Status and trends of rangelands in Central Karamoja, recommendations for enhancement of livestock production

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EXECUTIVE SUMMARY

Long periods of livestock keeping, increase in cultivation and sedentarisation and the recent climate change and variability have affected livelihoods and vegetation of Karamoja.

An assessment of the vegetation was conducted in three sites using Langdale Brown *et all* (1964) vegetation documentation as a baseline. Nadunget site was suspected to be overgrazed, Nakicumet to have a grazing gradient reducing from a central watering point outwards and Lorengedwat site with a prevalence of least utilized woodland.

A total of 16 and 21 quadrants (20×20 m^2) were sampled from Nadunget & Nakicumet sites respectively. Sixteen quadrants (30×30 m^2) were sampled to capture the higher tree density at Lorengedwat site. Each quadrant was nested with a 2×2 m^2 quadrant at the North East corner from which herbaceous species were recorded. Within the 20×20 m^2 and 30×30 m^2 quadrants, woody species (trees and shrubs) were enumerated and their cover subjectively estimated. Diameter at breast height (Dbh) for woody species >1.5 m was measured.

The three sites are species rich with 142, 135 and 135 species recorded at Lorengedwat, Nadunget and Nakicumet respectively. Although the sites were nearly equally species rich, they were dissimilar in species composition. Of the total number of species present, Nakicumet and Nadunget had more herbs (71.1% and 56.3 % respectively) compared to woody species, whereas Lorengedwat had more woody (53.5%) species compared to herbaceous species. Lorengedwat site harbored more perennial species making it more stable, while Nakicumet and Nadunget had more herbal layer, providing better soil cover. No alien invasive species were observed. The watering point at Nakicumet has no effect on the distribution of plants species.

Bush fires have promoted prevalence of fire resistant species (*Dichrostachus cinerea*, *Themeda triandra* and *Lanea humilis*). This appears to have been caused by over harvesting of woody species and increase in environment temperatures (by increasing fuel biomass and flammability). Results from the questionnaire corroborates with this observation as they emphasized the importance commercial wood harvesting as a livelihood.

Calculations of carrying capacity indicate that Lorengedwat and Nakicumet are under stocked while Nadunget site is twice overstocked in the growing season. A need to enhance the production of feed resource (including hay harvesting), regulated use of bush fires to promote availability of feed resources in the dry season is highlighted. Problems identified by herdsmen still point to the need for increased access to water and pasture. A number of locations in the three study sites were identified for surface water harvesting.

In conclusion, extensive wood harvesting as a livelihood and global warming, appear to have enhanced occurrence of bush fires. A threefold increase in cultivated land has substantially reduced the rangeland. Rangeland restoration will essentially benefit from increasing biomass of indigenous tree species. Solutions to reasons for bush burning e.g. control of ticks can be addressed by training herdsmen and equipping them with modern tick control methods and inputs and establishment of cattle dips. Efficient wood use e.g. use of improved kilns for charcoal production and use of biomass debris (from tree cutting and gardening) for fuel briquettes will optimize use of wood and may reduce wood off take.

1. INTRODUCTION

Karamoja region is located in the driest North-Eastern corner of Uganda. The main livelihood in the region is pastoralism, with little supplement from cropping, especially by cereals. Livestock is kept on communally used grazing pastures. The availability of the feed resources (grazing pastures) depends on weather conditions; livestock use/grazing intensity and bush fire (Bassett and Crumney 2003). In addition, wildlife use and other human uses also affect the availability of grazing pasture. Although the region has high livestock populations, livestock production is generally low due to poor pasture, cattle rustling, diseases prevalence, lack of water, poor breeds and long distances travelled by the stock looking for fodder and water. The use of communally used pastures limits the introduction of improved animal breeds that require special care and cannot move long distances.

The pastoralist system in Karamoja is undergoing radical changes that are negatively affecting the pastoral livestock production (Anderson and Robinson 2009). There has been increased promotion of sedentarisation and crop cultivation (the area under crops has increase three fold in 10 years 2000 to 2011 Nakalembe et. all. 2017), apparently to promote food security (Avery 2014) this has led to fragmentation and reduction of the rangeland. There is however a recent emphasis on the importance of livestock as the main coping livelihood for the human population in Karamoja. Government, UN agencies and NGO have therefore supported this sector by improving framework conditions (animal health, water, and marketing) and animal re-stocking. But little consideration has been placed on rangeland management for livestock nutrition and rangeland health.

The communities' response has often been reactive principally for survival leading to the use of various mal-adaptive strategies that have triggered environmental degradation with a chain of negative implications. The implications include: increased soil erosion and degradation, vegetation cover loss, decreased potential for carbon sequestration, increased distance covered in firewood collection, and increased occurrence of unpalatable plants species for livestock.

1.2. Vegetation Trends

Vegetation types, distribution of species, density and other growth characteristics in Karamoja region are mainly influenced by climate, use by wild wildlife, human activities (e.g. utilization for livestock), and bush fire. A number of studies, including; Thomas (1943), Robertson *et al.,* (2014) and Langdale-Brown et al (1964) have documented the vegetation of Karamoja. As early as 1940s, Thomas (1943) noted places with intense grazing around Kopopwa hill in the present Napak District, he also observed that extensive sheet erosion and annual bush fires sweep through the woodlands. Whereas the author suspected that the erosion was caused by livestock overstocking, the livestock numbers then were much fewer 812,000 (cattle and shoats) than they are today >5,943,698 (cattle and shoats). There is a likelihood that the influence by livestock may have worked in tandem with wild herbivores which were more numerous then than they are today (Lamprey et. all 2003). Langdale-Brown *et al.,* (1964) observed that dry *Acacia* savannah, bush lands and dry thickets that prevailed showed signs of degradation. He suspected that only moist thickets and grass steppe that existed appeared more or less natural climax vegetation types. This they argue was later worsened by the construction of dams which facilitated grazing far beyond

the carrying capacity, while the cessation of annual burning favored shrub growth.

The late 1970s marked the start of the period of decimation of Karamoja's wildlife because the Karimojong acquired automatic weapons. There followed two years of drought, famine stricken people heavily took to poaching. Consequently, a survey in 1995 revealed that the wildlife estate in Karamoja was substantially depleted (Lamprey et. all. 2003). Some surviving wildlife populations were sighted in the former controlled hunting areas which were also used for livestock grazing e.g. areas South of Toror hills. The area was considered suitable for wildlife and was consequently gazetted as part of Bokora-Matheniko Wildlife Reserve. Variations in numbers of livestock and wild herbivores are likely to have had considerable influence on the vegetation. Site Restriction of livestock populations into Karamoja and in protected kraals also has had its toll on Karamoja vegetation, livestock production and livestock health. Until 1990's the Karimojong herdsmen used to migrate during the dry season to the Districts South and West of Karamoja where they would find water and pasture. This used to alleviate the effects of shortage of range resources and over stocking on the rangelands in Karamoja.

In addition, the restriction of stock into Karamoja and into protected Kraals, together with increase in cropping, and restriction by cattle rustling has lead to overgrazing and crowding of animals, disease spread causing high mortality (especially of calves) fragmentation of the rangeland and a general decrease in livestock numbers. This has disrupted livestock production system that has been a viable refuge to environment shocks generating destitute orphaned herdsmen and enhancing out migration.

1.3. Current situation

Today, the semi-arid climate of the sub-region experiences erratic onset, distribution and cessation of seasonal rainfall and temperature fluctuations (Egeru *et. all* 2014. More frequent droughts, almost every 2 to 3 years are common, instead of every 5 years as it used to be. Over the last 25 years Karamoja experienced 14 droughts. Cattle rustling, restrictions of stock within Karamoja and to protected kraals, disease prevalence due to climate vagaries and livestock congestion, have reduced livestock numbers. The above factors have negatively impacted on agricultural production, natural resource management and livelihoods, heightening household poverty.

In the dire struggle for survival people have resorted to charcoal burning, commercial firewood exploitation, mineral mining/quarrying, brick lying/baking, uncontrolled bush fires, overstocking and exposure of soil to desiccation is resulting into deforestation, land degradation, soil erosion and decrease in soil fertility. Cattle herders who lost their livestock to rustlers and settled in areas previously insecure and formerly used for dry season grazing took up cropping. The government and development partners responded by providing humanitarian aid, and agro implements to promote cropping. These settlements have led to rangeland fragmentation and a reduction in dry season grazing rangeland. The current scramble for land is likely to further fragment the communal rangeland further.

Efforts at improving livestock production have emphasized provision of water (dams, valley tanks e.g. Arecek dam) and health (vaccination, cattle crushes, cattle dips) ignoring livestock nutrition and rangeland health.

It is against this background that a study on the status of the rangelands in Central Karamoja as a basis for developing strategies for rehabilitation and subsequent sustainable management was conducted. The study looked at the trends in the range prevailing conditions, and a review of factors that led to this situation. A review of traditional rangeland management methods was undertaken for possible revival of those that are desirable. The study served as a pre-intervention assessment to guide intervention and inform the monitoring and evaluation and appraisal of the interventions efforts.

1.4. Study sites

Vegetation in Karamoja has been documented by, Langdale-Brown *et al.,* (1964) and Robertson *et al.,* (2014). Basing on Langdale-Brown, et al. (1964), the three selected areas for this study partly lie in a Bushland vegetation type. These bush lands are described as 'unstable regression stages which develop from savannas and steppes as a result of overgrazing'. They are distinguished by the presence of numerous deciduous shrubs and a ground layer of scattered, sparse annual grasses and herbs. Overgrazing of savannas reduces the intensity of annual fires by suppressing herbaceous growth which fuels the fires, and as a result fire-susceptible shrubs increase. These shrubs easily dry out, and the effect compounded by the sparse vegetation in the ground layer, leaves open areas prone to soil erosion.

1.4.1. Nadunget site

Nadunget sub-county in Moroto District partly lies in a 'Tree and Shrub Steppe' vegetation type which is distinguished by abundant small deciduous trees and shrubs and an open grass layer (Figure 1). The study area also partly lies along a low lying riparian 'Moist Thicket' which is a natural climax community of dense thicket with occasional emergent trees. Currently, this area appears to be overgrazed probably because the area was the site of a protected kraal in 2011.

1.4.2. Nakichumet

Matany subcounty Napak district largely lies in a 'site with impeded drainage'. Plant communities on these site with periodic inundation are tree and grass savannas consisting of perennial grasses, sedges and mixed deciduous trees, and are characteristic of dry areas. Currently these area is transversed by livestock that come daily (especially in the dry season) to drink water from Arecek dam which holds water all year round. The area is expected to experience a spiral grazing gradient reducing outward from the centre (the drinking source).

1.4.3. Lorengedwat

Lorengedwat sub-county Nakapiripirit District**,** in addition to Bushland vegetation, lies in a 'Dry Thicket' of the *Acacia-Commiphora* type and also in the low in riparian 'Moist Thicket' Langdale-Brown *et al.,* (1964). The 'Dry Thickets' are related to the *Acacia-Commiphora* bushland that occur as scattered clumps separated by areas of grass steppe. Figure 1 shows the location of the study sites within the different Langdale-Brown *et al.,* (1964) vegetation types.

A more recent map (Robertson *et al.,* 2014) is generally in agreement with Langdale-Brown's 1964 map. It lumps the woodland and steppe vegetation types described above into 'woody vegetation' of the type 'Somalia-Masai Acacia-Commiphora deciduous bush land and thicket', described as having a sparse tree cover of often thorny species and grasses. The Napak study site

is characterized as having ‘non-woody vegetation’ of the type ‘edaphic wooded grassland on impeded drainage or seasonally flooded soils’ which matches with Langdale-Brown’s Communities in sites with impeded drainage’ (Figure 1). Given that Robertson *et al.*, (2014) map does not describe plant communities in the area, an effort will be made to use the older Langdale-Brown *et al.*, (1964) as a baseline for this study.

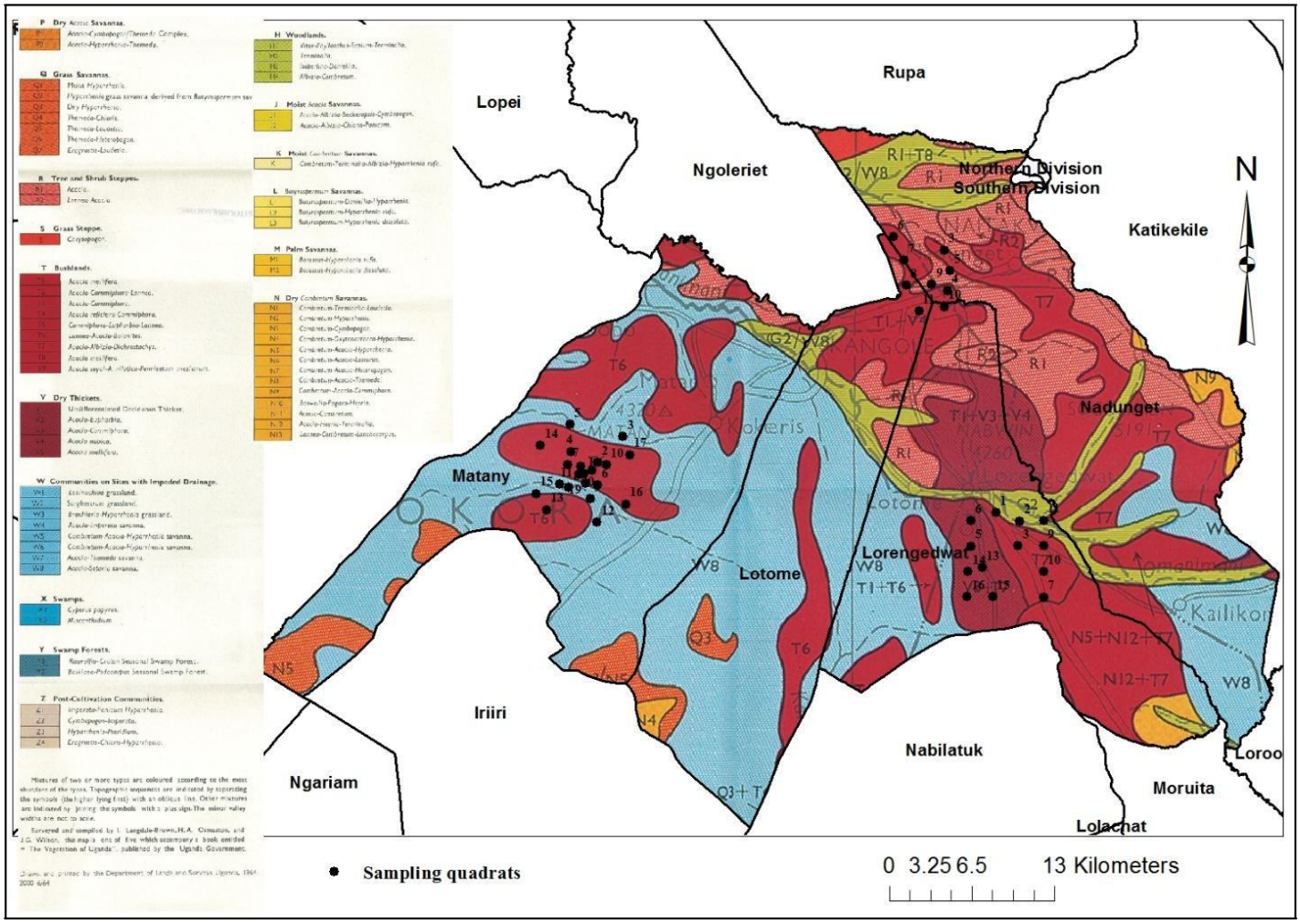


Fig.1 Location of study sites, showing the vegetation distribution according to Langdale-Brown *et al.,* (1964)

1.5. Objectives of the study

Given the above background to the study, the following objectives were developed to address the issues raised,

- **(i)** Assess the status of the rangeland using species composition, abundance, ecology, plant associations, and soil cover indices.
- **(ii)** Document traditional methods of rangeland management, knowledge, practices and opportunities for improvement of rangeland productivity,
- **(iii)** Locate, and appraise Water Harvesting Sites
- **(iv)** Estimate stock numbers, carrying capacity.

2.1. Status of the rangeland based on species composition, abundance, ecology, plant associations, and soil cover indices.

