Effect of Water Harvesting on Species Diversity and Overall Rangeland Recovery in Kagera Microcatchement

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ABSTRACT

Plant species diversity was investigated on ridges with and without water harvesting structures. The effect of water harvesting technology on the soil properties and rangeland recovery was also investigated. The experimental sites are located in Kifamba, Kakuuto County Rakai District. Plant species were recorded on a 50m horizontal transect aligned on the main transect running S-N on a 20 m lag. The quadrat method was used to sample grasses and herbs, whereas shrubs and trees were sampled on twenty five meter plots on consecutive horizontal transects. Soil physical and chemical properties, plant biomass and ground cover were determined along the landscape. Results indicate that, ridges with water harvesting structures had higher species diversity than those without water harvesting structures ($p<0.05$). The plant diversity on ridges with water harvesting (Shannon Diversity index) was $H' = 4.46$, while the diversity of ridges without water harvesting was $H' = 3.93$. The two types of ridges were significantly different ($p<0.001$) in terms of the diversity of plant species. The results further reveal that the introduction of water harvesting structures did not induce a landscape position pattern in the distribution of species, but that of grass biomass, despite the uniformity of chemical properties along the landscape ($p<0.05$).

Keywords: Ecology, Rangeland restoration, Species diversity, Land productivity.

management (NRC 1994). Degraded range lands (Busby *et al* ., 1995) can be reversed by altering the grazing season, stocking intensity and animal type which can restore the growth of forage plant populations. It can also be done through rotational grazing and withdraw of herbivores (Westoby, *et al.,* 1989) at certain seasons or after favourable climatic events ; non selective grazing (Acocks, 1964) and an increase in the browser : grazer ratio (Walker, 1980). Reversal of range land degradation may also involve the removal of domestic live stock and culling of other abundant herbivores as well as vegetation manipulation. This may latter involve reseeding combined with burning, herbicide treatment , or selective bush cutting (Gibbens *et al.,* 1992; Passera *et al.,* 1992). Barrow, (1991) notes that, to ensure profitable range land rehabilitation, there is need to first rehabilitate the physical environment by reducing erosion, increasing water infiltration, improving the water holding capacity of the soil, protecting the soil surface from the sun and frost, ameliorating salinisation and creating micro sites suitable for the seedlings of perennial plants. Barrow further comments that, when vegetation is completely lost, the only economically feasible management option at this stage appears to be non pastoral use of the area. In the rehabilitation of the rangelands, different water harvesting methods can be employed. These include, contour bunds, contour ridges, negarim micro catchment, semi-circular bunds, trapezoidal bunds, contour stone bunds, permanent rock dams and water spreading bunds. In the rangelands of the Kagera micro catchment, contour bunds are used to rehabilitate the degraded range lands. Therefore the major aim of the study was to find out the influence of water harvesting on plant species diversity, plant biomasss production and cover in the degraded range lands of the Kagera Basin.

MATERIALS AND METHODS

This study was carried out in Kakuuto county Rakai District and the study area covers approximately 2100 km^2. The district is located between 0 ° 35'- 1 ° 00' S and 31 ° 15'-31 ° 48' E. Three replicates of ridges with and without water harvesting structures were randomly selected. The main transect run south north, from the foot slope to the summit of the ridge. The horizontal transects of 50m (25m either side of the main transect) were laid at 20m intervals. On the horizontal transect three; 1x1m quadrats were selected randomly by use of random numbers.

The slope was divided into three sections. These included; the upper, middle and lower. These sections covered areas of the main transect in proportions equal to 1/5,2/5,and 2/5 of the length of the main transect. (Achan *et al.*, 1999). The study compared two sites, one with water harvesting and the other without water harvesting. It is assumed that the two sites were similar at the time water harvesting was introduced.

Grasses and herbs were assessed on the horizontal transects using 1*1 m^2 quadrats selected randomly by use of random numbers. Plants specimens were collected, labeled, pressed, and dried for identification at the Makerere University herbarium. Shrubs and Trees were assessed on the one side of the area demarcated by the main transect and two consecutive horizontal transects. The sample plot size was 20 x 25m.

