changes in plant species composition greatly influences on the sustainability of livestock production within the rangeland ecosystems (Sankaran et al. 2005).

In Kenya, land tenure changes from communal to open access due to population increase and migrations from high potential lands have reduced grazing resources in the arid and semi-arid (ASALs) rangelands (Fratkin 2001; Kirwa 2009). Loss of grazing resources has influenced change in land-use practices from traditional pastoralism to other non-compatible land-use enterprises in the rangelands such as crop farming and charcoal production (Kirwa 2009). The change in land use has further increased shrinkage and degradation in quality of pastures due to proliferation of invasive plant species such as *Lantana camara* and *Opuntia ficus-indica* species (Maina 2013). The situation has led to severe land degradation (Muchena 2008) in the Kenyan rangelands. A good example is the Suswa catchment in Narok County with gullies of over 25 m deep and 30 m wide (Khalif 2015).

In response to the increased land degradation within the Kenyan rangelands, numerous restoration approaches have been developed (Mureithi et al. 2010). Some of these approaches include the use of rangeland enclosures, reseeding, ripping of soil crust, and use of structural soil and water conservation structures such as terraces (Wasonga and Nyariki 2009; Kinyua et al. 2009, Mganga et al. 2010; Mureithi et al. 2016; Ruto 2015). Within Narok County, the Sustainable Land Management (SLM) project has undertaken diverse activities to restore degraded areas. These activities include rehabilitation of gullies in Suswa catchment through establishment of several soil and water conservation structures such as terraces, semicircular bands, check dams, cutoff drains, and water retention ditches. Community education and replanting of trees within the severely degraded areas was also done (Odini et al. 2015). However, despite the various rehabilitation approaches carried out, little research has been done to ascertain their effect on successful vegetation recovery. This coupled with the fact that many restoration approaches have failed in East Africa and more especially in Kenya gave drive to the study (Wasonga and Nyariki 2009; Mureithi et al. 2010). This study, therefore, hypothesized that the restoration and rehabilitation measures done in Suswa catchment has positively contributed to vegetation regeneration and species diversity enhancement, geared towards increased land productivity. Alternatively, the rehabilitation process did not significantly enhance vegetation regeneration and recovery.

Methods

Study area

The study was undertaken in Suswa catchment, Narok County, located in the Southwest of Kenya. The county is found within longitudes 34° 45′ E and 36° 00′ E and latitudes 0° 45′ S and 2° 00′ S. Suswa has mainly humic andosols which are well drained, friable and smeary, sandy clay to clay (Jaeztold et al. 2010). The soils have low organic matter and high silt/clay making them highly susceptible to erosion. The soils are arranged in layers with hard pans beneath a soft clay stratum that are easily eroded (Maina 2013).

Suswa has a temperature range of 16.9 to 20.5 °C with minimum range experienced in March while the maximum in July. The area receives bimodal rainfall with long rains experienced from March to June and short rains from September to November. Plant species typical of drylands such as *Acacia drepanolobium*, *Acacia xanthophloa*, *Olea africana*, *Albizia gumifera*, *Cordia ovalis*, *Croton dichogamus*, *Carrisa edulis*, *and Tarchonanthus camphorates* are dominant in the area (Reed et al. 2009). Agro-pastoralism in the wetter parts and largely pastoralism with cultivated patches in the drier parts forms the major economic activity in Suswa catchment.

The area is severely degraded with gullies of over 25 m deep and 30 m wide (Khalif 2015). In response to the severity of degradation in the area, the Sustainable Land Management (SLM) project rehabilitated the land through the establishment of several soil and water conservation structures such as water retention ditches, cutoff drains, semicircular bunds, and check dams to control land degradation due to erosion. Moreover, native trees and grass species were introduced to restore the land (Odini et al. 2015).

Research design

A completely randomized block design was used for this research with two land management practices (rehabilitated area and degraded area) forming blocks while plots (Angassa et al. 2010) were the three slope categories (upper, middle, and lower slope positions) and transects (100 m) were the main sampling points. Within each slope position, three 100-m-long transects were placed across the hill 30 m apart and 5 m away from the boundaries. Data on vegetation attributes was then collected during the wet and dry seasons in the year 2016.