Introduction

Basing on Langdale-Brown *et al*., (1964), the three selected areas for this study partly lie in a Bushland vegetation type. These bushlands are described as 'unstable regression stages which develop from savannas and steppes as a result of overgrazing'. They are distinguished by the presence of numerous deciduous shrubs and a ground layer of scattered, sparse annual grasses and herbs. Overgrazing of savannas reduces the intensity of annual fires by suppressing herbaceous fire fueling growth, subsequently promoting fire-susceptible shrubs. These shrubs easily die out once there is a fire, and the effect, compounded by the sparse vegetation in the ground layer, leaves open areas prone to soil erosion. The site at Nadunget also partly lies in a 'Tree and Shrub Steppe' vegetation type which is distinguished by abundant small deciduous trees and shrubs and an open grass layer. Part of it lies along a low lying riparian 'Moist Thicket' which is a natural climax community of dense thicket with occasional emergent trees. The site at Nakicumet in Napak district largely lies in an area 'with impeded drainage'. Plant communities on these sites with periodic inundation are tree and grass savannas consisting of perennial grasses, sedges and mixed deciduous trees, and are characteristic of dry areas. In addition to Bushland vegetation, Lorengedwat study area also lies in a 'Dry Thicket' of the *Acacia-Commiphora* type and also in the low lying riparian 'Moist Thicket'. According to Langdale-Brown *et al*., (1964), the Lorengedwat 'Dry Thickets' are related to the *Acacia-Commiphora* Bushland and occur as scattered clumps separated by areas of grass steppe. Figure 1 shows the location of the study sites within the different Langdale-Brown *et al*., (1964) vegetation types.

A more recent map (Robertson *et al*., 2014) is generally in agreement with Langdale-Brown's 1964 map. It lumps the woodland and steppe vegetation types described above into 'woody vegetation' of the type 'Somalia-Masai *Acacia-Commiphora* deciduous bushland and thicket', described as having a sparse tree cover of often thorny species and grasses. The Napak study area is characterized as having 'non-woody vegetation' of the type 'Edaphic wooded grassland on impeded drainage or seasonally flooded soils' which matches with Langdale-Brown's 'Communities in sites with impeded drainage' (Figure 2).

This study aims at determining the current vegetation status of the rangelands and recommend methods of management that can be adopted to slow down the degradation rate given the current grazing pressure that is due to the growing animal densities, other human population activities, climate change and hence sustainably utilize the 'critical landscape'.

Findings from this study will be compared to the Langdale-Brown, *et al.,* (1964) vegetation types as a baseline in comparing the current species composition, abundance and structure and highlight changes that have occurred over the last 50 years. Basing on the original vegetation types, species groupings and functionality, the study will analyze the current status of the rangelands. The study will recommend management strategies that can be adopted to slow down the rate of change of the vegetation given the current land use types, and hence sustainably utilize the 'critical landscape'.

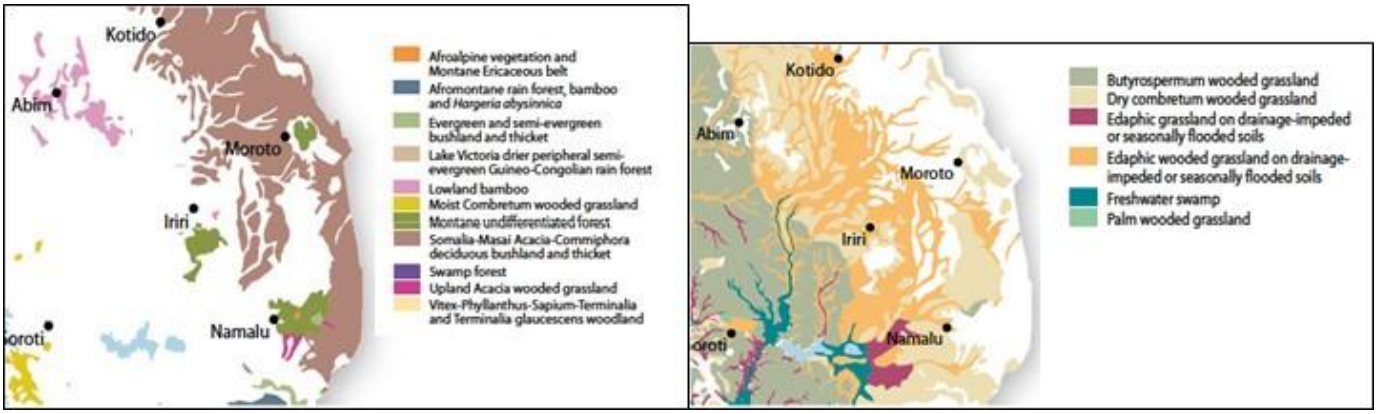
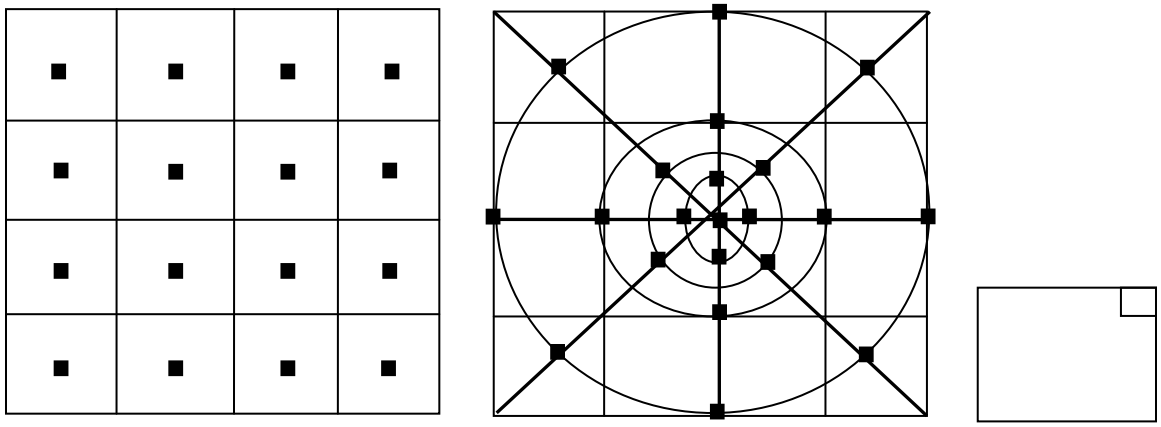


Figure 2. Robertson *et al*., 2014 Vegetation map



a) b) c)

Figure 3. Schematic presentation of the sampling design a) at Nadunget and Lorengedwat, b) at Nakicumet. c) A large quadrat nested with a small one.

2.2. Methods

Quadrants of 20 × 20 m^2 ware laid out at the Nadunget and Nakicumet, (30 × 30 m^2 for the Lorengedwat woodland, nested with a 2 × 2 m^2 quadrant at the North East corner (Figure 3) in order to avoid bias. The quadrant size at Lorengedwat was made bigger because of the higher tree density in this woodland.

Nadunget and Nakicumet are grassland areas. A total of 32 (16 quadrants from each site) were sampled from Nadunget and Lorengedwat, while at the Nakicumet site in Napak the center point of the watering area served as the focal point from where radiating transects were laid (Figure 3). This was done to have the quadrants concentrically positioned from the center so as to give an indication of the effect of grazing in relation to distance from the watering point. Including the central point, a total of 21 quadrants were sampled at Nakicumet. In some instances, the quadrant position was biased and shifted to areas with natural vegetation when a predetermined quadrant position fell on homesteads or cultivations. The sampling season was between June and August 2016, which is part of the late rainy (growing) season.

Within the 20×20 m^2 quadrants, woody species (trees and shrubs) were enumerated and recorded, and their cover subjectively estimated. Diameter at breast height (DBH) for those woody species taller than 1.5 m was measured for purposes of determining the vegetation structure. Herbaceous species were recorded from the 2×2 m^2 quadrants. These were not enumerated because of their indistinct growth forms but their densities were expressed as visual estimates of cover (Kent and Coker, 1994). The plants encountered were identified in the field with the help of botanical guides and those that could not be identified then were collected for subsequent identification at the Makerere University Herbarium. After the floristic assessments at each sample point, herbaceous species were clipped using a pair of scissors from 1×1 m^2 quadrants nested at the North East corner of the 2×2 m^2 quadrants. The fresh weight of this forage material was immediately weighed using a digital weighing scale.

The data was analyzed using Jaccard's similarity coefficient and Principal Components Analysis (NTSYS ver 2.1) in order to compare species composition of the sampled quadrants and sites, graphs were prepared using Microsoft Excel. The results are graphically presented as bar charts, tables and schematic drawings.

2.3. RESULTS AND DISCUSSION

2.3.1. Ecological status and plant community structure

a) Species richness

The three sites were found to be species rich with 142 species recorded for Lorengedwat, and 135 for Nadunget and 135 for Nakicumet. Although the sites were almost equally species rich, they were essentially dissimilar (based on Jaccard's similarity coefficients) with respect to species composition between the sites (Table 1; Appendix 1).

Table 1. Jaccard's similarity coefficients (%)

Site	Lorengedwat	Nakicumet
Nakicumet	28.1	
Nadunget	25	33.5

Of the total number of species present, Nakicumet and Nadunget had more herbs (71.1% and 56.3 % respectively) compared to woody species, whereas Lorengedwat had more woody (53.5%) compared to herbaceous species (Figure 4). Whereas woody species provide browse, most of the forage is provided by herbs. Of the total number

of species present, Nakicumet and Nadunget had more herbs (71.1% and 56.3 % respectively) compared to woody species, whereas Lorengedwat had more woody (53.5%) compared to herbaceous species (Figure 4). Whereas some woody species are browsed, most of the forage is provided by herbs as most of the livestock raised are grassers (cattle).

Woody species in rangelands in addition to availing browser play other major roles in water and nutrient cycles, as well as temperature regulation. Ecosystems with high species diversity are more temporally stable in ecosystem functioning than those with low diversity because they have a higher turnover of species that drive functions (Allan *et al.,* 2011). With respect to total number of herbaceous species, Nakicumet is a more stable rangeland because if the current dominant species were suppressed e.g. by overgrazing, other complementary species with similar driving function would take over dominance and function of the ecosystem would be stabilized with in terms of soil cover. While Nadunget and Lorengedwat are only moderately stable and their function as 'productive' rangelands could easily be altered over time if there are no/few alternative species that can support grazing as the key function of the rangelands and provide the necessary soil cover. This calls for planting of more trees in Nadunget and legumes in Lorengedwat.

Habits and life forms

Regarding life forms, all the sites had fewer annual species than perennial ones but the proportion of annuals in Lorengedwat (17.6%) was much lower compared to both Nakicumet (31.1%) and Nadunget (30.4%) (Figure 4). Dominance of perennial species in a plant community indicates that the community is stable or that it has reached a climax state (Pellant, *et al*., 2000).

In the case of the investigated sites Lorengedwat seems to be stable as a woodland, whereas the grasslands of Nadunget and Nakicumet may be considered to be less stable because they have more (ca. 30%) annual species. This result confirms the observation that there is more human disturbance at Nadunget and Nakicumet compared to Loregendwat. A routinely disturbed plant community shows dominance of annual species because they are quick to germinate and they quickly grow to maturity. Such a community can easily be colonized by invasive species, and is not resilient to shocks caused by e.g. long draughts, floods, overgrazing, etc. Human disturbances including tree cutting, charcoal burning, clearing for cultivation and grass cutting were observed at all the sites but the frequency of the observations was highest at Nadunget.

Focusing on potentially good grazing material, most of the herbaceous species present at the sites were perennial but the differences between the proportions of annual herbs and perennial ones were small (Figure 4). It would be preferred that the rangelands have significantly more perennial herbs than annual ones, implying greater plant community stability and availability of grazing material through all seasons, given favorable climatic factors. Comparing the three sites, although Lorengedwat had the least proportion of herbs, most of them were perennial (62.1%), indicating a higher level of plant community stability than Nadunget and Nakicumet with respectively 51.3% and 58.3% perennial herbs. Results from the questionnaire agree with this observation, showing that wood harvesting scored 55.1% while charcoal scored 36.6%. This emphasizes the importance of wood harvesting (both for charcoal, firewood and poles) and therefore calls for tree planting to increase the wood cover at Nadunget and Nakicumet. This will in addition generate suitable conditions for the prevalence of perennial herbs as was at the Lorengedawat woodland.

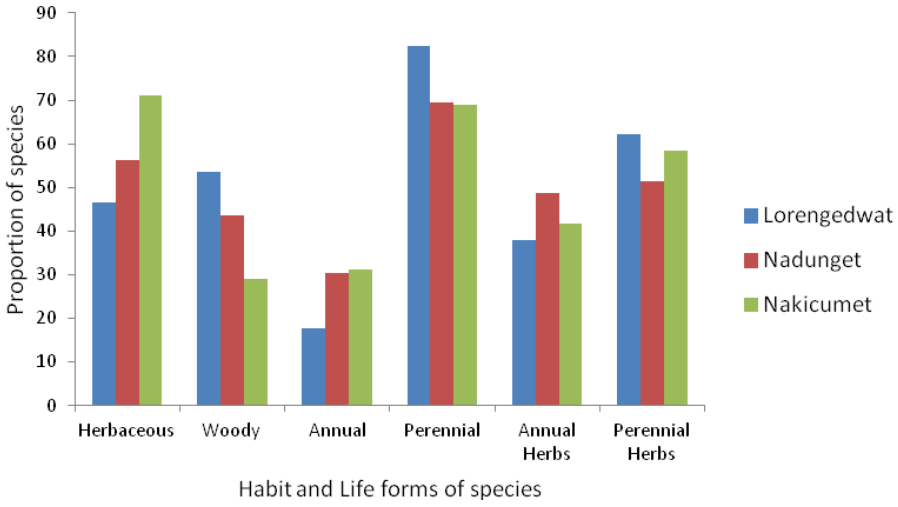


Figure 4. Comparison of habit and life forms of species within and between sites.

b) Plant cover – Herbaceous layer

Considering the ground layer separately from the shrub and tree layers, the plant cover of herbs (Table 2), in Nakicumet was up to 93.1%, Nadunget and Lorengedwat having lower herb covers of 70.6% and 38.4% respectively. The ground cover of herbs was lowest in Lorengedwat because of the shady environment created by the higher density of trees and shrubs at this site. Most herbaceous species are not tolerant to shade so they die off once shade intensity increases. The density of trees would need to be reduced if Lorengedwat was to be converted into a more productive rangeland. On the contrary, the open areas created by cutting of trees for charcoal in Nadunget do not lead to increased growth of herbaceous species because a lot of the land is already naked and exposed to seasonal sheet and gulley soil erosion. Thus, the soil in Nadunget has become compacted with hardly any accumulation of litter to enhance humus formation making it unsuitable for natural plant regeneration. In such a case regeneration could be enhanced by seeding forage species in the open patches, supporting them to germinate by covering the ground (e.g. with plant material in order to enhance humus build up) or contour furrowing, Ripping, potting to create barriers that would control erosion. Barriers like terraces and organic objects including cut or live plant material can be laid along contour lines to reduce the speed of running surface water and wind. Organic barriers would also help in creating a humus layer, hence contributing to nutrient recycling and soil moisture retention.

Bare ground is inversely proportional to the ground covered by herbs (Table 2). On average, the proportion of bare ground was low in Nakicumet (13.6%) but was fairly high in Nadunget (32.5%) and Lorengedwat (38.4%). The visual impression of bare ground is higher for Nadunget because the bare patches are consolidated and continuous, yet Lorengedwat that has a higher actual bare ground cover appears less open because the bare patches are small and discontinuous (patchy), interspersed with herbaceous vegetation and overshadowed by tree and shrub cover (Figure 5). Impacts of erosion by water and wind on the soil are high where bare patches are continuous, hence rendering such sites unstable. Therefore, Nadunget suffers more from erosion (is more unstable) than Lorengedwat.

Table 2. Percent cover of herbs and bare ground in the three sites

Quadrat No.	Lorengedwat		Nadunget		Nakicumet	
	Total herb cover[1]	Bare	Total herb cover[1]	Bare	Total herb cover[1]	Bare
1	78	40	18	70	101	15
2	77	25	35	50	87	15
3	62	40	111	25	91	15
4	68	30	78	30	96	2
5	74	25	70	30	69	30
6	49	60	60	20	105	2
7	61	40	69	30	77	20
8	60	40	91	10	73	25
9	85	10	58	40	96	3
10	79	40	74	50	117	0
11	70	50	80	25	91	10
12	50	50	58	25	99	2
13	49	40	104	10	100	3
14	52	50	41	70	89	20
15	38	50	90	20	89	20
16	69	25	92	15	109	15
17					89	10
18					80	60
19					108	1
20					109	3
Average cover	**63.8**	**38.4**	**70.6**	**32.5**	**93.1**	**13.6**

Totals of the individual covers for all herbaceous species present in every quadrant.