Species diversity of the recorded species was determined using the Shannon and Simpsons indices of diversity.

Cover was estimated following FAO cover estimation method. Biomass was harvested and the dry weight determined according to sections.

Soils were sampled at depth of 0-15 cm and 15-30 cm and analyzed for OM, pH, exchangeable P, exchangeable bases like K, Na, Ca, and texture using methods described by Okalebo, *et al.* (1993).

Saturated hydraulic conductivity (K_{sat}) was determined using a tension infiltrometer (Ankeny *et al.,* 1988; Prieksat *et al.,* 1992). Infiltration tests were carried out on each transect and for three suction heads: 30, 50, 80 mm. Wooding's (1968) solution for steady state flux from a circular source in conjunction with Ankeny *et al.,* (1991) method was used to determine the hydraulic conductivity associated with steady state flow (K_{sat}) attained for a pair of suction heads. Assuming the conductivity-potential relationship can be described by Gardner's (1958) exponential function, the relationship between the steady state flux rates Q_j, and the suction heads (h_j) is of the form:

$$\alpha = (\mathrm{Ln}\ (Q_1/Q_2)/\ (h_1-h_2)$$

provided that α remains constant for the head ranging from h_2 to h_1. K_{sat} was determined for each two pairs of heads (30-50 mm) and (50-80 mm).

The overall soil K_{sat} value at a given site was estimated by averaging the computed (K_{sat}) for the two pairs of heads for that specific site. Each K_{sat} value was computed following the equation:

$$\text{Ksat} = Q/\ (\exp(\alpha h)^*(\pi r^2 + 4r/\alpha)$$

Where r is the radius of the circular ponds.

RESULTS AND DISCUSSION

Plant species diversity

A total number of 164 plant species belonging to 37 families were recorded on ridges with and without water harvesting structures. The Poaceae (29 spp.), Fabaceae (18 spp..), Asteraceae (14 spp.) and Euphobiaceae (12 spp.) families were the most important since they contributed the highest number of plant species. However, ridges with water harvesting structures presented higher species richness than those without water harvesting structures ($p<0.05$).

Ridges with water harvesting structures had a total number of 105 plant species belonging to 32 families (Table I). Some of the plant species on ridges with water harvesting belonging to the Poaceae family included, *Bracharia bryzanta, Chloris pychnotrix* and *Panicum maximum*. Those belonging to the Fabaceae family included, *Desmodium asbcendens, Dolichos oliveri and Zonia setosa*. Some plant species of the Asteraceae family included, *Ageratum conyzoides, Vernonia aericulata and Dichrocephala intergrifolia*. The ones belonging to the Euphobiaceae family included, *Phylanthus numuloriifolia, Acalypha crenata and Euphorbia hirta*.

The following are some of the rare ones represented by one plant species: *Capparis fascularis* (Capparidaceae), *Asparagus africana* (Asperagaceae), *Carrisa edulis* (Apacynaceae) and *Gomphocarpus physocarpus* (Asclepidaceae).

Ridges with water harvesting structures had a total number of 57 plant species belonging to 20 families. The Poaceae family presented the highest number of plant species on ridges without water harvesting structures (Table I).

They included, *Hapachne schimperi, Bothriochloa inscupta and Sporobolus pyramidalis*. Other important families included, Fabaceae represented by *Crotalaria spp., Indigofera arrecta*. Those belonging to the Euphobiaceae family included, *Flueggea virosa*, and *Phyllanthus numolarifolia*. (Table I). The rare ones represented by one individual in a family included, *Alternanthera pungens* (Amaranthaceae) and *Clerodendrum myriciodes* (Verbanaceae) (Table I).