Vegetation sampling

To assess the diversity of aboveground herbaceous layer, in the rehabilitated area and degraded areas along a slope (upper, middle, and lower), line transect and quadrat count methods were used (Brady et al. 1995). Within each slope position, three 100-m-long transects were placed, and along each transect (tape), the species hit, the closest species to the hit, and the hits that landed on bare ground were recorded. Along the same transects, 1-m^2 quadrats were laid 25 m apart and herbaceous layer aboveground biomass determined by the use of the destructive method (t'Mannetje and Jones 2000). Forb and grass materials rooted within the quadrat were clipped 2 cm above the ground level (clipping at grazing height to give a more applicable measure of forage biomass). The various plant species clipped were then sorted into their relevant functional groups (perrenial grasses, forbs, and annual grasses). Their fresh biomass was immediately weighed to determine their aboveground fresh biomass and later oven-dried to a constant weight at 70 °C for 48 h after which aboveground biomass production was then determined and expressed in kg $DMha^{-1}$. In determining plant (species richness, composition, diversity, and relative abundance) direct visual observation was used to identify, count, and record individual plant species along transects at intervals of 1 m. Herbaceous species composition was then calculated using relative density as described by Krebs (1989) while species richness was determined as the number of different species represented in the sample. Cover was expressed as the relative number of hits on a species while the relative abundance was expressed as a percentage of the total number of hits of a functional group divided by the total number of hits in the sample.

In the determination of species diversity, the Shannon-Wiener diversity index as described by Krebs (1989) was used.

Shannon-Wiener diversity index (H')

$$H^{'} = -\sum\left[\left(\frac{n_1}{N}\right) \times \ln\left(\frac{n_1}{N}\right)\right]$$

where n_1 is the number of each individual species in the area, N is the total number of individuals recorded in the area, and ln is the natural log of the number.

Statistical data analysis

Data collected on vegetation attributes was subjected to analysis of variance (ANOVA) using Genstat Discovery 15th edition statistical software. A two-way ANOVA was used to determine if there were significant differences between means of the various herbaceous characteristics with respect to different land management practices, slope categories, and season. Tukey's HSD post hoc was used to separate treatment means where the F values were significant.

Results

Herbaceous species richness, relative abundance, and diversity

The herbaceous species richness, relative abundance, and diversity of perennial grasses significantly ($P \leq 0.05$) increased downslope being higher in the rehabilitated area compared to the degraded area respectively (Table 1). Seasonality did not significantly affect species richness ($P = 0.432$), relative abundance ($P = 0.065$), and diversity ($P = 0.740$) of perennial grasses (Appendix 1). However, higher values for species richness, relative abundance, and diversity of perennial grasses were recorded during the wet season than in the dry season (Table 1). The corresponding interactions of management*slope*season had no significant effect on the same attributes (Appendix 1). Generally, perennial grass species richness, relative abundance, and diversity increased downslope and were higher in the rehabilitated area compared to the degraded area.

The species richness, relative abundance, and diversity of forbs significantly ($P \leq 0.05$) increased upslope being higher in the degraded area compared to the rehabilitated area (Table 1). Seasonality significantly affected the species richness ($P = 0.001$), relative abundance ($P = < 0.001$), and diversity ($P = 0.010$) of forbs with higher values recorded in the wet season compared to the dry season. However, interactions due to management*slope*season did not show significant effect on the same attributes (Appendix 1).

Land management practice, slope and the corresponding interactions of management*slope*season did not show any significant effect on the species richness, relative abundance, and diversity of annual grasses (Appendix 1). However, season significantly affected the species richness ($P = 0.040$), relative abundance ($P = 0.032$), and diversity ($P = 0.018$) of annual grasses (Appendix 1).

Aboveground herbaceous biomass and percent ground cover

Aboveground biomass of perennial grasses significantly ($P \leq 0.05$) increased downslope being higher in the rehabilitated area than in the degraded area (Table 2). The same trend was also observed with percentage cover where rehabilitated area and degraded respectively (Table 2). Seasonality had a significant effect on aboveground biomass of perennial grasses ($P = 0.045$) with higher values observed in the wet season compared to the dry season (Table 2).