Figure 5. Continuous bare patches common at Nadunget and patchy ones at Lorengedwat.

c) Dominant grasses

The most dominant grasses at Nakicumet included *Themeda triandra*, *Bothriochloa insculpta*, *Setaria sphacelata* and *Sporobolus pyramidalis*. *Themeda triandra* is known to be a fire climax grass species whose seeds when buried in soil survive fires and quickly germinate at the onset of rains. These four species were reported to be liked by cattle especially *B. insculpta* which was reported to have some salty taste (results from the questionnaire showed that *B. inscalta* was among the most preferred of all forage by cattle). It was however pointed out that these species (apart from *B. insculpta*) were only very palatable when young and they were found to have grown very tall (up to 1 m) during the sampling season, an indication that grazing material was still abundant. *Sporobolus stapfianus* was dominant in areas that were highly disturbed. At Nadunget, the dominant species were *B. insculpta*, *Ischaemum afrum* and *Andropogon schirensis* and these were all said to be liked by cattle at all stages of growth. Dominant at Lorengedwat was *Heteropogon contortus*, *Themeda triandra*, *Panicum maximum* and *Cymbopogon caesius*. *Heteropogon contortus* and *Panicum maximum* are palatable at all stages of growth but the pastoralists preferred to graze their animals on *Heteropogon contortus* because it makes the animals fat. Most of the dominant fodder is grass, especially at the grasslands supplying close to adequate pasture in the rainy season. To improve livestock nutrition it is necessary to do seeding by legumes that would provide proteins at the same time enrich the soil especially in Nadunget and Nakicumet e.g. *Centrosema* and *Desmodium*. Nabuin Zonal Agricultural Reseach and Development Institute (ZARDI) could be supported to multiply identified legumes and to collect and propagate indigenous species.

d) Woody plant cover

For the shrub and tree layers (Table 3), the woody species contributed least ground cover in Nakicumet (28 %) and most in Lorengedwat (79.9 %), while Nadunget had 44.5 % cover. As cover of woody species increases, that of herbaceous species decreases (although woody and herbaceous species constitute different strata of vegetation) and eventually bare patches develop or their sizes increase. It is important

therefore to control the spread of woody species especially in Nadunget and Lorengedwat as a way of protecting the rangelands from degradation. Studies conducted in the semi-arid Ethiopian rangelands (Yusuf *et al*., 2015) established that restricting woody cover encroachment and improving herb cover by reducing grazing intensity are key strategies in maintaining soil organic carbon and total nitrogen, hence soil fertility. Adoption of management strategies that improve soil fertility while at the same time improving herb cover will be most desirable for improving the Karamoja rangelands, in this particular case Nadunget. Plant layers help support rangeland health; while the ground (herbaceous) layer protects the soil from erosion by providing a physical cover and their roots binding soil particles together. The tree and shrub layers contribute to nutrient recycling by fetching leeched nutrients from deeper soil layers and creating humus through litter, providing shade and litter which help in maintaining soil moisture, rain formation and subsequent lowering of temperatures. So the amount of herbaceous versus woody species should be kept at an optimum level that sustains a healthy rangeland. This information needs to be established for the three study sites. Apart from overgrazing, factors like trampling by large herds cause much reduction in the herb layer thus opening up the ground for establishment of woody species. This was observed at Nakicumet along a cattle track to the watering point, where all the grass died because of trampling but numerous seedlings of the fire resistant tree, *Lannea humilis*, were well established (Figure 6).

Most of the trees cut for wood especially charcoal were *Acacia* species and *Balanites*. *Balanites aegyptiaca* and *B. rotundifolia* are poor at regeneration and copicing especially when cut bellow knee height. Goats ingest the seed of *Balanites* and *Acacia* but deposit them in enclosures where they stay (goats) overnight at the manyatas. These seeds get lost from the rangeland, hampering regeneration of these trees. In protected areas where elephants and jackals occur, these animals serve as dispersers, ingested seed appear to germinate better than those not ingested. There is therefore a need to recover the seed and propagate for planting. Questionnaire results show how important wood harvesting is in the three sites. Under most management systems, 50% of the forage produced during the year should remain unglazed, 25% will be lost to trampling, insects and other animals, or rendered ungrazable due to livestock dung or urine. The remaining 25% of plant growth can be utilized by livestock (White and McGinty 1992).

Table 3. Percent cover of woody species in the three sites

Quadrat No.	Lorengedwat	Nadunget	Nakicumet
1	83	35	19
2	112	53	25
3	121	46	78
4	43	32	13
5	61	25	27
6	44	63	31
7	96	44	28
8	112	44	0
9	71	76	33
10	66	31	4
11	50	53	86
12	107	73	8
13	97	26	6
14	51	30	83
15	57	69	11
16	108	12	28
17			6
18			50
19			2
20			9
21			41
Average cover	**79.9**	**44.5**	**28**

N.B: Cover values are totals of individual woody species present in every quadrant.

Figure 6. Cattle track with established seedlings of *Lannea humilis* at Nakicumet.

2.1.4. Structure and frequency of woody species

The trees at all the sites were classified into four size classes basing on their DBH; hence >10cm, 5.1–10cm, 0.1–5cm and seedlings (including all those individuals less than 1.5m tall). At Nakicumet, most of the individuals were seedlings, the most numerous of

which were *Lannea humilis* (864), *Dichrostachys cinerea* (446), *Acacia Senegal* (222) and *A. drepanolobium* (116). There were a few individuals of large trees and other size classes (Table 4). It is crucial therefore to manage the frequency of fires at Nakicumet and prevent overgrazing at this site because decline in the cover of the herbaceous layer will create openings for establishment of the numerous seedlings of the fire resistant woody species (*Lannea humilis* and *Dichrostachys cinerea*).

Table 4. Frequency of woody species and their distribution across different size classes at Nakicumet

Family	Species	>10 cm	5.1-10 cm	0.1-5 cm	Seedlings	Total Frequency	No. of quadrats
Anacardiaceae	*Lannea humilis*	4	1	3	864	887	17
Fabaceae	*Dichrostachys cinerea*	1			446	447	9
Fabaceae	*Acacia senegal*	1			222	223	13
Fabaceae	*Acacia drepanolobium*	1	2		116	119	13
Malvaceae	*Grewia villosa*				52	52	6
Fabaceae	*Ormocarpum trichocarpum*				52	52	6
Fabaceae	*Acacia nilotica*				28	28	9
Fabaceae	*Acacia seyal*				26	26	7
Burseraceae	*Commiphora africana*				22	22	5
Balanitaceae	*Balanites aegyptiaca*	5	1		4	10	7
Capparaceae	*Cadaba farinosa*				9	9	3
Capparaceae	*Maerua parvifolia*				9	9	9
Fabaceae	*Acacia nubica*				6	6	1
Fabaceae	*Acacia gerradii*				5	5	1
Fabaceae	*Acacia polyacantha*				4	4	3
Rhamnaceae	*Ziziphus abyssinica*	1			3	4	3
Fabaceae	*Acacia mellifera*	1			2	3	3
Capparaceae	*Maerua edulis*				3	3	2
Balanitaceae	*Balanites rotundifolia*				2	2	2
Capparaceae	*Boscia salicifolia*				2	2	1
Malvaceae	*Grewia tenax*				2	2	2
Anacardiaceae	*Lannea triphylla*				2	2	1
Rutaceae	*Vepris glomerata*				2	2	1
Fabaceae	*Albizia amara ssp.*				1	1	1
Fabaceae	*Albizia anthelmintica*			1		1	1
Capparaceae	*Capparis sepiaria*				1	1	1
Boraginaceae	*Cordia monoica*				1	1	1

Nadunget had very few large trees, a few pole size ones (5.1–10cm DBH), and very many seedlings although these were not as numerous as at Nakicumet (Table 5). The big difference between the numbers of seedlings of dominating woody species for these two sites is probably a reflection of the poor soil conditions at Nadunget that do not seem to favor plant establishment. *Lannea humilis* was the most common woody species at the sites but Nadunget had only 184 seedlings and two trees, whereas Nakicumet had 864 seedlings and 23 trees. This suggests that overgrazing and probably frequent high intensity fires (Nakicumet had the highest herbaceous biomass that generates high intensity fire) at Nakicumet site are promoting *L. humilis.*

Table 5. Frequency of woody species and their distribution across different size classes at Nadunget

Family	*Species*	>10 cm	5.1-10 cm	0.1-5 cm	Seedlings	>10 cm	No. of quadrants
Anacardiaceae	*Lannea humilis*		2		184	186	7
Fabaceae	*Omocarpum trichocarpum*		1	2	148	151	14
Fabaceae	*Acacia nilotica*		1	2	87	90	11
Malvaceae	*Grewia villosa*				60	60	13
Malvaceae	*Grewia tenax*				58	58	12
Fabaceae	*Dichrostachys cinerea*				50	50	7
Fabaceae	*Acacia mellifera*				46	46	12
Capparaceae	*Maerua parvifolia*				31	31	5
Fabaceae	*Acacia seyal*			1	25	26	3
Capparaceae	*Cadaba farinosa*				23	23	8
Balanitaceae	*Balanites rotundifolia*		1		12	13	7
Balanitaceae	*Balanites aegyptiaca*		3	1	8	12	7
Boraginaceae	*Cordia monoica*				12	12	5
Fabaceae	*Acacia senegal*				12	12	4
Burseraceae	*Commiphora madagascariensis*	2	1		9	12	4
Capparaceae	*Capparis erythrocarpos*				11	11	4
Fabaceae	*Acacia tortilis*				6	6	3
Fabaceae	*Acacia drepanolobium*				6	6	1
Fabaceae	*Albizia anthelmintica*			1	4	5	4
Malvaceae	*Grewia trichocarpa*				5	5	4
Fabaceae	*Acacia nubica*				5	5	3
Capparaceae	*Maerua pseudopetalosa*				5	5	2
Rutaceae	*Zanthoxylum chalybeum*		1		4	5	2
Capparaceae	*Capparis fascicularis*				4	4	4
Fabaceae	*Acacia gerardii*		1	2		3	1
Capparaceae	*Capparis tomentosa*				3	3	1
Burseraceae	*Commiphora africana*				3	3	1
Capparaceae	*Capparis sepiaria*				2	2	2
Boraginaceae	*Cordia sinensis*				2	2	2
Capparaceae	*Maerua angolensis*				2	2	2
Euphorbiaceae	*Euphorbia candelabrum*	1				1	1
Capparaceae	*Maerua edulis*				1	1	1
Celastraceae	*Maytenus heterophylus*				1	1	1
Phyllanthaceae	*Phyllanthus ovalifolia*				1	1	1
Rhamnaceae	*Ziziphus abyssinica*				1	1	1

The most common woody species at Lorengedwat were the fire resistant *Dicrostachys cinerea* and *Lannea humilis* (Table 6). Unlike the other two sites, Lorengedwat had more trees of various species and is already established woodland but presence of the numerous seedlings of *Dicrostachys cinerea* needs to be pointed out. Apart from being fire resistant, *Dicrostachys cinerea* is known to be resistant against pushing and bending by strong animals (hence the local name Omulemanjovu – in southern Uganda). So the numerous seedlings could also be a result of strength against trampling.

Table 6. Frequency of woody species and their distribution across different size classes at Nadunget.

Family	Species	>10 cm	5.1-10 cm	0.1-5 cm	Seedlings	Total Frequency	No. of quadrats
Fabaceae	*Dichrostachys cinerea*	6	29	3	1121	1159	15
Anacardiaceae	*Lannea humilis*	6	18	5	283	314	15
Malvaceae	*Grewia trichocarpa*		11	20	175	206	16
Burseraceae	*Commiphora africana*	13	16	1	158	188	16
Anacardiaceae	*Lannea triphyla*	10	28	8	104	150	13
Malvaceae	*Grewia villosa*				113	128	16
Anacardiaceae	*Rhus natalensis*	3	18	7	100	128	13
Fabaceae	*Acacia brevipsica*			23	82	105	14
Rutaceae	*Zanthoxylum chalybeum*	8	4	1	68	81	15
Rutaceae	*Vepris glomerata*	2	4	1	49	56	5
Combretaceae	*Terminalia brownii*	9	6	3	28	45	15
Combretaceae	*Combretum aculeatum*	2	5	7	31	45	8
Ochnaceae	*Ochna inermis*		3	9	33	45	8
Capparaceae	*Maerua parvifolia*				2	40	8
Anacardiaceae	*Lannea fulva*	4	13	1	23	39	9
Fabaceae	*Acacia senegal*	1	3		35	39	9
Fabaceae	*Acacia nilotica*	13	12	2	10	37	11
Fabaceae	*Acacia mellifera*	12	4		13	29	4
Fabaceae	*Omocarpum trichocarpum*		4		24	28	12
Capparaceae	*Maerua edulis*				26	26	1
Fabaceae	*Albizia anthelmintica*	7	6		9	22	7
Euphorbiaceae	*Euphorbia candelabrum*	8	7		2	17	7
Capparaceae	*Boscia salicifolia*		1	1	15	17	6
Boraginaceae	*Cordia sinensis*		5	1	10	16	6
Burseraceae	*Commiphora schimperi*	3	7		6	16	4
Burseraceae	*Commiphora madagascariensis*	1	1		13	15	4
Convolvulaceae	*Ipomoea spathulata*		1		13	14	8

Fabaceae	*Acacia gerardii*	2			12	14	4
Fabaceae	*Albizia amara sp. sericocephala*	5			7	12	4
Fabaceae	*Acacia tortilis*	6	2		1	9	6
Malvaceae	*Grewia similis*			2	7	9	3
Capparaceae	*Maerua angolensis*				7	7	4
Balanitaceae	*Balanites aegyptiaca*	6			1	7	2
	(unidentifed tree)	2	4			6	4
Capparaceae	*Cadaba farinosa*		1	1	4	6	3
Balanitaceae	*Balanites rotundifolia*	1	2		3	6	2
Celastraceae	*Mystroxylon aethiopicum*		3		3	6	1
Capparaceae	*Boscia angustifolia*	4			1	5	4
Malvaceae	*Grewia flavescens*		1	1	3	5	3
Rubiaceae	*Rhytgynia sp.*			1	3	4	3
Capparaceae	*Maerua triphylla*	1	2		1	4	2
Ebenaceae	*Euclea divinorum*				4	4	2
Sapindaceae	*Allophylus sp.*	3		1		4	1
Combretaceae	*Combretum molle*				4	4	1
Malvaceae	*Grewia bicolor*				4	4	1
Capparaceae	*Maerua sp.*				4	4	1
Anacardiaceae	*Sclerocarya birrea*				4	4	1
Olacaceae	*Ximenia americana*	1	1		1	3	3
Menispermaceae	*Chasmanthera dependens*		1	1	1	3	3
Capparaceae	*Maerua crassifolia*				3	3	1
Capparaceae	*Maerua pseudopetalosa*				3	3	1
Malvaceae	*Grewia tenax*			1	1	2	2
Sapindaceae	*Allophylus africanus*				2	2	1
Boraginaceae	*Cordia monoica*			1	1	2	1
Malvaceae	*Pavonia patens*				2	2	1
Rutaceae	*Vepris nobilis*				2	2	1
Euphorbiaceae	*Euphorbia sp1*				1	1	2
Burseraceae	*Boswelia neglecta*				1	1	1
Capparaceae	*Capparis erythrocarpos*				1	1	1
Euphorbiaceae	*Croton dichogamus*		1			1	1
Simaroubaceae	*Harrisonia abyssinica*		1	1	1	1	1
Apiaceae	*Steganotaenia araliacea*		1	1	1	1	1

2.1.5. Effect of central watering point on species distribution at Nakicumet

The watering point at Nakicumet has no effect on the distribution of plants species. It was expected that locations equidistant from the watering point would have the same species of plants following dispersal and trampling by the animals but a Principal Components Analysis showed the distribution of plants to be random (Figure 7). There is probably some influence of human settlements on the distribution of plants in the rangeland but care was taken during sampling to keep away from observable human disturbances like homesteads, cultivations, paths, etc. It was clear though that trampling was highest at and towards the watering point as various cattle tracks converged. The effects of concentrated trampling towards the watering point could be mitigated by designating tracks that must be used by all herds from the various directions around the watering point. Alternatively, water could be piped further away from the current watering site, say to three other sites. This would reduce the number of stock watering from the site and thence reduce the effect of trampling at the site. In order to visualize the species distribution at Nakicumet, Figure 8 presents the distribution of dominant species found at the site. None of the species or species combinations showed patterns related to location of the contours around the watering point. This is in agreement with the result of the Principal Components Analysis.