Table I: Species list for ridges with water harvesting

Species.	Family.	Growth form	WHS	NWHS
Desmodium asbcendens	Fabaceae	S	+	+
Solanum macrocarpum	Solanaceae	S	+	
Teclea nobilis	Rutaceae	T	+	+
Zyzygium guineense	Myrtaceae	T	+	_
Asparagus africanus	Asparagaceae	S	+	+
Bracharia bryzantha	Poaceae	G	+	+
Phyllanthus numolariifolioa	Euphorbiaceae	S	+	+
Trilepisium madagascariensis	Malvaceae	S	+	_
Abutilon maceritianum	Malvaceae	S	+	+
Chloris pychnotix	Poaceae	G	+	_
Sida acuta	Malvaceae	H	+	_
Acacia gerrardi	Mimosaceae	T	+	+
Panicum maximum	Poaceae	G	+	_
Comelina benghalensis L.	Commelinaceae	H	+	_
Cissampelos mucranata	Meacispermaceae	H	+	_
Serna mimosefolia	Caesalpiniaceae	S	+	_
Oxalis corniculata Senna	Oxalidaceae	H	+	_
Themeda triandra L.	Paoceae	G	+	+
Lycopersicum escuIerutum	Solanaceae	H	+	_
Mimosa pigra	Mimosaceae	S	+	_
Acacia gagentica	Mimosaceae	T	+	_
Aldia spp.	Rubiaceae	T	+	_
Asystasia guhata	Acanthaceae	H	+	_
Pennisetum polystachyon	Poaceae	G	+	_
Kyllinga alba Nees	Cyperaceae	H	+	+
Alternanthera pungens	Amaranthaceae	H	+	+
Solanum macrocarpum	Solanaceae	S	+	_
Sporobolus pyramidalis	Poaceae	G	+	+
Commelina africana L.	Commelinaceae	H	+	_
Solanum incanum	Solanaceae	S	+	
Acalypha crenata	Euphorbiaceae	S	+	_
Physalis peruviana	Solanaceae	H	+	_

Ageratum conyzoides	Asteraceae	S	+	_
Celosia trigyna	Amaranthaceae	S	+	_
Sida cuneifolia	Malvaceae	S	+	_
Euphorbia hirta	Euphorbiaceae	H	+	_
Psidium guajava	Mytaceae	T	+	_
Cassia occidentalis	Caesalpiniaceae	S	+	_
Vernonia aericulata	Asteraceae	H	+	_
Rhus natalensis	Anacardiaceae	T	+	_
Triumfetta annua	Tiliaceae	S	+	_
Physallis capillaris	Euphorbiaceae	S	+	_
Lantana camara	Verbenaceae	S	+	_
Annona senegalensis	Annoniaceae	S	+	_
Acalypha bipartica	Euphorbiaceae	S	+	_
Gomphocarpus physocarpus	Asclepidaceae	S	+	+
Oxalis latifolia	Oxalidaceae	H	+	_
Dichrocephala integrifolia	Asteraceae	H	+	_
Solanum nigrum	Solanaceae	S	+	_
Bidens pilosa	Asteraceae	S	+	_
Dolichos oliveri	Papilionaceae	H	+	+
Bothriochloa crusculpha	Poaceae	H	+	+
Conyza sumatrensis	Asteraceae	H	+	+
Momordica freisiovonum	Cucurbitaceae	H	+	_
Hura crepitans	Euphorbiaceae	H	+	_
Ocimum gratissimum	Lamiaceae	S	+	_
Rhus vulgaris	Anacardiaceae	T	+	+
Asytasia guhata	Acanthaceae	H	+	+
Desmodium trifolium	Fabaceae	H	+	+
Phyllanthus corpillaris	Euphorbiaceae	S	+	_
Indigofera arrecta	*Fabaceae*	H	+	+
Kyallinga bulbosa	*Cyperaceae*	G	+	_
Ipomoea spp.	*Convolvaceae*	H	+	_
Kyllinga pumila	*Cyperaceae*	G	+	_
Marytemis senegalensis	*Celastraceae*	T	+	_
Dovyalis macrocalyx	*Flacourtiaceae*	T	+	_
Helicrysum gerberifolium	*Asteraceae*	H	+	_
Cymbopogon nardus	*Poaceae*	G	+	_