Forb aboveground biomass increased downslope; however, higher values were observed in the degraded area than in the rehabilitated area (Table 2). Percent cover of forbs significantly ($P \leq 0.05$) increased upslope being higher in the degraded area than in the rehabilitated area (Table 2). Seasonality significantly influenced aboveground biomass ($P = 0.001$) and percent cover ($P = 0.001$) of forbs (Appendix 2). The corresponding interactions of management*slope*season had no significant effect on the aboveground biomass ($P = 0.268$) and percent cover ($P = 0.344$) of forbs (Appendix 2).

Statistically, management practice and slope did not show any significant ($P \leq 0.05$) effect on the aboveground biomass and percent cover of annual grasses. However, higher values were recorded within the degraded area compared to the rehabilitated area (Table 2). Seasonality had a significant effect on the aboveground biomass ($P = 0.024$) and percent ground cover ($P = 0.032$) of annual grasses (Appendix 2), with higher values recorded during the wet season compared to the dry season (Table 2). The corresponding interactions of management*slope*season did not significantly affect aboveground biomass ($P = 0.418$) and percent cover ($P = 0.430$) of annual grasses (Appendix 2).

Table 1 Herbaceous species richness, relative abundance (%), and diversity in rehabilitated and degraded areas of Suswa catchment during wet and dry seasons

Treatment			Wet season							Dry season						
		Management	Rehabilitated area			Degraded area				Rehabilitated area			Degraded area			
		Slope	Upper	Middle	Lower	Upper	Middle	Lower	LSD	Upper	Middle	Lower	Upper	Middle	Lower	LSD
Abundance	Grasses	Annuals	1.50	0.60	0.00	6.50	3.70	2.30	5.40	0.00	0.00	0.00	0.00	1.37	2.73	2.43
		Perennials	77.97b	93.27c	99.10d	67.13a	79.70b	91.51c	3.10	88.70ab	95.6bc	99.90c	84.90a	85.90a	91.46a	7.88
	Forbs		15.53c	6.07b	0.90a	31.30d	16.57c	6.13b	4.98	11.30bc	1.40a	0.00a	15.10c	12.70bc	2.70ab	8.00
Diversity	Grasses	Annuals	0.11	0.00	0.00	0.11	0.10	0.36	0.31	0.00	0.00	0.00	0.00	0.10	0.20	0.18
		Perennials	1.35c	1.55e	1.91f	1.07a	1.23b	1.45d	0.07	1.30c	1.53d	1.86e	1.05a	1.22b	1.35c	0.02
	Forbs		0.43c	0.09a	0.02a	0.62d	0.46c	0.26b	0.07	0.21	0.33	0.00	0.35	0.25	0.13	0.44
Richness	Grasses	Annuals	0.67	0.00	0.00	0.67	0.67	3.33	2.45	0.00	0.00	0.00	0.00	0.33	0.67	0.59
		Perennials	4.67b	8.30d	10.30e	3.00a	5.00b	6.67c	0.84	4.00b	8.00e	10.00f	2.60a	5.00c	6.00d	0.42
	Forbs		1.60b	1.00ab	0.30a	5.30d	4.00c	2.00b	0.70	1.30bc	0.33a	0.00a	2.00c	2.00c	1.00b	0.94

Means with different letters within the row are significantly different ($P \leq 0.05$) > Tukey's HSD test

Table 2 Aboveground herbaceous biomass (kg/ha) and percent cover (%) in rehabilitated and degraded areas of Suswa catchment during wet and dry seasons