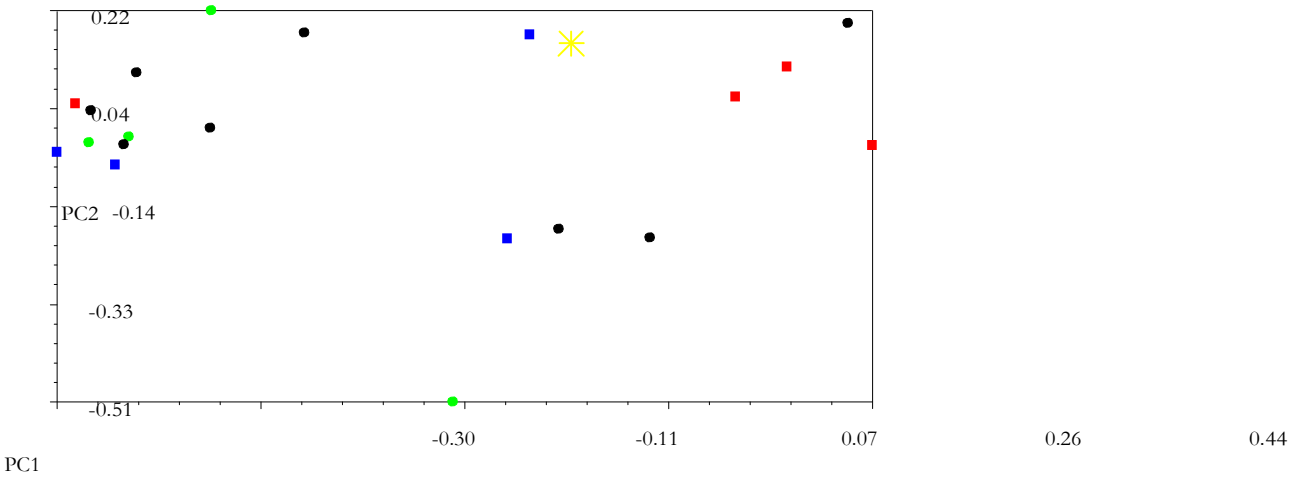


Figure 7. Principal Components Analysis of quadrants at Nakicumet showing clustering based on similarity in species composition**.** (Distances from watering point: Yellow star = watering point, Green circle = 0.7 km, Blue square = 1.4 km, Red square = 2 km, Black circle = 4 km).

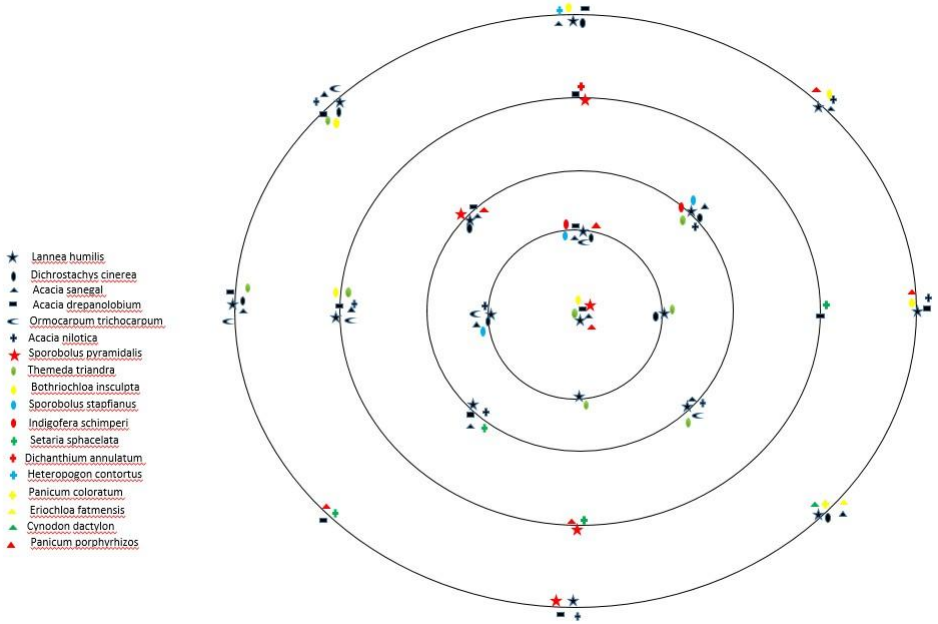


Figure 8. Schematic presentation of the distribution of the dominant species at Nakicumet. (Black symbols represent woody & colored herbs species).

Invasive species

No alien invasive species were observed, except indigenous ones were observed, less palatable, shallow- rooted plants were not assessed, however few cactus were observed in Nadunget, this form food for camels that are kept by herdsmen at the Nadunget site.

Within the sampled areas, five of the encountered indigenous species are listed as invasive (Global Invasive Species Database; www.iucngisd.org/gisd/). They include; *Acacia nilotica*, *Commelina benghalensis*, *Cynodon dactylon*, *Dichrostachys cinerea* and *Heteropogon contortus*. However, research on invasive species in Uganda is in its primary stages therefore the degree of invasiveness of these species at national level is not yet known. It is important to note here that *Dichrostachys cinerea* and *Heteropogon contortus* were among the most abundant species found, but are unlikely to cause any danger to other species as they are indigenous and form part of the forage for livestock.

Health status of the sites

Health of rangelands may be assessed basing on various sets of indicators including; integrity and ecological status, plant community structure, hydraulic function and nutrient recycling, site stability and presence of noxious weeds (Pellant, *et al*., 2000; Adams *et al.,* 2005). A healthy rangeland should have a mixture of native perennial grasses, forbs and woody species. These three categories of plants were found to occur in the study areas, bellow a detailed assessment of the species present.

In view of all indicators measured, Adams *et al*., (2005) proposed use of the following scale of scores to measure rangeland health: 0–49% as unhealthy, 50–74% as healthy with problems, and 75–100% as healthy. Thus, the same scale was adopted for the following indicators; diversity and cover of herbs, diversity of perennial species and diversity of perennial herbs. The scale was used in inverse for distribution of bare patches and percent cover of woody species, and it was modified to score herbaceous species height such that height of 0.7–1m was considered to be healthy, with problems for 0.5–0.74m and unhealthy for height below 0.5 m. The actual values used in this assessment are given and discussed in the preceding sections of the report. Table 7 summarizes the scores.

Table 7. Summary of health status assessed by selected indicators at the study sites

Indicator	Lorengedwat	Nadunget	Nakicumet
Diversity of herbs	Unhealthy	Healthy with problems	Healthy with problems
Cover of herbs	Healthy with problems	Healthy with problems	Healthy
Diversity of perennials	Healthy	Healthy with problems	Healthy with problems
Diversity of perennial herbs	Healthy with problems	Healthy with problems	Healthy with problems
Distribution of bare patches	Healthy with problems	Unhealthy	Healthy
Cover of woody species	Unhealthy	Healthy with problems	Healthy
Height of herb layer	Healthy	Unhealthy	Healthy

The direct and indirect effects of drought, excessive grazing, and/or excessive densities or cover of noxious, invasive or low-value plants can render rangelands dysfunctional relative to conserving water and nutrients and yielding the products and services needed by society (Thurow 1991). Over time the vegetative composition changes as the palatable, productive deep-rooted grasses die out and are replaced by smaller, less palatable, shallow-rooted plants (Archer and Smeins 1991, Briske 1991). The efficiency of water use on rangelands can be increased by controlling undesirable vegetation (Ueckert 1979, Thurow and Hester 2001).

Generally, there is a reduction of wood cover which would increase herbaceous cover (for grazing, this is positive, but not for browsing), however instead there is an increase in bare ground as a result of the soils inability to retain water.

Mechanical land treatments such as ripping, furrowing, and pitting can expedite natural recovery of decertified rangelands (Valentine 1971, Whisenant 1999) by increasing resistance to surface runoff, shattering compacted soil layers, and thereby increasing rainfall infiltration and retention. The soil disturbance provides a seedbed for new plant establishment. Seeding, planting of desirable indigenous trees, in the over trampled areas close to the Arecek dam at Nakicumet, and on the various bare patches at Nadunget can go a long way in restoring the functionality of the different functional groups and promote prevalence of perennial herbal species, enhancing the resilience of the rangeland.

2.2. Traditional practices of rangeland management, knowledge, and opportunities for modern rangeland management

2.2.1 Methods

A household survey was conducted to determine the knowledge, practices and opportunities for modern rangeland management. A representative sample of 98 households was selected randomly to participate in the study. Each household was represented by the households head or any member of the household found grazing the livestock. Data were collected using questionnaires and Focus group discussion. Data collected were entered in MS-Excel 2013 and imported into the Statistical Package for Social Scientists (SPSS 17) and STATA 12. Prior to final analysis, data were cleaned using visual and computer aided checks based on summary statistics generated in SPSS 17 and STATA 12 in order to identify any errors and outliers. The clean data were then analyzed using descriptive statistics, for example, means, frequencies, percentages and totals. Multiple choice questions were analyzed using multiple response analysis in SPSS 17.

2.2.2 Results and Discussion

Household attributes

Table 8 below shows that out of the 98 respondents, majority had no formal education (80.61%). Most of the respondents were married (69.4%e) and were Catholics (81.6%) among others.

Table 8 Sampling intensity and attributes of respondents

Education level	**No. of Households**	**Percent (%)**
No formal education	79	80.61
Incomplete primary	17	17.35
Complete primary	2	2.04
Total	**98**	**100**
Marital status		
Single/Never married	30	30.6
Married	68	69.4
Total	**98**	**100**
Religion		
Catholic	80	**81.6**
Protestant	12	**12.2**
Non	6	**6.1**
Total	**98**	**100**

Table: 9 Relationship of respondent to the household head

Relationship to the Household head	**No. of HHs**	**Percent (%)**
Head of household	75	76.5
Son/Daughter	15	15.3
Brother/Sister	1	1.0
Mother/Father	3	3.1
Other Relatives	4	4.1
Total	**98**	**100**

Household size is the number of persons who live in a household. Table 10 below shows that overall the average household size was 5.97 persons (*i.e. 2.89 males and 3.04 females*) which is higher than National average of 4.7 persons (UBOS, 2014). Table 10 also shows that average household size was 6.42 persons in Moroto district, 5.88 persons in Napak district and 5.59 persons in Nakapiripirit district. According to the National Population and Housing Census (UBOS, 2014), the average household size in Moroto was 4.4 persons, 5.3 persons in Napak and 5.7 persons in Nakapiripirit districts.

Table 10: Household size

Gender	Average HH size in Moroto district	Average HH size in Napak district	Average HH size in Nakapiripirit district	Overall Household size
Males	2.88	2.73	3.06	2.89
Females	3.55	3.03	2.53	3.04
Overall	6.42	5.88	5.59	5.97

Food security

Table 11. Food security in the household

District	Average number of meals per day
Moroto	1.69
Napak	1.55
Nakapiripirit	1.75
Overall	1.66

Fig. 9 Quarters in a year of household food inadequacy (n=98)

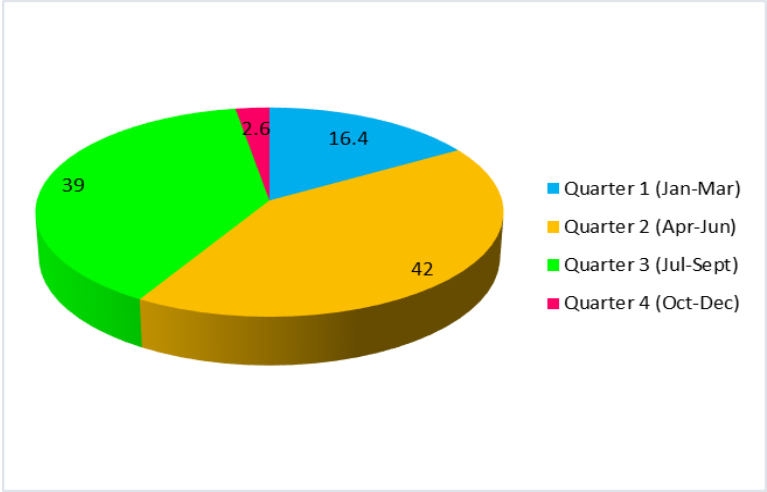


Fig. 10 Months in which household mainly faced with inadequate food

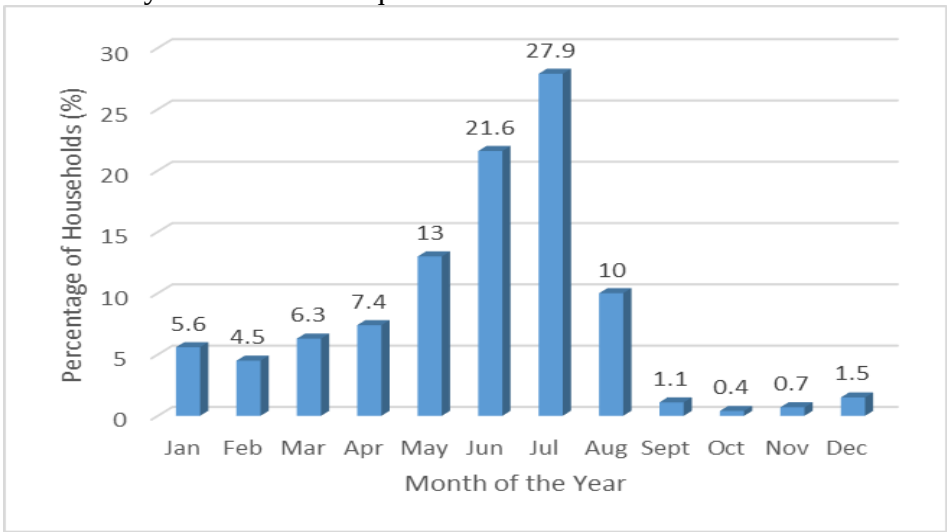


Table 12: Ownership of livestock by households

Type of Livestock	Average number of Livestock	Approx. Mean livestock
Cattle	4.45	5
Goats	7.03	7
Sheep	11	11
Donkeys	1.77	2
Others e.g Chicken	6.21	6

Rangeland utilization

Out of the 98 households which participated in the study, 84 households (85.7%) mainly grazed on communal land (i.e. 30.6% in Moroto, 25.5% in Napak and 29.6% in Nakapiripirit districts) as shown in Table 13 below.

Table 13 (a): Households that mainly graze on communal grounds

District	No. of HHs	Percent (%)
Moroto	30	30.6
Napak	25	25.5
Nakapiripirit	29	29.6
Total	84	85.7

Table 14: Main way of herd keeping.

District	Individual (%)	Collective (%)	Total (%)	No. of Households
Moroto	6	29.8	35.7	30
Napak	7.1	22.6	29.8	25
Nakapiripirit	3.6	31	34.5	29
Total	**16.7**	**83.3**	**100**	**84**

Table 15 below shows that out of the 84 households which mainly grazed on communal land, majority households (83.3%) practiced collective herd keeping.

Table 15: Main way of herd keeping.

District	Individual (%)	Collective (%)	Total (%)	No. of Households
Moroto	6	29.8	35.7	30
Napak	7.1	22.6	29.8	25
Nakapiripirit	3.6	31	34.5	29
Total	**16.7**	**83.3**	**100**	**84**

Out of the 98 households which had livestock, majority (98.8%) practiced rotational pattern of grazing animals (*i.e. 35.8% in Moroto, 28.4% in Napak and 34.67% in Nakapiripirit districts*). Overall, a few households (1.2%) practiced permanent pattern of grazing.

Table 16: Main period/months of grazing the livestock

District	Percent of Cases (%)
Quarter 1 (Jan-	10.0%
Quarter 2 (Apr-	13.8%
Quarter 3 (Jul-	15.0%
Quarter 4 (Oct-	17.5%
All Year	73.8%

Table 17 below shows that overall, a livestock moved, on average, 11.94km to access the communal grazing grounds.

Table 17: Distance (in Kilometres) between the household/Kraal and grazing grounds

District	Average Distance (in Km) to communal grounds		
	Average (km)	Minimum (Km)	Maximum (Km)
Moroto	12	3	30
Napak	14.36	3	25
Nakapiripirit	10.78	3	30
Overall	**11.94**	**3**	**26**

Table 18 below shows that overall, majority of the households (83.53%) observed that the grazing area was mainly characterized by short grasses and sparse short trees.

Table 18: Main characteristic of the grazing area

District	Short grasses and sparse short trees (%)	Tall grasses and sparse short trees (%)	Tall grasses and closed tall trees (%)	Total (%)	No. of HHs (#)
Moroto	93.55	3.23	3.23	100	31
Napak	88	4.0	8.0	100	25
Nakapiripirit	68.97	0.0	31.03	100	29
Overall	83.53	2.35	14.12	100	85

Table 19: Perception on quality of pasture in the grazing grounds

Grazing ground/area	**Excellent**	**Good**	**Average**	**Poor**	**Very poor**	**Total**	**No. of HHs**
Communal ground	55.1	21.4	7.1	3.1	0.0	86.7	85
Own ground	0.0	7.1	0.0	0.0	0.0	7.1	7

Table 20 below shows that overall; the main decision maker on use of grazing grounds was the head of the households (48.8%), followed by Elders in the community (18.6%), and Kraal leader (17.4%) among others.