Sida ovata	*Malvaceae*	S	+	_
Aspilia africana	*Asteraceae*	S	+	_
Desmodium gangeticum	*Papilionaceae*	S	+	_
Erythrococa bengenis	*Euphorbiaceae*	T	+	_
Clerodendrum myriciods	*Verbanaceae*	S	+	+
Tagetes minuta	*Asteraceae*	S	+	+
Clausena onisata	*Rutaceae*	T	+	_
Melanthera scandens	*Asteraceae*	S	+	_
Capparis fascularis	*Capparidaceae*	S	+	_
Flueggea virosa	*Euphorbiaceae*	S	+	+
Sida rhomboidea	*Malvaceae*	S	+	+
Grewia simulis	*Tiliaceae*	T	+	_
Carissa edulis	*Apocynaceae*	S	+	+
Euphorbia unaquilatera	*Euphorbiaceae*	S	+	_
Ocimum suave	*Lamiiaceae*	S	+	_
Zornia setosa	*Fabaceae*	H	+	_
Abildigaardia ovata	*Cyperoceae*	G	+	+
Aristida adoensis	*Poaceae*	G	+	_
Loudetia kagerensis	*Poaceae*	G	+	+
Sporobolus stapfianus	*Poaceae*	G	+	+
Leonotis nepetifolia	*Laminaceae*	S	+	+
Crotalaria vatkeana	*Fabaceae*	S	+	+
Indigofera spicata	*Fabaceae*	H	+	+
Alysicarpus zeyheri	*Fabaceae*	S	+	_
Eriosema shirense	*Fabaceae*	S	+	_
Indigofera encarginella	*Fabaceae*	H	+	_
Pycnospora lutescens	*Fabaceae*	S	+	+
Andropogon schirensis	*Poaceae*	G	+	_
Eragrostis tenuifolia	*Poaceae*	G	+	_
Eragrostis racemosa	*Poaceae*	G	+	+
Ficus sycomorus	*Moraceae*	T	+	_
Solanum anguivi	*Solanaceae*	H	+	_
Blighia unijugata	*Sapindaceae*	T	_	+
Andropogon schirensis	*Poaceae*	G	_	+
Albizia coriaria	*Mimosaceae*	T	_	+
Desmodium ramosissimum	*Fabaceae*	S	_	+

Alysicarpus rugosus	*Fabaceae*	S	–	+
Microglossa angolensis	*Asteraceae*	S	–	+
Microglossa pyrifolia	*Asteraceae*	S	–	+
Urena lobata	*Malvaceae*	S	–	+
Laggera alata	*Asteraceae*	S	–	+
Cyperaceae cyperoides	*Cyperaceae*	G	+	+
Desmodium setigerium	*Fabaceae*	H	–	+
Fimbristylis dichotoma	*Cyperaceae*	H	+	+
Capparisreny thiocapus	*Capparidaceae*	S	–	+
Pennisetum perpureum	*Poaceae*	G	+	+
Hypoxis obtusa	*Hypoxidaceae*	H	–	+
Pterigota becquartii	*Steculiaceae*	T	–	+
Hyparrhenia spp.	*Poaceae*	G	+	+
Bothriochloa crusculpha	*Poaceae*	G	–	+
Cacanium schuenfeathu	*Bresseraceae*	S	–	+
Justicia exegua	*Acanthaceae*	H	–	+
Cyperaceae rotundus	*Cyperaceae*	G	+	+
Loudetia simplex	*Cyperaceae*	G	–	+
Hoslundia opposita	*Lamiaceae*	S	–	+
Vitex spp.	*Vitaceae*	T	–	+
Hapachne schimperi	*Poaceae*	G	–	+

Key:

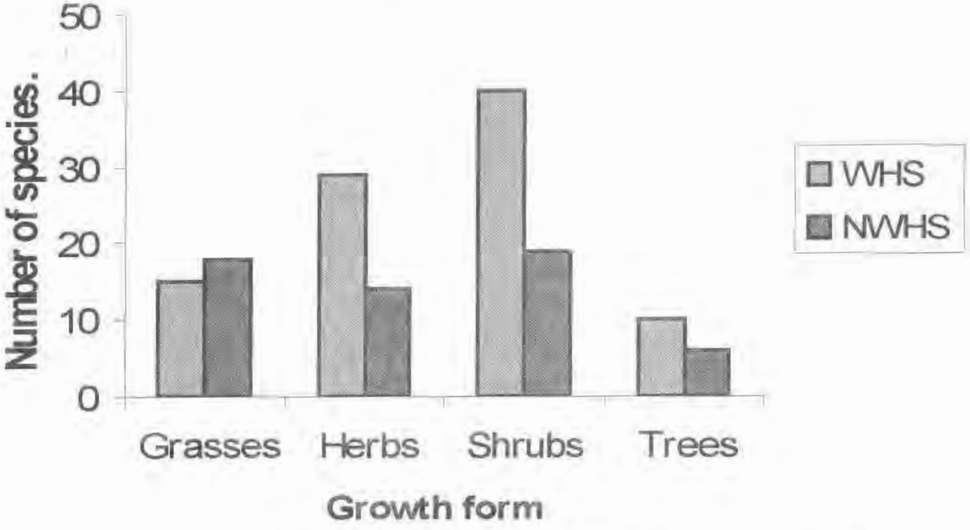
S = Shrubs
H = Herbs
G = Grass
T = Trees

Of the 37 families, 17 did not occur on ridges with water harvesting structures. Some included: Moraceae, Rutaceae, Convolvaceae, Celastraceae and Flacourtiaceae. Five of the 37 families were only represented on ridges without water harvesting structures. They included: Sapindaceae, Hypoxidaceae, Steculiaceae, Bresseraceae and Vitaceae.

The diversity of ridges with water harvesting (Shannon index) was $H^{/}=4.46$, while the diversity of ridges without water harvesting structures was $H^{/}=3.93$. The two types of ridges were found to be highly significantly different ($p<0.001$) in terms of the diversity of plant species.

The plant species seen above belong to different growth forms ranging from grasses to trees. Shrubs are most dominant for both types of ridges. These are followed by herbs, grasses and trees for ridges with water harvesting structures and grasses, herbs and trees for ridges without water harvesting structures. The establishment of water harvesting structures seems to encourage the growth of shrubs as compared to grasses where there is no water harvesting structures.

Comparing the two types of ridges, those with water harvesting structures presented higher species number for shrubs and herbs. Grasses were more on ridges without water harvesting structures. Trees were Higher on ridges with water harvesting structures (Figure 1).



WHS= Sites with water harvesting structures.
NWHS= Sites without water harvesting structures.

Figure 1 : Growth forms of plant species compared on the two types of ridges

The introduction of water harvesting structures did not affect the landscape pattern in plant distribution ($p<0.05$) (Table II). It only increased the diversity of species for all sections. The number of plant species ranged between 57 and 64 on ridges with water harvesting structures and 14 - 22 on ridges without water harvesting structures. Sections of ridges with water harvesting structures had higher number of common species as compared to the corresponding ones without water harvesting structures. ($p<0.05$) (Table II).

Table II: Plant species distribution along the toposequence

Section	WHS	NWHS
Lower	64 (28)	16 (0)
Middle	59 (25)	22 (1)
Upper	57 (28)	14 (1)

Total number of species (common species)

Key:
WHS = Water harvesting structures
NWHS = No water harvesting structures

Biomass was found to be treatment dependent. It was higher on ridges with water harvesting structures ($p<0.05$). The mean weight of biomass was 19.59 t/ha and 7.13 t/ha on ridges with and without water harvesting structures respectively. For ridges with water harvesting structures, the middle part had the highest biomass (27.22 t/ha) compared to other sections of the landscape i.e. 15.3 and 16.3 t/ha for lower and upper sections respectively ($p<0.05$). For ridges without water harvesting structures, higher values of biomass were recorded at the lower and middle sections (8.6 t/ha in average) ($p<0.05$) (Figures 2 and 3). This suggests that the middle section recovered relatively faster than other sections of the ridge. Sections of ridges with water harvesting structures had higher biomass compared to the corresponding sections without water harvesting structures ($p<0.05$). Biomass changes were reflected on ground cover; (86.1%) on ridges with water harvesting structures representing an increase of 69.2% compared to ridges without water harvesting structures. All sections of ridges with water harvesting had higher cover compared to corresponding sections of control ridges ($p<0.05$). However for all treatment no significant difference was observed between different sections of the ridges ($p<0.05$). This confirms a uniform cover recovery across ridges.