		Wet season							Dry season						
Treatment	Management	Rehabilitated area			Degraded area				Rehabilitated area			Degraded area			
	Slope	Upper	Middle	Lower	Upper	Middle	Lower	LSD	Upper	Middle	Lower	Upper	Middle	Lower	LSD
Aboveground biomass	Annual grasses	0.0	0.0	0.0	16.7	22.0	56.7	49.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Perennial grasses	284.0a	701.0b	1459.0c	229.0a	453.0ab	635b	295.0	223.0c	391.0d	895.0e	114.0b	236.0c	4.2a	20.6
	Forbs	4.0a	4.3a	50.7ab	50.0ab	74.0b	194.7c	57.9	2.0a	4.3a	8.0a	5.0a	14.0a	46.3b	15.1
Percent cover	Annual grasses	1.6	0.0	0.0	3.3	3.0	1.9	7.0	0.0	0.0	0.0	0.0	0.7	1.3	1.2
	Perennial grasses	42.3b	64.6d	74.7e	31.3a	45.0b	57.5c	2.8	40.0b	58.1c	68.0d	29.0a	42.0b	54.7c	2.7
	Forbs	10.00c	2.67a	1.33a	19.6d	12.0c	7.0b	2.2	4.0ab	0.7ab	0.0a	6.3b	6.0b	2.3ab	3.8

Means with different letters within the row are significantly different ($P \leq 0.05$) > Tukey's HSD test

Percent herbaceous composition

Land management practice, slope, and season had an effect on species composition. Generally, during the wet season, *Aristida adoensis* was the most abundant species in the area with abundances of 1.76, 2.82, and 5.52% in the upper, middle, and lower slope positions of the rehabilitated area and 1.13, 2.11, and 3.17% in the upper, middle, and lower slope positions of the degraded area respectively (Table 3).

The percentage composition of perennial grasses *Themeda triandra* and *Chloris gayana* was high in the lower slope position (0.59 and 0.70%) compared to the middle (0.35 and 0.24%) and upper slope position (0.25 and 0.12%) within the rehabilitated area during the wet season (Table 3). However, *Cymbopogon afranardus* mainly dominated the upper slope position (0.68%) within the degraded area (Table 3). Seasonality did not significantly impact perennial grass composition.

High frequencies of forbs such as *Pentanisia ouranogyne*, *Euphorbia inequilatera*, and *Sirene species* were found in the upper slope position and mainly within the degraded site. *Hypoestes verticillaris* was the most abundant forb within the upper slope position with percentages of (0.57%) in the degraded and (0.16%) in the rehabilitated area respectively (Table 3). Forbs such as *Polyghala sphenoptera* disappeared during the dry season.

There were high proportions of annual grasses such as *Aristida keniensis* and *Eragrostis tenuifolia* in the upper slope position in the degraded area compared to the upper slope position in the rehabilitated area (Table 3). There were seasonal changes in species composition with some annual grasses such as *Eragrostis tenuifolia* disappearing during the dry season (Table 3).

Generally, forbs and annual grasses showed a higher percentage composition in the upper slope positions within the degraded area compared to the rehabilitated area. Contrary perennial grasses dominated the lower slope position within the rehabilitated area.

Discussion

Species richness, relative abundance, and diversity

The significantly higher species richness, relative abundance, and diversity of perennial grasses compared to forbs and annual grasses in the rehabilitated area could be attributed to improved soil fertility as a result of reduced runoff and erosion due to the establishment of soil and water conservation structures in the study area (Singh et al. 2011). Rehabilitation of severely degraded areas have been found to enhance vegetation recovery which in turn reduces soil erosion and enhances soil fertility and plant biodiversity (Tongway and Ludwig 2011). The rehabilitation activities in the study area could have achieved this and hence the observed improvement in plant species diversity and land cover. The findings of this study are consistent with those of Mureithi et al. (2016) who while working in Laikipia, reported a higher species richness and diversity in areas under community conservation than in open communal areas. Similarly, Singh et al. (2011) working in the degraded Aravalli hills in Western India found a higher species diversity in areas with soil and water conservation structures.