Fig.11 Perception of quality of grazing area

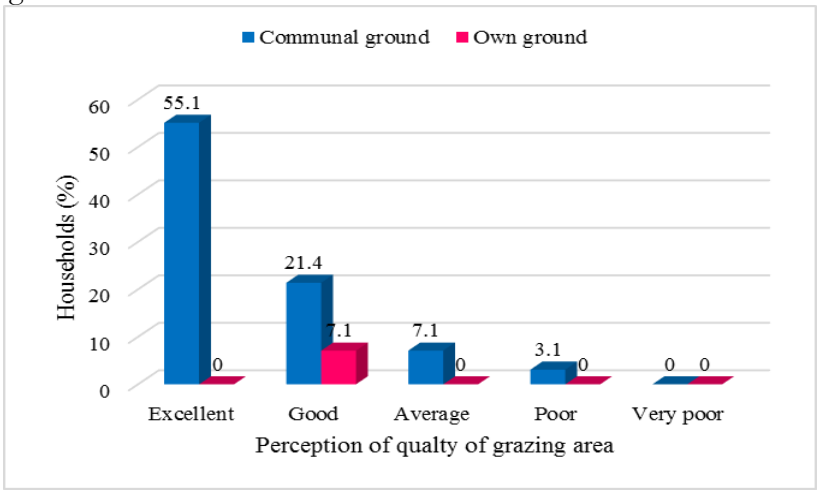


Table 20: Main decision maker on use of grazing grounds

Main decision maker on use of grazing grounds	Moroto district (%)	Napak district (%)	Nakapiripirit district (%)	Total (%)
Clan leader	6.3	12.0	6.9	8.1
Kraal leader	9.4	40.0	6.9	17.4
Elders in the community	12.5	24.0	20.7	18.6
Head of Household alone	62.5	24.0	55.2	48.8
Husband, Spouse and Children	9.4	0.0	6.9	5.8
Local Council Committee	0.0	0.0	3.4	1.2
Total (%)	**100**	**100**	**100**	**100**
No. of Households (#)	**32**	**25**	**29**	**86**

Table 21 below shows that grazing animals was mainly done by the Children & Adult males (57.1%). Hunting was mainly done by adult males (62.2%). Farming was done by all household members (61.2%). Quarrying was mainly done by adult male & female (25.5%). Wood harvesting e.g, firewood collection was mainly done by adult females (23.5%) and adult male & female (22.4%). Charcoal burning was mainly done by adult male & female (42.9%). Brick making was mainly done by adult males (32.7%). Household work/general domestic work was mainly done by adult females (43.9%). Herbal medicine was mainly done by adult males (31.6%) and also by adult male & female (34.7%). Craft making was mainly done by adult males (67.3%).

Table 21: Responsibility of family members in family business

	Household member								
Activities engaged in by the households.	Children (%)	Adult male (%)	Adult female (%)	All household members (%)	Child & Adult male (%)	Adult male & female (%)	Children & Adult females (%)	Overall (%)	No. of HHs (#)
Grazing animals	7.1	20.4	0.0	0.0	57.1	0.0	0.0	84.7	83
Hunting	3.1	62.2	0.0	0.0	10.2	1.0	0.0	76.6	75
Farming	0.0	1.0	1.0	61.2	4.1	9.2	0.0	76.5	75
Quarry work	2.0	6.1	13.3	13.3	0.0	25.5	2.0	62.2	61
Recreation	34.7	10.2	3.1	11.2	2.0	5.1	1.0	67.3	66
Wood harvesting e.g firewood collection	5.1	13.3	23.5	12.2	0.0	22.4	5.1	81.6	80
Charcoal burning	0.0	3.1	3.1	17.3	2.0	42.9	1.0	69.4	68
Brick making	2.0	32.7	4.1	3.1	1.0	7.1	0.0	50	49
Household work/General domestic work	1.0	7.1	43.9	17.3	0.0	5.1	3.1	77.6	76
Herbal medicine	0.0	31.6	4.1	2.0	1.0	34.7	0.0	73.5	72
Craft making	1.0	67.3	0.0	0.0	0.0	0.0	0.0	68.4	67

Alternative, competing uses of rangelands

Table 22 below shows that overall, most important activities in the grazing grounds were wood harvesting e.g. firewood collection (55.1%), followed by farming (46.9%), charcoal burning (36.7%), and herbal medicine collection (15.3%) among others. Other important activities were collection of Craft materials (37.8%), recreation (35.7%) and hunting wildlife (26.5%) among other important activities.

Table 22: Perception on Importance of other activities in the grazing grounds

Perception on Importance of other activities in the grazing grounds							
Other Activities engaged in and within the grazing area	Very important (%)	Important (%)	Neutral (%)	Less important (%)	Not important (%)	Overall (%)	No. of HHs
Hunting	10.2	26.5	6.1	16.3	2.0	61.2	60
Farming	46.9	2.0	1.0	0.0	0.0	50	49
Quarry work	14.3	18.4	4.1	4.1	1.0	41.8	41
Recreation	14.3	35.7	2.0	3.1	0.0	55.1	54
Wood harvesting e.g firewood collection	55.1	18.4	0.0	1.0	0.0	74.5	73
Charcoal burning	36.7	13.3	4.1	1.0	0.0	55.1	54
Brick making	5.1	6.1	4.1	12.2	6.1	33.7	33
Herbal medicine collection	15.3	14.3	24.5	5.1	0.0	59.2	58
Collection of Craft materials	9.2	37.8	2.0	4.1	3.1	56.1	55

Overall, majority households (76.5%) experienced some challenges during grazing. Table 23 below shows that the main problems faced were Long distance to search for pasture (69.3%). Inadequate water (38%), Poor quality pasture (48%) and Long distant to search for water (48%).

Table 23: Problems faced during grazing of livestock

Problems faced during grazing of livestock	**Percent (%) n=75**
Poor quality pasture	48.0%
Inadequate water	68.0%
Long distance to search for pasture	69.3%
Long distant to search for water	48.0%
Predators	5.3%
Conflict (land conflict or conflict over water)	14.7%

Out of the 98 households which participated in the study, a total of 85 households (86.7%) documented the main security provider to livestock. Table 24 below shows that the main provider of security was UPDF (76.5%), followed by Local council defense (61.2%), dogs (45.9%), household head (41.2%), and elders (30.6%) based on percentage of cases.

Table 24: Main provider of security to livestock

Security provider	Percent of Cases
UPDF	76.5%
Uganda Police	20.0%
Local council defense	61.2%
Household Head	41.2%
Other relatives	15.3%
Clan members	24.7%
Kraal leaders	20.0%
Elders	30.6%
Dogs	45.9%
Others	1.2%

Bush burning and setting of wild fires:

Figure 25 below shows that out of the 98 households which participated in the study, overall majority (62.2%) burnt bushes in the grazing grounds. Bush burning, compared to no burning scored highest in all districts, in Moroto (78.8%) consented to burning, Napak (51.5%) and Nakapiripirit (56.25%).

Fig.12 Bush burning in the grazing grounds

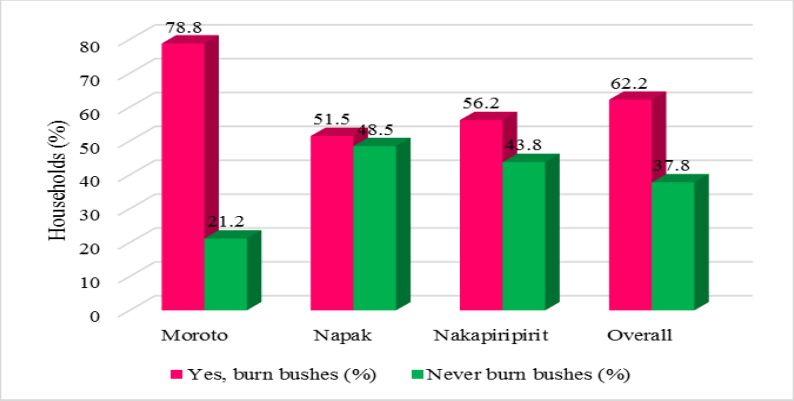


Table 24: Sanctioning/Ordering for bush burning

	Who mainly Sanctions/Orders for bush burning (%)								
Reasons for bush burning or wild fires	**Head of family (%)**	**Clan head (%)**	**Chief (%)**	**Other family members (%)**	**Non (%)**	**Head of HH & Clan leader (%)**	**Head of HH & Other family members (%)**	**Total (%)**	**No. of HHs**
To prepare land for farming/	77.5	1.0	20.0	2.0	1.0	2.0	3.1	100	40
To allow new pasture to grow	76.6	4.3	0.0	4.3	2.1	8.5	4.3	100	47
To kill vectors e,g Ticks and mites	88.1	4.8	0.0	2.4	0.0	2.4	2.4	100	42
Hunting wildlife	50.0	15.6	0.0	15.6	15.6	3.1	0.0	100	32
Scare away predators	75.0	0.0	0.0	0.0	12.5	12.5	0.0	100	8
Clear the bushes for security/vision	85.0	10.0	0.0	0.0	0.0	5.0	0.0	100	20
Traditional practice/culture	66.7	33.3	0.0	0.0	0.0	0.0	0.0	100	3
For fun/recreation	66.7	0.0	0.0	33.3		0.0	0.0	100	3

Table 25: Frequency of burning bushes or setting wildfire

	Frequency of bush burning					Main Period in Months of the Year/Quarters (%)						
Reasons for bush burning or wild fires	**Always (%)**	**Rarely (%)**	**Never (%)**	**Total (%)**	**No. of HHs (#)**	**Quarter 1 (Jan-Mar)**	**Quarter 2 (Apr-Jun)**	**Quarter 3 (Jul-Sept)**	**Quarter 4 (Oct-Dec)**	**All year**	**Total (%)**	**No. of HHs (#)**
To prepare land for farming/	72.7	22.7	4.5	100	44	59.1	13.6	9.1	0.0	18.2	100	22
To allow new vegetation to grow e.g pasture	61.4	36.4	2.3	100	44	59.1	13.6	22.7	0.0	4.5	100	22
To kill vectors e,g Ticks and mites	64.1	33.3	2.6	100	39	60	20	20	0.0	0.0	100	20
Hunting wildlife	64	28	8	100	25	71.4	7.1	14.3	0.0	7.1	100	14
Scare away predators	14.3	64.3	21.4	100	14	50	50	0.0	0.0	0.0	100	2
Clear the bushes for security/vision	29.4	58.8	11.8	100	17	75	25	0.0	0.0	0.0	100	4
Traditional practice/culture	20	20	60	100	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
For fun/recreation	25	25	50	100	8	50	50	0.0	0.0	0.0	0.0	2

Table 26: Main copping mechanism to drought.

Main copping mechanism to drought.	Moroto district (%)	Napak district (%)	Nakapiripirit district (%)	Overall (%)	No. of HHs (#)
Splitting herd/Splitting herd	21.4	52.0	25.9	32.5	26
Access Valley dams & other water points	50.0	32.0	33.3	38.8	31
Graze early morning when grass is still cool and fresh.	0.0	4.0	11.1	5.0	4
Others e.g Migration	28.6	12.0	29.6	23.8	19
Total	100.0	100	100	100	80

Table 26 above shows that the main coping mechanism was accessing valley dams & other water points (38.8%), followed by splitting herd/splitting herd (32.5%), and migration (23.8%).

Acceptability of modern, improved methods of rangeland management

Table 27: Modern/ improved methods rangeland management

Modern/ improved methods rangeland management	Ever heard (%)	Never heard (%)	Total (%)	Total No. of HHs (#)	Prefer (%)	Not prefer (%)	Total (%)	No. of HHs (#)
Short-term rotational grazing?	68.4	1.0	69.4	68	29.6	2.0	31.6	31
Complementary use of grazing ground by grazers and browsers?	61.2	2.0	63.3	62	25.5	2.0	27.6	27
Rangeland improvement by sowing specific fodder plants/ plantation of fodder banks?	35.7	18.4	54.1	53	20.4	0.0	20.4	20
Co-existence of wild animals and domestic livestock? Pasture cropping?	4.1	3.1	7.1	7	1.0	0.0	1.0	1
Others specify Modern/ improved methods rangeland management?	2.0	0.0	2.0	2	2.2	0.0	2.0	2

Table 27 above shows that rangeland improvement by sowing specific fodder plants/ plantation of fodder banks is preferred to traditional methods of short-term rotational grazing Complementary use of grazing ground by grazers and browsers.

2.2.3. Discussion

The household size in Moroto District may be higher in this study compared to the national average because the study targeted rural population whose literacy is low, level of education and exposure to family planning and valuing of family size is low.

Most households had 2 meals in a day in the morning before they disperse to go for work (except snacks for those who stay home) and in the evening after return from work, this may be the general practice even when there is plenty of food, however the quantity consumed varies according to how much food is in stock.

The worst shortage of food is experienced in the second quarter i.e. April through June after the reserves have been depleted for food and paying for farm labour and or increased consumption to cope with energy needed cultivation activities. In the fourth quarter the stocks would have been replenished with first harvest from the month of October through December. The number of cows declared by respondents may not be dependable because people prefer to declare few numbers just in case the objective of the study is to support the poor families e.g. by livestock restocking.

Grazing on communal rangeland was the commonest and most dominant, but the rangeland has problems of grazing control as no one takes control to ensure rotation, the grazing site suffers from problems of the tragedy of the commons. Interventions in the communally grazed areas will suffer from challenges of land tenure, ownership and the practice of communal grazing. It may be true that there is an attempt on rotational grazing but no single authority, body regulates the grazing in terms of which herd graces where, when and for how long.

Group herding as practiced presents challenges of disease spread, when herder, vaccinates, treats or sprays his stock and others don't, disease can spread from those that are not treated to those treated.

The highest average distance moved to graze animals was in Napak district may because of the dam stock come from far both for water grazing do not (14.36km), followed by Moroto (12km) and Nakapiripirit district (10.78%). The distances covered daily during grazing livestock may not be accurate, and authentic as the majority of the respondents are illiterate and have no idea on how far, long a kilometer is, the estimates are just subjective.

The survey revealed that Kraal leader; Elders in the community and head of Households are key decision makers on livestock management. It is therefore important to target Kraal leaders, Elders in the community and Head of Households to implement interventions to address the issues of livestock production.

The study was done in the rainy season when, pasture is abundant so respondents observed the pasture to be in good condition; the result would have been different if the study was done in the dry season.

Results from the questionnaire showed how important wood harvesting is in the three sites. This emphasizes the need for tree

planting preferably indigenous species that have been depleted, are viable and will restore ecosystem stability and resilience; most used by the people e.g. *Balanites aegyptiaca, Acacia nilotica, Faidherbia albida, Albizia* species among others.

Investments should therefore target adults who normally engage in activities that are mal-adaptive to the environment and engage in activities that are not mal-adaptive such as dam construction, tree propagation and planting, crafts making etc. Most of the children especially boys that are not school going are looking after cattle, an effort (bye laws should be developed to outlaw children of school going age from herding livestock) should be made to motivate adults look after the cattle and leave the children to go to school.

Problems identified by herdsmen still point at challenges to do with water and pasture. Investments should still not exclude increased access to water and pasture. It will also entail wise uses of the two resources that are available.

There is a high score in the role of the army that may have had influenced from the advent of protected Kraals. However, there is a need to reduce the role of the army in protecting livestock as the army has a national defense mandate, build the capacity of local defense forces should be built to serve this role..

In all districts, the number of people that admitted to burning was more than those that did not. The figure for those who admitted should normally be higher as some of them believe, or know that burning vegetation is condemned. So they wish to appear to be good citizens who do not destroy their environment. So the actual numbers who should have admitted must be high. Target the reasons given to address the issue of fire regulation and planned use of fire.

The main reasons given for burning include preparing land for farming, to allow new forage to grow e.g. pasture, kill vectors e.g. ticks and mites. The issue of vectors and increased access to pasture, e.g. pasture growing and pasture harvesting should be addressed and educating people on the wise use of fire should be undertaken. Manuals on use of fire for rangeland management, opportunistic delineation of areas can be considered to demonstrate the disadvantages of uncontrolled use of bush fires.

Splitting herd, access to valley dams & other water points, migration, all still point to the need for more water for stock, and pasture. This point to the need for controlled bush burning, promotion of farmer managed regeneration and the use of enclosures and increased access to water. The use of solar powered boreholes may be viable to provide water for animals that stay behind after others have migrated in the dry season.

The herdsmen are conversant with short-term rotational grazing, complementary use of grazing grounds by grazers and browsers, rangeland improvement by sowing specific fodder plants/plantation of fodder banks to enhance livestock production. There is a need to recognize the centres of power in the management of rangelands and promote/support such groups in rangeland management.

Proposals for rangeland improvement, from the questionnaire results and status of the rangeland condition point to a need for the following;

- Increased access to water sources, construction of more dams and solar powered boreholes,
- Regulated use of bush fires, to enhance availability of forage, provide solutions for vector (ticks) control so as to reduce the need to burn as a means to eradicate the to use fire e.g. establish cattle dips.
- Reduce cutting trees, plant more indigenous trees and promote farmer managed regeneration and establishment and management of enclosures to restore rangeland, improve availability of forage.