The observed difference in species richness, biomass and cover is attributed to water harvesting which increased the moisture content of the soil, after soil improvement as illustrated by soil chemical (Table III) and hydraulic properties (Table IV). Ridges with water harvesting technologies had higher values for all parameters ($p<0.05$) especially P, Na, Ca, Silt, pH, and OM, and showed

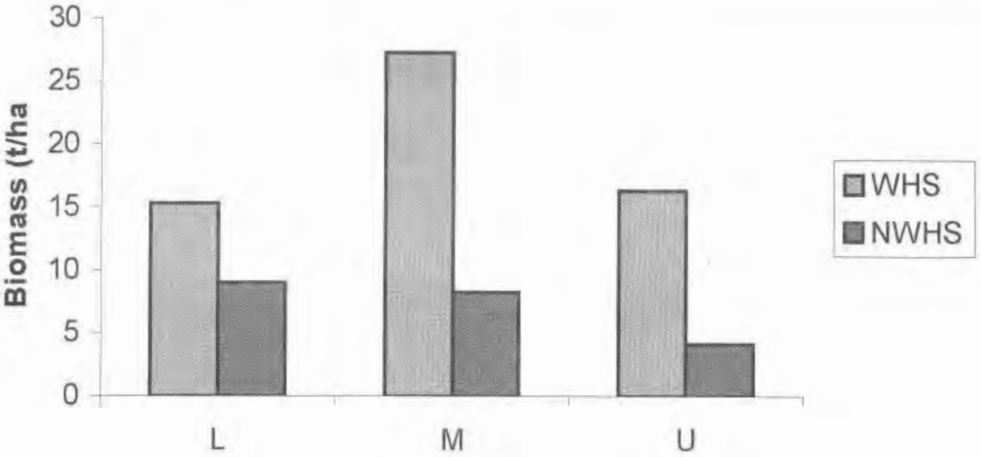


Figure 2: Change in biomas along the landscape on ridges with and without water harvest structures

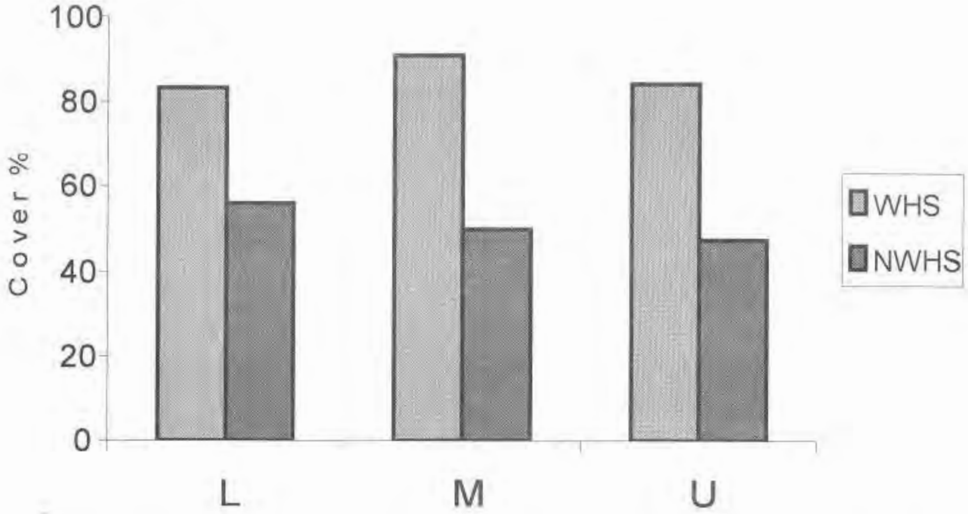


Figure 3: Change in ground cover along the landscape on ridges with and without water harvesting technologies

section variability ($p<0.05$), while those without water harvesting showed uniformity in OM up to the depth of 0 to 30 cm. Hydraulic properties also were higher on soils with water harvesting structures compared to the control, and had similar pattern as chemical properties along the toposequence.