Further, the higher species richness, diversity, and relative abundance of perennial grasses compared to that of forbs and annual grasses downslope could be due to improved soil fertility as a result of the transportation and accumulation of soil sediments downslope. Slope gradient influences the accumulation and export of soil nutrients downslope, thereby directly or indirectly affecting

Table 3 Percent herbaceous composition in rehabilitated and degraded areas of Suswa catchment during wet and dry seasons

		Wet season						Dry season					
		Rehabilitated area			Degraded area			Rehabilitated area			Degraded area		
Species	Functional group	Upper	Middle	Lower	Upper	Middle	Lower	Upper	Middle	Lower	Upper	Middle	Lower
Aristida adoensis	Perennial grass	1.76	2.82	5.52	1.13	2.11	3.17	1.64	2.7	5.4	0.94	1.88	2.7
Chloris gayana	Perennial grass	0.12	0.24	0.7	NP	0.12	0.23	0.12	0.12	0.7	NP	0.12	0.23
Cymbopogon afronardus	Perennial grass	0.47	NP	NP	0.68	NP	NP	0.47	NP	NP	0.68	NP	NP
Cynodon plectostachyus	Perennial grass	NP	NP	NP	NP	0.12	NP	NP	NP	NP	NP	0.12	NP
Digitaria scalarum	Perennial grass	0.59	0.82	1.41	NP	0.7	0.94	0.47	0.7	1.41	NP	0.47	0.82
Ergrostis biflora	Perennial grass	NP	NP	0.35	NP	NP	NP	NP	NP	0.35	NP	NP	NP
Eragrostis brownie	Perennial grass	NP	NP	0.23	NP	NP	NP	NP	NP	0.23	NP	NP	NP
Eustachyus paspaloides	Perennial grass	NP	0.24	0.35	NP	NP	0.23	NP	0.24	0.35	NP	NP	0.23
Harpachne schimperi	Perennial grass	0.59	1.06	1.41	0.23	0.35	0.82	0.47	0.94	1.29	0.23	0.35	0.7
Hyparrhania disoluta	Perennial grass	0.12	0.7	1.29	0.11	0.35	0.94	0.12	0.7	1.29	0.11	0.35	0.82
Hyparrhania hirta	Perennial grass	0.12	0.59	0.47	0.11	0.23	0.35	0.12	0.47	0.35	0.11	0.23	0.35
Hyparrhania lintonii	Perennial grass	0.7	1.29	2.23	0.34	0.94	1.29	0.59	1.17	2.11	0.34	0.82	1.17
Sporobolus discosporus	Perennial grass	NP	0.7	1.64	NP	0.47	1.41	NP	0.59	1.53	NP	0.35	1.17
Sporobolus fimbriatus	Perennial grass	0.12	0.47	0.23	0.11	0.35	0.23	0.12	0.47	0.23	0.11	0.35	0.23
Themeda triandria	Perennial grass	0.35	0.35	0.59	NP	0.12	0.47	0.35	0.35	0.59	NP	0.12	0.47
Sporobolus fimbriatus	Perennial grass	0.12	0.47	0.23	0.11	0.35	0.23	0.12	0.47	0.23	0.11	0.35	0.23
Aristida keniensis	Annual grass	0.12	NP	0.12	0.23	0.11	0.12	NP	NP	0.12	NP	0.12	0.12
Eragrrostis tenuifolia	Annual grass	0.12	NP	NP	0.35	0.23	0.12	NP	NP	NP	NP	NP	NP
Borreria stricta	Forb	0.12	NP	NP	0.23	0.12	0.12	0.12	NP	NP	0.12	NP	0.12
Euphorbia inequilatera	Forb	0.12	NP	NP	0.23	0.12	NP	0.12	NP	NP	0.12	0.12	NP
Fuerstia Africana	Forb	NP	NP	NP	0.23	0.35	NP	NP	NP	NP	NP	0.12	NP
Hypoestes verticillaris	Forb	0.16	NP	NP	0.57	0.12	NP	0.12	NP	NP	0.35	0.12	NP
Pentanisia ouranogyne	Forb	NP	NP	NP	0.45	NP	NP	NP	NP	NP	0.23	NP	NP
Polyghala sphenoptera	Forb	NP	NP	NP	0.11	NP	NP	NP	NP	NP	NP	NP	NP
Satureia biflora	Forb	0.12	0.12	NP	0.45	0.59	NP	NP	NP	NP	0.23	0.35	NP
Sirene SPP.	Forb	0.12	NP	NP	0.23	NP	NP	NP	NP	NP	0.23	NP	NP