2.3. Locating and appraising Water Harvesting Sites

Introduction:

Water harvesting is the process of inducing surface runoff and directing the runoff into a reservoir. Surface runoff can be induced artificially using artificial catchment such as roof or paved surface or naturally using natural catchment such as rock surface or soil with low infiltration capacity. In the latter case, runoff is created when rainfall intensity exceeds infiltration capacity. In natural catchment, typical of rangeland areas in Karamoja region, runoff flow via storm water drains into local watercourses, reaches or streams.

Rainwater harvesting provides water supply during period of water scarcity. The water can be used for human, livestock and crops.

2.3.1. Locating, and appraising the sites

Identification and appraisal of rainwater harvestings was done as follows;

Site location

Stream network (drainage) and terrain (contours) maps were overlaid to identify potential areas for water harvesting. The stream networks were defined using the Digital Elevation Model (DEM) obtained from the Shuttle Radar Topography Mission (STRM) at 30-meter resolution. Minimum drainage area of 400 hectares (assumed as the minimum catchment size for any water harvesting site) was used to define the stream network. The base map of Uganda, available on line at http://www.gfk-geomarketing.de/en/digital_maps/uganda.html was used in delineating the contour and drainage maps (Figures 13 & 14).

Spatial representation of the sites is shown in Figure 13 & 14. In Figure 13 contours and drainage are overlaid. The figure was used to identify direction of flow, availability of depression, which can serve as potential storage sites, and availability of rock surface. In Figure 14, slope was used to identify very high slope, which is not suitable. Slope range for good water harvesting site based on the storage technology is given below.

2.3.2. Appraising the identified sites

The sites were appraised based on hydrological consideration as describe here below;

1. Field inspection

A check list of decision rules for selection of suitable water harvestings sites was developed. Using the developed checklist, field inspections were carried out to confirm suitability of the identified sites. Global Positioning Systems (GPS) was used to navigate to the identified water harvesting sites.

Check list/decision rules for selection of the suitable water harvesting site-based on storage technology and harvesting surface

2. Valley tank/pond

(i) Ideal location of the pond should be on narrow stream with high ground on either side of the stream
(ii) Slope should be less than 5%
(iii) Land use may be barren or shrub
(iv) Soil should be sandy clay loam
(v) Presence of water indicating vegetation, signifying presence of shallow ground water. The vegetation used was *Acacia Seyal*, most dominant vegetation in the area.

3. Sand dam

(i) Slope should be less than 4%, preferably between 2 to 4%.
(ii) Potential of the catchment to produce coarse sand: Ground trothing was conducted to ascertain this
(iii) Suitable size of the width of the river to ensure extensive aquifer formation
(iv) Seepage under the river bed where the river bed aquifer is formed should be minimum. This was checked during field survey
(v) Vegetation that indicates the presence of shallow groundwater as proof of the riverbed capacity to store water.

4. Rock catchment

(i) The rock that makes up the catchment should be bare and free of vegetation/soil. It should have no fractures, cracks, or soil pockets that would result in a loss of water through seepage.
(ii) There should be no severe soil erosion in the catchment area
(iii) There should be sizable area of the rock catchment.

2.3.3. Recommendation

The list of coordinates for the identified water harvesting sites and suitable technology for the water harvesting is given in appendix 2. A total of 6 sites were identified in "Nadunget" Moroto District, 9 sites were identified in "Lorengedwet" Nakapiripirit District and 7 sites were identified "Nakicumet" Napak District. In Nadunget, one site (GPS coordinate 677950 Easting, 270908 Northing) is highly suitable for dam construction. The rest of the sites are suitable for valley tank and rock catchment (Appendix 2). In Lorengdwet, two sites (GPS coordinates 685750 Easting, 246972 Northing & 685742 Easting, 246962 Northing) are highly suitable for valley tank development, however, the flow has to be diverting from the main stream, in order

to minimize siltation of the tanks. The rest of the sites are suitable for valley tank development. In Napak, one sites (GPS coordinates 645979 Eastings; 258686 Northing) have very high potential for rock catchments development. Site number 5 with coordinates 646084 Easting; 258701 Northing have very high potential for development of valley tank with stream diversion should be considered. The validation/appraisal given for each site is based on hydrological consideration. Other considerations including social and economic suitability needs to be conducted before any of the sites can be recommended for development.

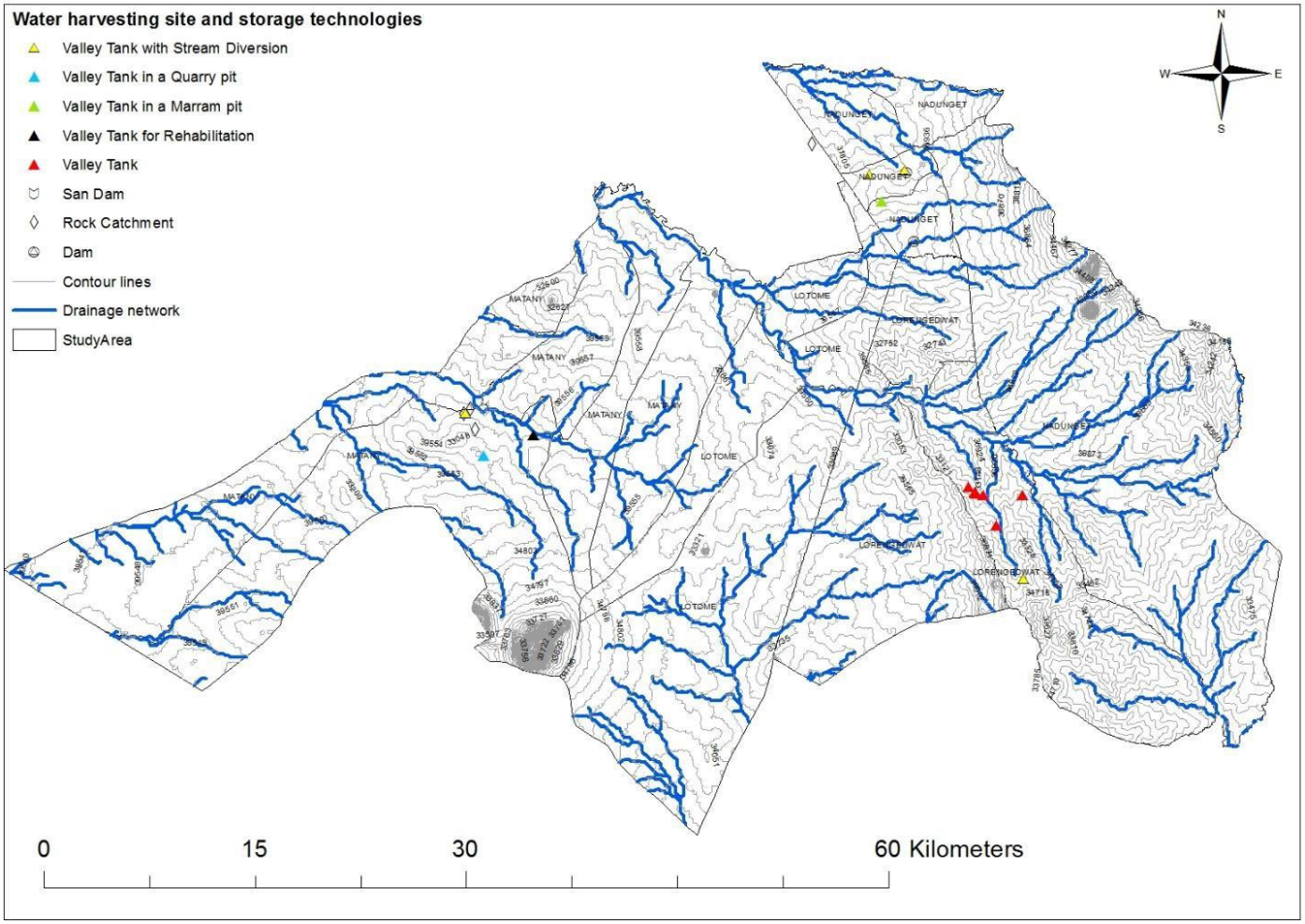


Figure 13: Contours and stream network overlaid, showing the identified water harvesting sites

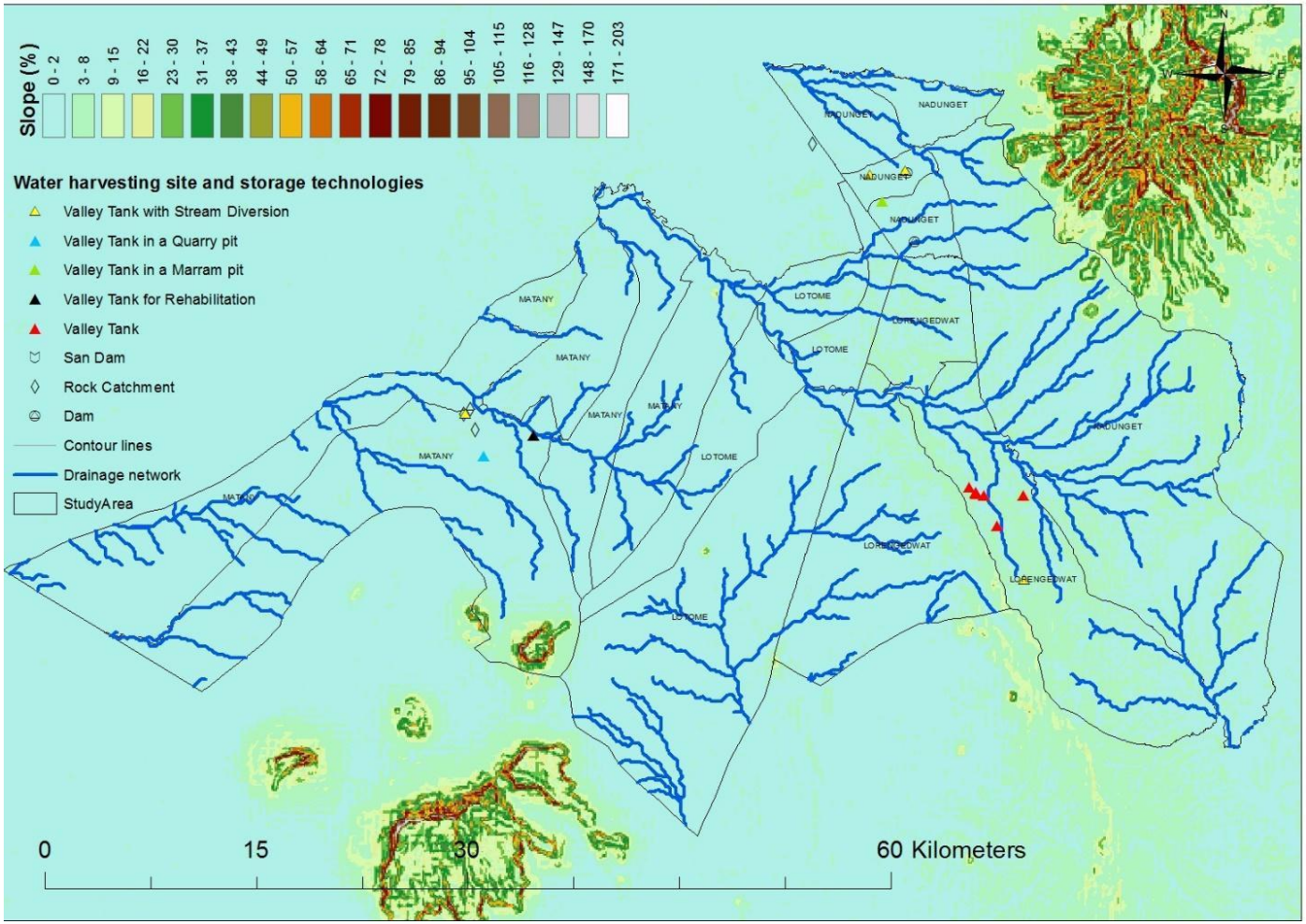


Figure 14: Slope and stream network overlaid showing identified water harvesting sites

2.4. Estimating stock numbers, carrying capacity.

2.4.1. Primary Production

Lorengedwat had a moderate average primary production (wet weight) of 417.5 g/m^2, bare ground was low to medium (10)25 – 50(60) %. Plant height of the herb layer ranged from 0.5 – 1.2 m and the dominating species included the grasses; *Panicum maximum*, *Heteropogon contortus* and *Themeda triandra*. There were signs of old burning observable at Lorengedwat and these three grasses, being perennial, would recover well after fire. This site would require management interventions aimed at reducing the extent

of exposed ground.

Average primary production at Nadunget was low at 242.2 g/m^2. Bare ground cover was low to moderate ranging between (10) 20 – 50 (70) %, with some extreme cases having very open ground. The herbaceous plant height was generally short (0.1 – 0.5 m) and the dominating species included the perennial grasses *Andropogon schirensis* and *Bothriochloa insculpta*, and the forb dominating where the grass cover was very low. Tree cutting was the main type of disturbance observed in Nadunget. Tree cutting opens up the ground for colonization by perennial herbs (including grasses) but with the high levels of already exposed ground coupled with trampling from grazing, the soil gets compacted and sheet erosion hampers the natural regeneration of the vegetation.

Average primary production was high at Nakicumet (694 g/m^2). This was probably a result a combination of low bare ground cover, (2)15–25(30) %, and a tall herbaceous layer at (0.3) 0.6–1.4m. The dominating species here included the perennial grasses; *Sporobolus pyramidalis*, *Themeda triandra*, *Bothriochloa insculpta* and *Setaria sphacelata*. Tree cutting and burning were the disturbances observed in this area but negative effects on the primary production would be realized if the exposed ground extent was high. Table 28 below compares the average values of primary production, percent bare ground cover and height of the herb layers at the three study sites.

Table 28. Average values for primary production, bare ground cover, dry matter estimate, estimate carrying capacity and height of herb layer for the three study sites.

	Lorengedwat	Nadunget	Nakicumet/ Matany
Primary Production (g/m2)	417.5	242.2	694
Bare ground cover (%)	38	35	17
Height of herb layer (m)	0.9	0.4	1
Dry matter per m^2 (0.27% moisture content Aleper 2013)	304.76 gm	176.81 gm	506.62gm
25% harvest efficiency gm/ m^2	76.19	44.26	126.6
Dry matter production tons sq.km^2	14,435.53	1,912.5	58,437.12
Estimated foraging grazing area km^2	189.52 sq km	43.27	461.37
Total dry matter production per area	14,435.53 tonns	1,912.5tonns	58,437.12tonns
Estimated dry matter consumption kg per cow/month	273	273	273
Estimated cattle numbers	8,500	16,000	26,684
Estimated carrying capacity	52,877.4	7,005.5	214,055.4
Current status	Under stocked	>2Overstocked	Under stocked

Estimated weight of East African cattle 350 kgs, 1,000 Lbs = 455 kgs

Estimation of carrying capacity

Daily dry matter consumption
NB a cow is expected to consume 2.6% of body weight on dry matter basis, so we can estimate the dry mater production per month and estimate how many cows can be supported (no variation in forage demand).

1 East African cow 350kg will consume (350000gs /100) ×2.6 =9,100gm

(350/100) 2.6=9.1kg per day

Monthly dry matter consumption

9.1×30=273 kg dry mater per month,
273/1000=0.273 tonns per month

Dry matter production

Dry matter primary production square per metre **Lorengedwat** (417.5/100) ×27%
=417.5-((417.5/100) ×27) moisture
=417.5-112.72=**304.76 gm**

Dry matter primary production square per metre **Nadunget** (242.2/100) ×27%
=242.2-((242.2/100) ×27) moisture
=242.2-65.39=**176.81 gm**

Dry matter primary production square per metre **Matany** (694/100) ×27%
=694-((694/100) ×27) moisture
=694-187.38=**506.62gm**

25% **harvest efficiency per sq. metre** (White and McGinty 1992),

Lorengedwat
304.76/100×25=76.19gm

Nadunget
176.81/100×25=44.2

Matany
506.62/100×25=126.66

Total dry mater production per area

Lorengedwat
1000×1000=1000000 (sq m per Km)×189.52 (area in sq. km)× 76.19gm gm (dry matter harvest efficiency per metre)
=14,439,528,800gm/1000kg/1000tonns=**14,435.53 tonns**

Nadunget
1000×1000=1000000 (sq.m per Km)×43.27×44.2=1,912,534,000 gm/1000kg/1000tonns **=1,912.5tonns**

Matany
Dry matter production per sq. Km **Matany**
1000×1000=1000000×461.37×126.66=58,437,124,200/1000kg/1000tonns=**58,437.12tonns**

Carrying Capacity

Lorengedwat
If a cow needs 0.273 tonns of dry matter per month, how many cows will graze 14,435.53?