Table III: Selected soil properties of ridges with and without water harvesting technologies

Treatment	Section	Depth cm	pH	OM %	P mg/kg	K Cmol/kg	Na Cmol/kg	Ca Cmol/kg	Sand %	Clay %	Silt %	TC
Ridges with water harvesting	Lower	0-15	5.2	15.2	15.1	0.6	0.3	2.5	39.7	27.0	33.3	CL
		15-30	5.1	10.7	15.2	0.4	0.2	1.4	34.7	33.0	32.3	CL
	Middle	0-15	5.3	10.0	16.2	0.5	0.2	2.4	35.7	32.3	32.0	CL
		15-30	5.0	6.53	7.9	0.3	0.1	1.0	31.7	36.3	32.0	CL
	Upper	0-15	5.5	11.2	13.6	0.6	0.3	2.6	36.3	31.7	32.0	CL
		15-30	5.0	7.70	8.9	0.2	0.1	0.8	31.0	35.7	33.3	CL
Ridges without water harvesting	Lower	0-15	4.6	9.4	8.2	0.6	0.1	1.6	37.5	33.6	28.9	CL
		15-30	4.3	8.0	5.1	0.4	0.1	0.6	36.8	35.6	27.6	CL
	Middle	0-15	4.6	8.1	6.0	0.5	0.1	1.0	37.9	34.3	27.8	CL
		15-30	4.4	6.8	3.5	0.3	0.1	0.3	35.9	33.6	30.5	CL
	Upper	0-15	4.5	7.3	5.7	0.4	0.1	0.5	31.5	37.6	30.9	CL
		15-30	4.3	5.7	3.2	0.3	0.1	0.2	28.8	38.9	32.3	CL
Lsd Treat •			0.14	3.70	ns	0.03	0.59	ns	ns	ns	2.12	
Lsd Section			Ns	ns	ns	ns	ns	ns	ns	Ns	Ns	
Lsd Depth			0.14	ns	4.73	0.03	0.59	ns	ns	Ns	ns	

Table IV: Hydraulic properties of soils along the landscape

Treatment	Landscape Position	Q (cm^3/min) h=30 mm	Q (cm^3/min) h=50 mm	Q (cm^3/min) h=50 mm	K_{sat} (cm/min)	Alpha (cm^{-1})
WHS	Upper	48.1	11.0	5.3	0.19	0.38
	Middle	77.8	32.7	9.3	0.29	0.41
	Lower	88.7	38.8	12.7	0.28	0.37
NWHS	Upper	64.3	20.6	7.9	0.19	0.44
	Middle	22.5	6.7	3.3	0.18	0.41
	Lower	45.6	14.0	5.3	0.21	0.41
Lsd_{treat}		Ns	12.3	3.7	0.05	Ns
Lsd_{pos}		Ns	21.3	Ns	Ns	Ns

CONCLUSION AND RECOMMENDATIONS

The study shows that, water-harvesting structures are effective in improving plant diversity and as a consequence, biomass and ground cover were also enhanced after three years of establishment. The study too shows that, contour bunds can improve significantly the chemical and physical properties of the degraded rangelands. However, there is need for continued monitoring of the rangeland recovery process in order to establish the different recovery phases and their associated plants diversities. The water harvesting technology can be used to rehabilitate the "bare hills" in South-Western Uganda. These barehills generate excessive runoff (Majaliwa *et al.*, In Press) and yet the only practice so far recommended is afforestation. A combination of water harvesting structures and afforestation may lead to faster recovery and hence reduced runoff and pollution of water bodies.

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