NP not present

vegetation distribution (Zuo 2012). Slope also affects the physical chemical properties of the soil which in turn affects the distribution and diversity of species (Enright et al. 2005). Soils in higher altitudes are frequently washed of their nutrients which are then deposited in the lower slopes (Hosseinzadeh et al. 2016). These findings corroborates with those of Zheng et al. (2014); Karami et al. 2015 and Hosseinzadeh et al. (2016) who reported a decreasing species diversity and richness with increasing altitude. Contrary to these findings, Baldock and Smith (2009) in their study in Nubra valley region in Ladakh reported an increasing herbaceous species diversity and abundance upslope, a fact they attributed to increased grazing pressure on lower slope position from the inhabitants.

The seasonal variation in species richness with significantly lower species richness, diversity, and relative abundance of forbs and annual grasses during the dry season could be presumed to be a result of reduced moisture content in the soil due to low rainfall (Gutierrez and Whitford 1987). Low rainfall amounts during the dry season could have negatively impacted annual grasses which are shallow rooted with short lifespan. The results corroborate with those of Angassa et al. (2010) who reported higher species diversity and richness during the wet season in his study on the effect of communal enclosures on the diversity of herbaceous layer in southern Ethiopia.

Herbaceous biomass production and percentage ground cover

Higher biomass production and percentage cover of perennial grasses in the rehabilitated area could be as a result of improved land management due to the establishment of soil and water conservation structures such as semi-circular bands, cutoff drains, and terraces. Terraces have been found to improve soil physico-chemical properties such as soil moisture content, soil hydraulic conductivity, soil organic carbon, nitrogen, phosphorus, and potassium (Ruto 2015). Aboveground biomass and ground cover are positively correlated with the amount of water and nutrients in the soil which are the main limiting components in severely degraded areas (Singh et al. 2011).

Further, improved ground cover and above ground biomass of perennial grasses compared to forbs and annuals in the rehabilitated area could be due to reduced grazing pressure in the rehabilitated sites. Proper grazing management through livestock exclusion has been found to enhance the range condition in areas that are severely degraded (Allen et al. 1995; Wasonga et al. 2011). Moreover, lower biomass production and percentage cover of perennial grasses in the degraded area could be a result of year round grazing which could not allow quick vegetation recovery in the study area (Verdoodt et al. 2010). These findings corroborates with those of Singh et al. (2011) who reported higher biomass production and percent cover in areas rehabilitated through rainwater harvesting. Similarly, Monsour et al. (2013) found a higher percentage cover and biomass production in areas rehabilitated with stone terraces compared to unterraced ones.

Higher aboveground biomass and percent cover of perennial grasses in the lower slope position compared to forbs and annual grasses could be due to improved soil fertility downslope. This is in agreement with previous studies which have indicated that vegetation growth is directly related with phosphorus, soil organic carbon, potassium, and total nitrogen (Marcuzzo et al. 2013). Singh et al. (2011) in his study on Aravalli hills in western India found higher herbaceous biomass production and percent cover on lower slopes than in upper slopes.

The significant changes in aboveground biomass and percent cover between seasons could be attributed to rainfall variability. Sufficient soil moisture content generally increases plant biomass (Robinson et al. 2013).

Herbaceous species composition

The results indicated differences in species composition between sites, seasons, and among slope positions. The dominance of forbs and annuals in the degraded areas could be attributed to poor land management as a result of overgrazing (Solomon et al. 2007) and depleted soil fertility due to frequent soil erosion in the study area which has gullies of over 25 m deep and 30 m wide (Khalif 2015). Abundance and dominance of forbs and annual grasses is an indication of poor range condition due to mismanagement or changes in plant species composition in the ecosystem (Camp 1997). Anderson and Hoffman (2007) noted that poorly managed communal rangelands had lower proportion of perennial grasses compared to forbs and annual grasses. Increased number of perennial grasses compared to forbs and annuals in the rehabilitated area could also be an indication of reduced runoff, a fact attributable to improved ground cover (De Groot et al. 1992). This is in agreement with Everson et al. (2007) who noted reduced runoff rates in the rehabilitated areas than in the degraded areas.