14,435.53/0.273=**52,877.4 number of cattle**

Nadunget

1,912.5/0.273=**7,005.5 number of cattle**

Matany

58,437.12/0.273=**214,055.4 number of cattle**

Calculations shown on the table above indicate that all the sites are under stocked except Nadunget site which is more than twofold overstocked. The figures suggest that Matany and Lorengedwat harbor fewer numbers of livestock than can be supported by the forage at this season, however a number of assumptions hold:

(i) Not all dry matter harvested may be palatable for livestock,
(ii) The rangeland boundaries are not delineated,
(iii) No consideration was given for other herbivores other than cattle and wild herbivore termites.

It is expected that the rangeland sites can anyway support higher numbers in the wet growing season (particularly in Nadunget and Lorengedwat), there is therefore need to manage fire in such a way that standing hay saved for livestock to subsist on in the dry season. Grazing areas can be zoned in such a way that any burning applied is done when humidity conditions can favor a re-growth of pasture. Efforts should also be put in place to grow and harvest hay, or harvest from naturally growing pasture. This can be done hand in hand with establishment of enclosures and breed improvement especially for dairy production.

3 CONCLUSION AND RECOMMENDATIONS

1. Grazing management involves balancing the numbers of animals with the forage supply, selecting the appropriate species and classes of animals to be grazed, controlling the timing of grazing and distributing grazing evenly across the landscape (Briske and Heitschmidt 1991). The challenge with this is the tenure of communal grazing where there no management plans or management authority for grazing, no grazing units, the rangeland is used by all but managed by none. The herdsmen could be organized into groups for the management of specific communal grounds. Communal areas could then be delineated into grazing units and their management entrusted to a committee that can make management plans to regulate grazing, use of bush fires and any support for improvement of the rangelands.

2. Rangeland resource managers must learn to work with the natural ecological processes of energy flow, the hydrological cycle, and mineral cycles to manage vegetation and soils in order to achieve and maintain high infiltration rates to minimize losses of water, soil and nutrients in surface runoff (Ludwig *et al.*, 1997, Whisenant 1999). To prevent further degradation of the ecosystems, the following may be considered:

3. Comparing the three sites, although Lorengedwat had the least proportion of herbs, most of them were perennial (62.1%), indicating a higher level of plant community stability than Nadunget and Nakicumet with 51.3% and 58.3% perennial herbs respectively. Diversity of herbs needs to be enhanced especially at Lorengedwat so that reduction in a particular species because of overgrazing, drought or any other factor may be offset by an increase in a related species in order to maintain the ecosystem function. Planting legumes like *Centrosema, Desmodium* could enhance herbal diversity.

4. Results from the questionnaire recorded a high importance of wood harvesting (both for charcoal, firewood and poles) there is a need to increase the wood cover at Nadunget and Nakicumet to replace the harvested stock in order to restore the role of the woody functional group at this sites. There is need to promote woodlot planting for wood harvesting and also replace those that have been cut. Indigenous trees like *Balanites* sp., *Acacia* sp., *Faidherbia albida, Tamarindus indica, Sclerocarya birrea, Acacia melifera, Albizia* among others should be promoted. These trees have various ethnobotanical uses for fodder, shade, food and

shelter; they will also serve as windbreaks and protect the soil.

5. Height of herb layer: very low herb layers expose more soil surface ultimately leading to soil erosion. Such areas are prone to being overgrazed especially if there is overstocking of animals cover of herbs needs to be increased at both Lorengedwat and Nadunget and in this way the size of the bare patches will decrease, ultimately increasing water infiltration and primary production. This can be done by seeding of the preferred grazing material that can be propagated (e.g *Bothriochloa insculpta, Heteropon contortus* and legumes *Centrosema, Desmodium*) while putting in place mechanisms to control soil erosion e.g. by ripping, contour furrowing.

6. Cover of woody species is very high at Lorengedwat if this woodland area is to be used for grazing. Factors that enhance the encroachment of woody species should be controlled. They include overstocking, changes in fire frequency and intensity, changes in nitrogen deposition, increasing atmospheric CO2 concentration and climate change. Herdsmen should be trained in the regulated use of fire for managing the rangelands. On the other hand, promotion of camels can make the woodlands more productive as the camels will forage on the tree browse which is available all year round. Camels also produce more milk than the current indigenous cows.

7. The questionnaire results show a need for increased access to pasture and water especially in the dry season, the time of shortage. From the estimates of primary production, it is clear that 2 sites Matany and Lorengedwat can support more cattle in the growing season, the challenge of pasture shortage is mainly experienced in the dry season. There is therefore need to promote pasture harvesting and growing to provide feed in the dry season at least for stock that people are dependent on e.g. lactating cows. Training and promotion for pasture harvesting and growing should go hand in hand with introduction and promotion of improved livestock breeds.

8. Location of watering point has no effect on the distribution of plant species at Nakicumet, but the impacts of trampling are amplified close to the watering point. Therefore, cattle tracks should be designated in areas near watering points in order to reduce on the size of areas left bare as a result of trampling. Alternatively, water could be piped further away from the current watering site, say to three other locations away this would reduce the number of stock watering from the site and thence reduce the trampling at the site minimizing the patches.

9. Suitable sites for water harvesting were identified based on hydrological consideration; however the validation for each site should further consider social and economic suitability. Economic and social assessment of the sites should be conducted to corroborate their feasibility for development. Establishment of other watering sources will reduce the impact of trampling, degradation at the dam.

10. Farmer managed regeneration and enclosure management at private level could be promoted to reduce rangeland degradation and increase availability of forage. At such enclosures naturally growing pasture can be harvested or cultivatedt. Fodder production in

enclosures not only enables enclosure owners to stock fodder for use during the dry season (Gaani et al., 2002; WOCAT 2003) but have also been reported to reduce herding needs amongst enclosure owners in Chepareria hence individuals have more time for cultivation Makokha et al., (1999), Wernersson (2013) and Karmebäck (2014). Enclosures have improved soil stability, improved hydrological cycles, and nutrients recharge and exchange and carbon sequestration on a landscape level (Scherr et al., 2012). Enclosures will relieve some school going age children who spend time herding in Karamoja to be able to go to school. Enclosures are considered part of disaster risk reduction (DRR) programming, the theory being that they protect livestock assets, and therefore livelihoods, from the impact of drought (Napier and Desta 2011).

11. Fire is an integral factor in the evolution of rangelands in the Karamoja woodlands where it maintains grasslands especially of annual species. It causes top kill (killing of the above ground shoots causing them to re-grow from the stem at various heights above ground) of shrubs, tree seedling and keeps them stunted. In many areas in Karamoja one will find a cohort of suppressed tree seedlings and saplings that are trapped by annual burning (and also browsing). In all the sites there were signs of bush fire in the previous dry season as evidenced by stems burnt dry on top and with fresh green re-growths from bellow. A seedling that has suffered top kill can remain suppressed with a well-developed root system for as long as there is annual burning and browsing, but can grow to a size beyond top kill if there is no fire even for 2 consecutive years. There a need to educate the herdsmen on benefits of regulated use of fire to improve availability of forage and reverse degradation. Opportunistic selection of sites can be made in areas with natural fire breaks e.g. rivers and roads, such areas can be managed to demonstrate of the effect of fire on the vegetation. Investments on vector (e.g. ticks) control by e.g. use of cattle dips and devising other ways of disposing moribund material e.g. by making briquettes may reduce the need for bush burning.

4. Problems encountered

Inaccessibility of sites, many of the sites identified were very inaccessible. We had to cross Rivers, over stony surfaces especially at the Lorengedwat site and at the dam site specifically during humid conditions. We had to walk long distances to reach some sites.

Wild animals, in one occasion we encountered two viper snakes, we also cited footprints of large wild animals, most likely buffalo, which made us to work with constant fear especially at the Lorengedwat woodland.

It was also not easy to get a car to hire especially when the owners knew the vehicle would be driven in the wilderness with no roads.

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6: APPENDICES

Appendix 1: List of plant species

Family	Species	Lorengedwat	Nadunget	Napak	Habit	Life form	Propagation mode
Acanthaceae	*Asystacia mysorensis*		1		Herb	Annual	Seed
Acanthaceae	*Asystacia schimperi*			1	Herb	Annual	Seed
Acanthaceae	*Barleria acanthoides Vahl*		1		Shrub	Perennial	Seed
Acanthaceae	*Barleria eranthemoides C.B. Cl.*	1	1		Shrub	Perennial	Seed
Acanthaceae	*Crabea velutina*	1			Herb	Annual	Seed
Acanthaceae	*Dicliptera laxata C. B. Cl.*		1		Herb	Perennial	Seed
Acanthaceae	*Dyschoriste radicans*	1	1		Herb	Annual	Seed
Acanthaceae	*Hygrophyla auriculata*		1	1	Herb	Annual	Seed
Acanthaceae	*Justicia anselliana (Nees) T.*	1	1	1	Herb	Annual	Seed
Acanthaceae	*Justicia caerulea Forsk.*		1		Herb	Perennial	Seed
Acanthaceae	*Justicia exigua*		1	1	Herb	Annual	Seed
Acanthaceae	*Justicia glabra*		1		Herb	Annual	Seed
Acanthaceae	*Ruellia patula Jacq.*	1		1	Herb	Annual	Seed
Agavaceae	*Sanseveria ehrenbergii*	1			Herb	Perennial	Rhizome
Agavaceae	*Sanseveria suffruticosa*	1		1	Herb	Perennial	Rhizome
Aloaceae	*Aloe secundiflora*		1		Herb	Perennial	Rhizome
Aloaceae	*Aloe tweediae Christian*	1	1	1	Herb	Perennial	Rhizome
Amaranthaceae	*Achyranthes aspera*	1	1		Herb	Annual	Seed
Amaranthaceae	*Psilotrichum schimperi*			1	Herb	Annual	Seed
Anacardiaceae	*Lannea fulva Engl.*	1			Shrub/Tree	Perennial	Seed, Cutting
Anacardiaceae	*Lannea humilis (Oliv.) Engl.*	1	1	1	Shrub/Tree	Perennial	Seed
Anacardiaceae	*Lannea triphylla (Hochst.ex A.*	1		1	Shrub/Tree	Perennial	Seed
Anacardiaceae	*Rhus natalensis Krauss.*	1			Shrub/Tree	Perennial	
Anacardiaceae	*Sclerocarya birrea (A.Rich.)*	1			Tree	Perennial	Seed, Cutting
Anthericaceae	*Chlorophytum cameroonii Bak.*	1	1	1	Herb	Perennial	Seed, Rhizome
Anthericaceae	*Chlorophytum subpetiolatum*	1	1	1	Herb	Perennial	Seed, Rhizome

Anthericaceae	*Chlorophytum sp.*		1		Herb	Perennial	
Apiaceae	*Steganotaenia araliacea Hochst.*	1			Tree	Perennial	Wilding, Cutting
Apocynaceae	*Caralluma dicapuae (Chiov.)*		1		Herb	Perennial	
Apocynaceae	*Marsdenia rubicunda (K. Schum.)*		1		Shrub	Perennial	
Apocynaceae	*Sarcostemma andongense*		1		Shrub	Perennial	
Apocynaceae	*Sarcostemma viminale (L.) L.*	1			Shrub	Perennial	
Apocynaceae	*Secamone sp.*	1			Shrub	Perennial	
Araceae	*Arisaema sp.*	1		1	Herb	Perennial	
Asparagaceae	*Asparagus africanus Lam.*	1	1	1	Shrub	Perennial	
Asparagaceae	*Asparagus falcifolia*	1			Shrub	Perennial	
Asparagaceae	*Asparagus flagellaris (Kunth.) Bak.*	1	1	1	Shrub	Perennial	
Asteraceae	*Aspilia kotschyi (Sch. Bip.) Oliv.*	1		1	Herb	Annual	
Asteraceae	*Aspilia pluriseta Schweinf.*			1	Herb	Annual	
Asteraceae	*Crassocephalum bojeri*	1			Herb	Perennial	
Asteraceae	*Kleinia longiflora DC*			1	Herb	Perennial	
Asteraceae	*Vernonia cinerea (L.) Less*	1			Herb	Annual	
Asteraceae	*Vernonia smithiana*	1		1	Herb	Annual	
Balanitaceae	*Balanites aegyptiaca (L.) Delile*	1	1	1	Tree	Perennial	Seed, Root
Balanitaceae	*Balanites rotundifolia (Van Tiegh.)*	1	1	1	Shrub/Tree	Perennial	Seed
Boraginaceae	*Cordia monoica*	1	1	1	Shrub	Perennial	Seed, Wildings
Boraginaceae	*Cordia sinensis Lam.*	1	1		Shrub	Perennial	Seed, Wildings,
Boraginaceae	*Heliotropium strigosum Willd.*			1	Herb	Perennial	Seed
Burseraceae	*Boswelia neglecta*	1			Tree	Perennial	
Burseraceae	*Commiphora africana (A. Rich.)*	1	1	1	Shrub/Tree	Perennial	Cuttings
Burseraceae	*Commiphora madagascariensis*	1	1		Shrub/Tree	Perennial	
Burseraceae	*Commiphora schimperi (Berg.)*	1			Shrub/Tree	Perennial	
Capparaceae	*Boscia angustifolia A. Rich.*	1			Tree	Perennial	
Capparaceae	*Boscia salicifolia*	1		1	Tree	Perennial	
Capparaceae	*Cadaba farinosa Forssk.*	1	1	1	Shrub	Perennial	
Capparaceae	*Capparis erythrocarpos Isert*	1	1		Shrub	Perennial	
Capparaceae	*Capparis fascicularis DC*		1		Shrub	Perennial	

Capparaceae	*Capparis sepiaria*		1	1	Shrub	Perennial	
Capparaceae	*Capparis tomentosa*		1		Shrub	Perennial	
Capparaceae	*Maerua angolensis*	1	1		Shrub/Tree	Perennial	
Capparaceae	*Maerua crassifolia Forssk.*	1			Tree	Perennial	
Capparaceae	*Maerua edulis (Gilg & Gilg-Ben)*	1	1	1	Shrub	Perennial	
Capparaceae	*Maerua parvifolia Pax*	1	1	1	Shrub	Perennial	
Capparaceae	*Maerua pseudopetalosa (Gilg &*	1	1		Shrub	Perennial	
Capparaceae	*Maerua triphylla*	1			Shrub/Tree	Perennial	
Capparaceae	*Maerua sp.*	1			Shrub	Perennial	
Celastraceae	*Maytenus heterophylus*		1		Shrub	Perennial	
Celastraceae	*Mystroxylon aethiopicum (Thunb.)*	1			Tree	Perennial	
Cleomaceae	*Cleome monophylla L.*	1			Herb	Annual	Seed
Combretaceae	*Combretum aculeatum Vent*	1			Shrub	Perennial	
Combretaceae	*Combretum molle R. Br. ex G. Don*	1			Tree	Perennial	
Combretaceae	*Terminalia brownii Fresen*	1			Tree	Perennial	
Commelinaceae	*Aneilima sp.*			1	Herb	Annual	
Commelinaceae	*Commelina africana L.*	1	1	1	Herb	Perennial	Rhizome
Commelinaceae	*Commelina albescens Hassk.*	1		1	Herb	Perennial	Rhizome
Commelinaceae	*Commelina benghalensis L.*	1	1		Herb	Perennial	Rhizome
Commelinaceae	*Commelina erecta L.*		1	1	Herb	Perennial	Rhizome
Commelinaceae	*Commelina foliosa*			1	Herb	Perennial	Rhizome
Commelinaceae	*Commelina imberbis Hassk.*	1	1	1	Herb	Perennial	Rhizome
Commelinaceae	*Commelina reptans Brenan*	1		1	Herb	Perennial	Rhizome
Commelinaceae	*Cyanotis foecunda*		1		Herb	Perennial	
Commelinaceae	*Cyanotis sp.*	1			Herb	Perennial	
Convolvulaceae	*Evolvulus alsinoides*			1	Herb	Annual	
Convolvulaceae	*Ipomoea cairica*		1		Herb	Perennial	
Convolvulaceae	*Ipomoea cordofana Choisy*		1		Herb	Perennial	
Convolvulaceae	*Ipomoea spathulata Hall.f.*	1	1		shrub	Perennial	Seed
Convolvulaceae	*Ipomoea sp1*			1	Herb	Perennial	
Convolvulaceae	*Seddera bagshawei Rendl*		1	1	Herb	Annual	seed

