EFFECT OF RANGELAND REHABILITATION ON SOIL PHYSICO-CHEMICAL PROPERTIES AND DIVERSITY OF HERBACEOUS LAYER IN SUSWA CATCHMENT, NAROK COUNTY,

JOSEPH NYUKI OMBEGA

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DECLARATION

This thesis is my original work and has not been presented for the award of a degree in any other university.

JOSEPH NYUKI OMBEGA

Signature………………………………..Date………………………………

Department of Land Resource Management and Agricultural Technology, Faculty of Agriculture, University of Nairobi.

This thesis has been submitted with our approval as university supervisors

Dr. STEPHEN M. MUREITHI

Signature………………………………..Date………………………………

Department of Land Resource Management and Agricultural Technology, Faculty of Agriculture, University of Nairobi.

Dr. ANNE N. KARUMA

Signature………………………………..Date………………………………

Department of Land Resource Management and Agricultural Technology, Faculty of Agriculture, University of Nairobi.

Dr. OSCAR K. KOECH

Signature………………………………..Date………………………………

Department of Land Resource Management and Agricultural Technology, Faculty of Agriculture, University of Nairobi.

DEDICATION

This thesis is dedicated to my dear father Mr. John Ombega Orina, my mother Mrs. Veronicah Moraa Ombega and my family members for their endless support during my study. Thank you!

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ACRONYMS AND ABBREVIATIONS

ASALs	Arid and Semi - Arid Lands
C	Carbon
CBD	Convention for Biological Diversity
CEC	Cation Exchange Capacity
EMG	Environment Management Group
FAO	Food and Agricultural Organisation
GEF	Global Environmental Fund
GOK	Government of Kenya
K	Potassium
MEA	Millennium Ecosystem Assessment
N	Nitrogen
NEMA	National Environmental Management Authority
P	Phosphorus
RAE	Rehabilitation of Arid Environments [RAE] Trust
ROK	Republic of Kenya
SRR	Society for Rangeland Restoration
SLM	Sustainable Land Management
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SSA	Sub Saharan Africa
UN	United Nations
UNDP	United Nations Development Programme

UNEP	United Nations Environmental Programme
USDA	United States Development Agency

FOREWORD

The chapters in this thesis are structured as papers. I therefore, would like to apologize to the reader for any inconveniences caused by this mode of presentation.

GENERAL ABSTRACT

Land degradation is a global challenge and its effects on plant and soil biodiversity are profound and negative. Land degradation negatively affects soil fertility and plant diversity and hence people's wellbeing. This study assessed the effect of land rehabilitation on soil physico-chemical properties and diversity of herbaceous layer in a severely degraded rangeland in Suswa catchment, Narok County, Kenya. Vegetation attributes (Aboveground Biomass, Total Cover, Composition, Relative abundance, Richness and Diversity of herbaceous layer) and soil parameters (Bulk Density, Aggregate Stability, Texture, Hydraulic Conductivity, Penetration Resistance, Moisture Content, Nitrogen, Organic Carbon, soil pH, Potassium and Phosphorus) were determined within the rehabilitated and degraded areas along a slope (upper, middle and lower slope positions). Within each slope position three 100 m transects were laid 30 m apart. Vegetation attributes were then determined along each transect at intervals of 1m. Soil parameters were also collected at intervals of 25 m using a soil auger for laboratory analysis. The results of the analysis showed that herbaceous biomass production, diversity, relative abundance, composition and richness of perennial grasses significantly ($P \leq 0.05$) increased downslope being higher in the rehabilitated area than in the degraded area. The highest biomass production (1,459 kg/ha) and ground cover (74.67 %) were recorded in the lower slope rehabilitated area. Similarly, soil moisture content, aggregate stability, porosity, hydraulic conductivity, total organic carbon, nitrogen, available phosphorus and potassium significantly ($P \leq 0.05$) increased downslope being higher in the rehabilitated area than in the degraded area. Conversely, the diversity, relative abundance, composition, percent cover, species richness and aboveground biomass of forbs and annual grasses significantly ($P \leq 0.05$) increased upslope with higher values recorded in the degraded area. The mean bulk density, % sand and penetration resistance were significantly ($P \leq 0.05$) higher in the degraded area and increased upslope with highest bulk density (1.21 g/cm^3) and sand content (85 %) recorded in the upper slope degraded area.

This study clearly demonstrates that with proper land management soil and vegetation diversity can be greatly improved. However, in areas with steep topographical gradient use of structural soil and water conservation techniques such as retention ditches, cut off drains and terraces is highly recommended.