The observed pattern of species composition with large number of perennial grasses in the lower slope position of the rehabilitated area could be a result of improved fertility, drainage, and depth of the soils downslope (Boll et al. 2005; Enright et al. 2005).

Reduced frequency and dominance of annual grasses and forbs during the dry season may be attributed to low soil moisture content. Annuals and forbs are generally shallow rooted, and therefore, slight changes in soil moisture content with high temperatures affect their growth (Yan et al. 2015). Annuals also respond to rainfall variations faster than perennial species because of their fast growth and early completion of life cycle (Miranda et al. 2009).

Conclusions

This study reiterates that land management, slope position, and season influences floristic composition and vegetation structure. In general, herbaceous species diversity, species richness, relative abundance, percent composition, biomass production, and percent cover of perennial grasses significantly increased downslope being higher in the rehabilitated area compared to the degraded area. On the contrary, the same attributes for forbs and annual grasses were higher in the degraded area and increased upslope. However, forb biomass decreased with increase in slope, a fact which could be associated with increased fertility downslope. Seasonal variations were also observed mainly on forbs and annual grasses for the same attributes with low values recorded during the dry season. The noted differences on species composition and diversity show that management practice, slope, and season influence species composition and diversity and, therefore, should be considered for sustainable land management. Moreover, the study concluded that effective rangeland rehabilitation has the potential to enhance vegetation regeneration and hence forage productivity.

Appendix 1

Table 4 Response of herbaceous species richness, diversity, and relative abundance to treatments

	Relative abundance			Diversity			Richness		
	Grasses			Grasses			Grasses		
Treatment	Annual	Perennial	Forbs	Annual	Perennial	Forbs	Annual	Perennial	Forbs
Management	0.340	< 0.001	< 0.001	0.012	< 0.001	0.011	0.020	< 0.001	< 0.001
Slope	0.719	< 0.001	< 0.001	0.240	< 0.001	0.001	0.154	< 0.001	< 0.001
Season	0.032	0.065	< 0.001	0.018	0.73	0.010	0.040	0.043	< 0.001
Management*slope	0.026	0.157	0.070	0.067	< 0.001	0.969	0.056	< 0.001	0.035
Management*season	0.447	0.064	0.081	0.582	0.161	0.106	0.147	0.056	< 0.001
Slope*season	0.106	< 0.001	0.039	0.611	0.007	0.219	0.373	0.062	0.020
Management*slope*season	0.23	0.673	0.118	0.742	0.057	0.383	0.226	0.461	0.067

Probability (significance detected at $P < 0.05$, highly significant at $P < 0.01$) > Tukey's HSD test

Appendix 2

Table 5 Response of aboveground biomass production and percent cover to management, slope, season, and their interactions

	Aboveground Biomass			Percent cover		
	Grasses			Grasses		
Treatment	Annual	Perennial	Forbs	Annual	Perennial	Forbs
Management	0.024	< 0.001	< 0.001	0.025	< 0.001	< 0.001
Slope	0.418	< 0.001	< 0.001	0.411	< 0.001	< 0.001
Season	0.024	0.025	< 0.001	0.032	0.056	< 0.001
Management*slope	0.418	< 0.001	0.006	0.190	< 0.001	0.085
Management*season	0.024	0.120	< 0.001	0.103	0.024	< 0.001
Slope*season	0.418	0.014	0.002	0.654	0.106	< 0.001
Management*slope*season	0.418	0.137	0.268	0.43	0.254	0.344

Probability (significance detected at $P < 0.05$, highly significant at $P < 0.01$) > Tukey's HSD test

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Authors' contributions

JO designed the study, collected the data, participated in the data analysis, and drafted the manuscript write-up and revision. SM was part of the study design, data cleaning and analysis, manuscript write-up, and revision. OK was part of the study design, data analysis and presentation, and manuscript editing. AK was part of the research design, methodology, and data analysis and contributed to the results, manuscript write-up, and manuscript editing. CKK was part of the research and paper write-up. All the authors read and approved the final manuscript

Competing interests

The authors declare that they have no competing interests.

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