Cucurbitaceae	*Cucumis prophetarum L.*			1	Herb	Annual	Seed
Cyperaceae	*Cyperus boreochrysocephalus Lye*		1	1	Herb	Perennial	
Cyperaceae	*Cyperus cyperoides*	1			Herb	Perennial	
Cyperaceae	*Cyperus esculentus*	1			Herb	Perennial	
Cyperaceae	*Cyperus hirtellus (Chiov.) Kuk.*			1	Herb	Perennial	
Cyperaceae	*Cyperus impubes*	1		1	Herb	Perennial	
Cyperaceae	*Cyperus obtusiflorus Vahl*		1	1	Herb	Perennial	
Cyperaceae	*Cyperus rotundus*			1	Herb	Perennial	
Cyperaceae	*Scleria sp.*			1	Herb	Annual	
Ebenaceae	*Euclea divinorum Hiern.*	1			Shrub/Tree	Perennial	
Euphorbiaceae	*Acalypha lanceolata Willd.*	1	1	1	Herb	Perennial	
Euphorbiaceae	*Croton dichogamus Pax*	1			Tree	Perennial	
Euphorbiaceae	*Dalechampia parviflora Lam.*	1	1		Herb	Perennial	
Euphorbiaceae	*Euphorbia candelabrum Kotschy*	1	1		Tree	Perennial	Wilding, Cutting
Euphorbiaceae	*Euphorbia crotonoides Boiss.*	1	1		Herb	Annual	seed
Euphorbiaceae	*Euphorbia heterochroma Pax.*		1		Shrub	Perennial	
Euphorbiaceae	*Euphorbia hirta*		1		Herb	Annual	seed
Euphorbiaceae	*Euphorbia inaequilatera*		1		Herb	Annual	
Euphorbiaceae	*Euphorbia indica Lam.*		1	1	Herb	Annual	
Euphorbiaceae	*Euphorbia schimperiana*			1	Herb	Annual	
Euphorbiaceae	*Euphorbia sp1*	1			Shrub	Perennial	
Euphorbiaceae	*Micrococca mercurialis*		1		Herb	Annual	Seed
Euphorbiaceae	*Tragia plukenetii*		1	1	Herb	Perennial	Seed
Fabaceae	*Acacia brevipsica Harms*	1			Shrub	Perennial	Seed
Fabaceae	*Acacia drepanolobium*		1	1	Shrub	Perennial	Seed
Fabaceae	*Acacia gerardii Benth.*	1	1	1	Shrub/Tree	Perennial	Seed
Fabaceae	*Acacia mellifera (Vahl) Benth.*	1	1	1	Shrub/Tree	Perennial	Seed
Fabaceae	*Acacia nilotica (L.) Del.*	1	1	1	Tree	Perennial	Seed
Fabaceae	*Acacia nubica*		1	1	Shrub	Perennial	seed
Fabaceae	*Acacia polyacantha*			1	Tree	Perennial	Seed
Fabaceae	*Acacia senegal (L.) Willd.*	1	1	1	Shrub/Tree	Perennial	Seed

Fabaceae	*Acacia seyal*		1	1	Tree	Perennial	Seed
Fabaceae	*Acacia tortilis*	1	1		Tree	Perennial	Seed, Wildings
Fabaceae	*Albizia amara ssp. sericocephala*	1		1	Tree	Perennial	Seed
Fabaceae	*Albizia anthelmintica Brongn.*	1	1	1	Tree	Perennial	Seed
Fabaceae	*Alysicarpus rugosus*		1	1	Herb	Annual	Seed
Fabaceae	*Alysicarpus vaginalis (L.) DC*			1	Herb	Annual	Seed
Fabaceae	*Chamaecrista mimosoides*	1		1	Herb	Annual	Seed
Fabaceae	*Clitoria ternatea L.*	1		1	Herb	Perennial	Seed
Fabaceae	*Crotalaria cephalotes*		1		Herb	Annual	Seed
Fabaceae	*Crotalaria sp.*	1	1		Herb	Annual	Seed
Fabaceae	*Crotalaria sp1*	1			Herb	Annual	Seed
Fabaceae	*Crotalaria sp2*			1	Herb	Annual	Seed
Fabaceae	*Dichrostachys cinerea (L.) Wight &*	1	1	1	Shrub/Tree	Perennial	Seed, Wildings,
Fabaceae	*Dolichos kilimandsharicus Taub.*	1			Herb	Perennial	Seed
Fabaceae	*Indigofera arrecta*	1	1	1	Herb	Perennial	Seed
Fabaceae	*Indigofera schimperi*	1	1	1	Herb	Perennial	Seed
Fabaceae	*Indigofera spicata*			1	Herb	Perennial	Seed
Fabaceae	*Indigofera sp.*			1	Herb	Annual	Seed
Fabaceae	*Indigofera sp1*			1	Herb	Annual	Seed
Fabaceae	*Ormocarpum trichocarpum (Taub.)*	1	1	1	Shrub/Tree	Perennial	Seed
Fabaceae	*Rhyncosia minima*		1	1	Herb	Perennial	Seed
Fabaceae	*Senna bicapsularis*		1	1	Shrub	Perennial	Seed
Fabaceae	*Sesbania sp.*			1	Herb	Annual	Seed
Fabaceae	*Stylosanthes fruticosa (Retz.) Alston*	1		1	Herb	Perennial	Seed
Fabaceae	*Tephrosia bracteolata Guill. &*			1	Shrub	Perennial	Seed
Fabaceae	*Tephrosia linearis*	1		1	Herb	Annual	Seed
Fabaceae	*Tephrosia pumila (Lam.) Pers.*	1	1		Herb	Annual	Seed
Fabaceae	*Tephrosia sp.*		1		Herb	Annual	Seed
Fabaceae	*Teramnus sp.*			1	Herb	Annual	Seed
Fabaceae	*Vigna membranacea A. Rich.*	1			Herb	Annual	Seed
Fabaceae	*Vigna sp.*	1		1	Herb	Annual	Seed

Geraniaceae	*Monsonia angustifolia A. Rich.*	1		1	Herb	Annual	Seed
Hyacinthaceae	*Scilla sp.*	1			Herb	Perennial	
Lamiaceae	*Hoslundia opposita*			1	Shrub	Perennial	Seed, Root
Lamiaceae	*Leucas martinicensis*	1	1	1	Herb	Annual	
Lamiaceae	*Orthosiphon australis*		1	1	Herb	Perennial	
Lamiaceae	*Orthosiphon parvifolius*		1	1	Herb	Perennial	
Lamiaceae	*Plectranthus barbatus Andr.*	1		1	Shrub	Perennial	
Malvaceae	*Abutilon grandiflorum*		1		Shrub	Annual	Seed
Malvaceae	*Abutilon mauritianum*		1	1	Shrub	Annual	Seed
Malvaceae	*Cochorus trilocularis L.*		1		Herb	Annual	Seed
Malvaceae	*Grewia bicolor Juss.*	1			Shrub/Tree	Perennial	Seed, Root
Malvaceae	*Grewia flavescens Juss.*	1			Shrub/Tree	Perennial	Seed, Root
Malvaceae	*Grewia similis*	1			Shrub/Tree	Perennial	Seed, Root
Malvaceae	*Grewia tenax*	1	1	1	Shrub/Tree	Perennial	
Malvaceae	*Grewia trichocarpa A. Rich.*	1	1		Shrub/Tree	Perennial	Seed, Root
Malvaceae	*Grewia villosa Wild.*	1	1	1	Shrub	Perennial	Seed, Root
Malvaceae	*Hibiscus articulatus A. Rich.*			1	Herb	Perennial	Seed
Malvaceae	*Hibiscus canabinus*		1	1	Shrub	Annual	Seed
Malvaceae	*Hibiscus flavifolius*		1	1	Herb	Perennial	
Malvaceae	*Hibiscus palmatus*		1		Herb	Annual	
Malvaceae	*Hibiscus trionum*	1			Herb	Annual	Seed
Malvaceae	*Melhania velutina*		1		Shrub	Annual	
Malvaceae	*Pavonia ellenbeckii Guerke*		1		Shrub	Perennial	
Malvaceae	*Pavonia patens*	1			Shrub	Perennial	Seed
Malvaceae	*Sida acuta*		1	1	Shrub	Perennial	
Malvaceae	*Triumfetta flavescens L.*		1		Shrub	Perennial	
Menispermaceae	*Chasmanthera dependens Hochst.*	1			Shrub	Perennial	
Phyllanthaceae	*Phyllanthus maderaspatensis L.*		1	1	Herb	Perennial	
Phyllanthaceae	*Phyllanthus niruli*			1	Herb	Annual	
Phyllanthaceae	*Phyllanthus ovalifolia*		1		Shrub	Perennial	
Ochnaceae	*Ochna inermis (Fossk.) Schweinf.*	1			Shrub	Perennial	

Olacaceae	*Ximenia americana*	1			Shrub/Tree	Perennial	Seed, Suckers
Poaceae	*Andropogon gayanus Kunth*			1	Herb	Perennial	
Poaceae	*Andropogon schirensis*		1	1	Herb	Perennial	Tillers
Poaceae	*Aristida adscencionis*		1		Herb	Annual	
Poaceae	*Bothriochloa bladhii*			1	Herb	Perennial	Tillers
Poaceae	*Bothriochloa insculpta (A. Rich.) A.*	1	1	1	Herb	Perennial	Tillers
Poaceae	*Brachiaria brizantha*		1	1	Herb	Perennial	Seed, Tillers
Poaceae	*Brachiaria eruciformis (J.E.Smith)*		1		Herb	Annual	
Poaceae	*Brachiaria leersoides*		1		Herb	Annual	
Poaceae	*Cenhrus ciliaris*	1	1	1	Herb	Perennial	Seed, Tillers
Poaceae	*Chloris gayana*			1	Herb	Perennial	
Poaceae	*Chloris lamproparia*		1		Herb	Annual	
Poaceae	*Chloris pycnothrix*		1		Herb	Annual	
Poaceae	*Chrysopogon serrulatus Trin*	1			Herb	Perennial	
Poaceae	*Cymbopogon caesius (Hook. &*	1			Herb	Perennial	Tillers
Poaceae	*Cynodon dactylon*	1	1	1	Herb	Perennial	Tillers
Poaceae	*Dactylocteneum aegyptiaca*		1		Herb	Annual	
Poaceae	*Dichanthium annulatum*		1	1	Herb	Perennial	Tillers
Poaceae	*Digitaria abyssinica*			1	Herb	Perennial	Tillers
Poaceae	*Digitaria ternata*		1		Herb	Annual	
Poaceae	*Dinebra retroflexa*		1		Herb	Annual	
Poaceae	*Echinochloa colona*			1	Herb	Annual	
Poaceae	*Eragrostis cilianensis (All.) Lut.*		1		Herb	Annual	
Poaceae	*Eragrostis heteromera*			1	Herb	Perennial	
Poaceae	*Eragrostis superba Peyr.*	1		1	Herb	Perennial	Tillers
Poaceae	*Eriochloa fatmensis*		1	1	Herb	Annual	
Poaceae	*Heteropogon contortus (L.) Roem.*	1		1	Herb	Perennial	Tillers
Poaceae	*Hyparrhenia rufa*			1	Herb	Perennial	
Poaceae	*Hyperthelia dissoluta*	1		1	Herb	Perennial	Tillers
Poaceae	*Ischaemum afrum (J.F. Gmel.)*		1		Herb	Perennial	
Poaceae	*Lintonia nutans*	1	1	1	Herb	Perennial	Tillers

Poaceae	*Microchloa kunthii*	1			Herb	Perennial	Tillers
Poaceae	*Panicum atrosanguineum A. Rich.*	1		1	Herb	Annual	
Poaceae	*Panicum coloratum*		1	1	Herb	Perennial	
Poaceae	*Panicum maximum Jacq.*	1			Herb	Perennial	Seed, Tillers
Poaceae	*Panicum porphyrhizos*	1		1	Herb	Annual	
Poaceae	*Pennisetum mezianum Leek*	1	1		Herb	Perennial	Tillers
Poaceae	*Sehima nervosum (Rottler) Stapf*	1		1	Herb	Perennial	
Poaceae	*Setaria pumila (Poir.) Roem. &*		1	1	Herb	Annual	
Poaceae	*Setaria sphacelata*		1	1	Herb	Perennial	Seed, Tillers
Poaceae	*Sporobolus panicoides A. Rich.*		1	1	Herb	Annual	
Poaceae	*Sporobolus pyramidalis P. Beauv.*			1	Herb	Perennial	Tillers
Poaceae	*Sporobolus stapfianus Gand*	1	1	1	Herb	Perennial	Tillers
Poaceae	*Themeda triandra Forssk.*	1		1	Herb	Perennial	Tillers
Poaceae	*(unidentified grass)*			1	Herb	Perennial	
Polygalaceae	*Polygala abyssinica Fres.*			1	Herb	Annual	
Polygalaceae	*Polygala sphenoptera*		1		Shrub	Perennial	
Rhamnaceae	*Ziziphus abyssinica*		1	1	Shrub/Tree	Perennial	Seed
Rubiaceae	*Kohautia coccinea Royle*		1		Herb	Annual	
Rubiaceae	*Oldenlandia corymbosa L.*	1		1	Herb	Annual	
Rubiaceae	*Pentanisia ouranogyne S. Moore*		1	1	Herb	Annual	
Rubiaceae	*Pentas parviflora Hiern*			1	Herb	Annual	
Rubiaceae	*Rhytgynia sp.*	1			Shrub	Perennial	
Rubiaceae	*Spermacocce princei*			1	Herb	Annual	
Rubiaceae	*Spermacocce pusilla*	1	1		Herb	Annual	
Rubiaceae	*Spermacocce sp.*	1			Herb	Annual	
Rutaceae	*Rhus natalensis Krauss.*	1			Shrub	Perennial	
Rutaceae	*Vepris glomerata (Hoffm.) Engl.*	1		1	Shrub/Tree	Perennial	
Rutaceae	*Vepris nobilis*	1			Shrub/Tree	Perennial	Seed, Wildings
Rutaceae	*Zanthoxylum chalybeum Engl.*	1	1		Shrub/Tree	Perennial	Seed, Wildings
Sapindaceae	*Allophylus africanus P. Beauv.*	1			Shrub	Perennial	Seed, Wildings
Sapindaceae	*Allophylus sp.*	1			Shrub	Perennial	

Sapindaceae	*Cardiospermum halicacabum*		1		Herb	Annual	Seed
Scrophulariaceae	*Craterostigma hirsutum S. Moore*	1			Herb	Perennial	Seed, Rhizome
Scrophulariaceae	*Cycnium tubulosum*			1	Herb	Perennial	
Simaroubaceae	*Harrisonia abyssinica*	1			Shrub	Perennial	
Solanaceae	*Lycium shawii*		1		Shrub	Perennial	
Solanaceae	*Solanum albicaule*		1	1	Shrub	Perennial	Seed
Solanaceae	*Solanum camplyacanthum A. Rich.*	1	1	1	Shrub	Perennial	Seed
Solanaceae	*Solanum coagulans*		1		Shrub	Perennial	Seed
Solanaceae	*Solanum hastifolium*		1		Shrub	Perennial	Seed
Solanaceae	*Solanum taitense*	1			Shrub	Perennial	Seed
Verbanaceae	*Lantana sp.*			1	Shrub	Perennial	
Verbenaceae	*Lippia javanica*	1	1		Shrub	Perennial	
Vitaceae	*Cissus quadrangularis*	1	1		Shrub	Perennial	
Vitaceae	*Cissus rotundifolia*	1			Shrub	Perennial	
Vitaceae	*Cyphostemma serpens (A.Rich.)*	1			Herb	Perennial	
	(unidentifed tree)	1			Tree	Perennial	
	(unidentifed tree-Ewapetu)	1			Tree	Perennial	
Species totals		**142**	**135**	**135**			

Appendix 2: Water harvesting technology and suitability

S/N	Study area	Water Harvesting Technology	Hydrological suitability assessment	Coordinate	
				XR	YR
1	Lorengdwet	Valley Tank	High	683796	250819
2	Lorengdwet	Valley Tank	High	681818	253534
3	Lorengdwet	Valley Tank	High	682289	253154
4	Lorengdwet	Valley Tank	High	682324	253152
5	Lorengdwet	Valley Tank	High	682910	252973
6	Lorengdwet	Valley Tank	High	682375	253079
7	Lorengdwet	Valley Tank	High	685692	252943
8	Lorengdwet	Valley Tank with Stream Diversion	Very high	685750	246972
9	Lorengdwet	Valley Tank with Stream Diversion	Very high	685742	246962
1	Nadunget	Rock Catchment	High	670707	277880
2	Nadunget	Valley Tank with Stream Diversion	High	674780	275634
3	Nadunget	Dam	High	677442	275855
4	Nadunget	Valley Tank in a Marram pit	Low	675651	273780
5	Nadunget	Dam	Very high	677950	270908
6	Nadunget	Valley Tank with Stream Diversion	High	677307	275961
1	Napak	San Dam	High	655566	274427
2	Napak	Valley Tank in a Quarry pit	Low	647397	255731
3	Napak	Valley Tank for Rehabilitation	High	650943	257221
4	Napak	Rock Catchment	Very high	645979	258686
5	Napak	Valley Tank with Stream Diversion	Very high	646084	258701
6	Napak	Rock Catchment	High (micro catchment)	646769	257630
7	Napak	Rock Catchment	Very high	646418	259065