Keywords: Rangeland rehabilitation; Soil physico-chemical properties; Slope, Herbaceous layer

CHAPTER ONE

1.1 General Introduction

Land degradation is a serious problem affecting approximately 1.5 billion people and 24 % of land area in the world (Lal *et al.*, 2012). Approximately about one fifth of rangelands are experiencing land degradation (Millennium Ecosystem Assessment (MEA), 2005). In Africa, an estimated 75 % of drylands are affected by moderate to high degradation (Olukoye and Kinyamario, 2009) with more severity of land degradation experienced in Sub-Saharan Africa (United Nations, 2011). The United Nations Environmental Programme, (2002) estimates thirty percent of Kenya's total land mass as being affected by severe to very severe land degradation. Recent studies on spatial and temporal patterns on land degradation in Kenya have showed an increase in intensity and extent with over 30 % of forests, 20 % of cultivated areas and 10 % of rangelands being degraded (Muchena *et al.,* 2008).

The causative agents of this degradation include population increase, deforestation, lack of defined property rights, charcoal production, poverty, overgrazing and unsustainable agricultural practices (Waswa *et al.,* 2013; Nesheim *et al.,* 2014). The situation is exacerbated by climate variability and change and migrations from high potential lands (Kirwa *et al.,* 2009; Khalif, 2014). This has led to depletion of palatable plant species, decreased vegetation cover and reduced soil nutrients as a result of frequent soil erosion and runoff (Haileslassie *et al.,* 2005; Mekuria *et al.,* 2007). Loss of land productivity has negatively impacted on pastoral livelihood due to reduced carrying capacity of pasturelands (Vetter *et al.,* 2005).

In Kenya increased migrations from high potential lands has reduced grazing resources in the rangelands (Fratkin *et al.,* 2001; Kirwa *et al.,* 2009). Loss of grazing resources has influenced change in land use from pure pastoralism to agro-pastoralism (Kirwa *et al.,* 2009). The changes in land use has further increased shrinkage and degradation in quality of pastures due to proliferation of invasive alien plant species such as *Lantana camara* and *Opuntia ficus* (NEMA, 2009; Maina *et al.,* 2013) and fragmentation of communal lands (Dalle *et al.,* 2006; Solomon *et al.,* 2007). Fragmentation of communal grazing areas has negatively affected soil productivity characteristics such as soil hydraulic conductivity, bulk density and aggregate stability (Rai *et al.,* 1998) which has led to increased land degradation because of frequent erosion and runoff (Muchena *et al.,* 2008). An example of a severely degraded rangeland in Kenya is the Suswa catchment with gullies of over 30 m wide and 25 m deep (Khalif, 2014). This has negatively impacted on land productivity and pastoral livelihood within the area due to lack of sufficient grazing resources (Odini *et al.,* 2015). This situation is widely distributed across most of the grazing rangelands of Kenya where pastoralism is the main livelihood option.

Generally, severe land degradation, hinders autogenic recovery of vegetation due to inadequate soil seed bank, decreased soil functioning and lack of good micro-sites for germination (van den Berg and Kellner 2005; Abebe *et al.,* 2006). It also favours establishment of invader species (Byers *et al.,* 2002), survival and dominance of short-lived, un-preferred annual plant species rather than the palatable perennial ones (Sahar *et al.,* 2012). The invader species in turn negatively impact on the native species as they deplete soil and water resources at a higher rate (Dogra *et al.,* 2010). Further, the loss of above ground biomass and cover enhance soil nutrient losses such as soil organic carbon (Dong *et al.,* 2012), phosphorus and nitrogen (Zhou *et al.,* 2005) thus reducing land productivity (Wen *et al.,* 2013a, b). Alterations in soil organic carbon levels greatly influence the soil texture, soil aggregate stability and structure, which have an influence on soil organic carbon dynamics and microbial activity (Boivin *et al.,* 2009).

Removal of ground cover reduces the soil organic matter content resulting to soil compaction (Soene *et al.*, 1994). Soil compaction influences other soil properties such as hydraulic conductivity and water retention thus affecting vegetation structure due to limited access and movement of water and air, reduced microbial activity in the soil and poor root growth (Lal *et al.*, 2005). Too much exposure of the soil to wind, water and other environmental factors, as a result of reduced ground cover increases soil erosion, thereby reducing soil depth and soil organic carbon levels, thus ultimately affecting rangeland productivity (Li *et al.*, 2008, McClaren *et al.*, 2008).

Proper rehabilitation techniques are thus required and can be achieved through sustainable utilization of these lands with management strategies that have limited negative impact on the soil (Liebig *et al.,* 2006). Successful restoration of degraded lands enhances vegetation recovery, reduces soil erosion (Descheemaecker *et al.,* 2006) and ultimately restores soil fertility and biodiversity (Mekuria *et al.,* 2007; Tongway and Ludwig, 2011).

1.2 Problem Statement

The increase in unsustainable land use practices such as charcoal burning, overgrazing, inapropriate farming practices and lack of defined property rights (Nesheim *et al.*, 2014), has led to increased land degradation in Kenya with over 30 % of forests 20 % of croplands and 10 % of rangelands being degraded (Muchena *et al.,* 2008). According to FAO, (2010), Kenya's rangelands are the worst affected by land degradation. A good example is the Suswa Catchment in Narok County which is severely degraded with gullies of over 30 m wide and 25 m deep (Khalif, 2014). Much of the soil nutrients have been depleted a fact exacerbated by lack of sufficient ground cover as a result of overgrazing and charcoal production (Odini *et al.*, 2015).

In response to the increasing land degradation within the Kenyan rangelands, numerous restoration approaches have been developed (Mureithi *et al.*, 2010). Some of these approaches include:

rangeland enclosures, reseeding, ripping of soil crust and use of terraces (Wasonga *et al.*, 2009; Kinyua *et al.*, 2009, Mganga *et al.*, 2010; Mureithi *et al*., 2014; Ruto, 2015). Within Narok County, the Sustainable Land Management (SLM) initiative has undertaken diverse activities to restore degraded areas. These activities include rehabilitation of gullies in Suswa through establishment of several soil and water conservation structures such as terraces, semicircular bands, check dams, cut-off drains and water retention ditches. Community education and replanting of trees within the severely degraded areas was also done (Odini *et al.*, 2015). However, despite the various rehabilitation approaches carried out, limited research work has been done to ascertain their effect on vegetation and soil properties in the area. This coupled with the fact that there are only limited cases of successful rangeland rehabilitation initiatives in East African drylands (RAE, 2004; Mengistu *et al.*, 2005), and the fact that policies on sustainable land management are not consistent and are quite unreliable (Nkonya *et al.*, 2011); gave drive to this study.

1.3 Justification

Most livestock production in Kenya takes place in the rangelands, which are estimated to support about 25 % of the country's human population and slightly over 65 % of livestock (Kabubo-Mariara *et al.*, 2009). Despite the enormous contribution of these rangelands towards the country's gross domestic product (GDP), land degradation is extensive (FAO, 2010). Thus, failure to address land degradation caused by such factors like inept grazing systems, climatic variations, population expansion, and human activities like charcoal production and overgrazing will lead to continued pasture/forage scarcity in the Kenyan rangelands. This will in turn negatively impact on pastoral livelihoods that largely depend on natural environment and livestock in particular for their survival. Therefore, this study aims at providing information that can help in sustainable management of severely degraded lands. This will be achieved by quantifying the effects of land rehabilitation on selected soil and vegetation attributes; so as to inform policy for future interventions against any unsustainable land use practices.

1.4 Scope of Study

1.4.1 Objectives

The broad objective of this study was to assess the effect of rehabilitation methods on rangeland productivity within Suswa catchment, Narok County, Kenya. The specific objectives of this study were:

1. To determine the effect of rangeland rehabilitation on above ground herbaceous cover, biomass, plant species richness, diversity and relative abundance.
2. To assess the effect of rangeland rehabilitation on soil physico-chemical properties (Bulk Density, Aggregate Stability, Texture, Hydraulic Conductivity, Penetration Resistance, Moisture Content, Nitrogen, Organic Carbon, Potassium and Phosphorus).

1.4.2 Hypotheses

1. There is a significant effect of rangeland rehabilitation on above ground herbaceous cover, biomass, plant species richness, composition, diversity and relative abundance.
2. There is a significant effect of rangeland rehabilitation on soil physico-chemical properties.

1.5 Study Area

The study was undertaken in Suswa catchment Narok County, located in the Southwest of Kenya. The catchment is found within longitudes 36°21′00″E and latitudes 1°09′00″S. Suswa has mainly humic Andosols which are well drained, friable and smeary, sandy clay to clay (Jaetzold *et al.*, 2010). The soils have low organic matter and high silt /clay ratio making them highly susceptible to erosion. The soils are arranged in layers with hard pans beneath a soft clay stratum that are easily eroded (Maina, 2013).

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

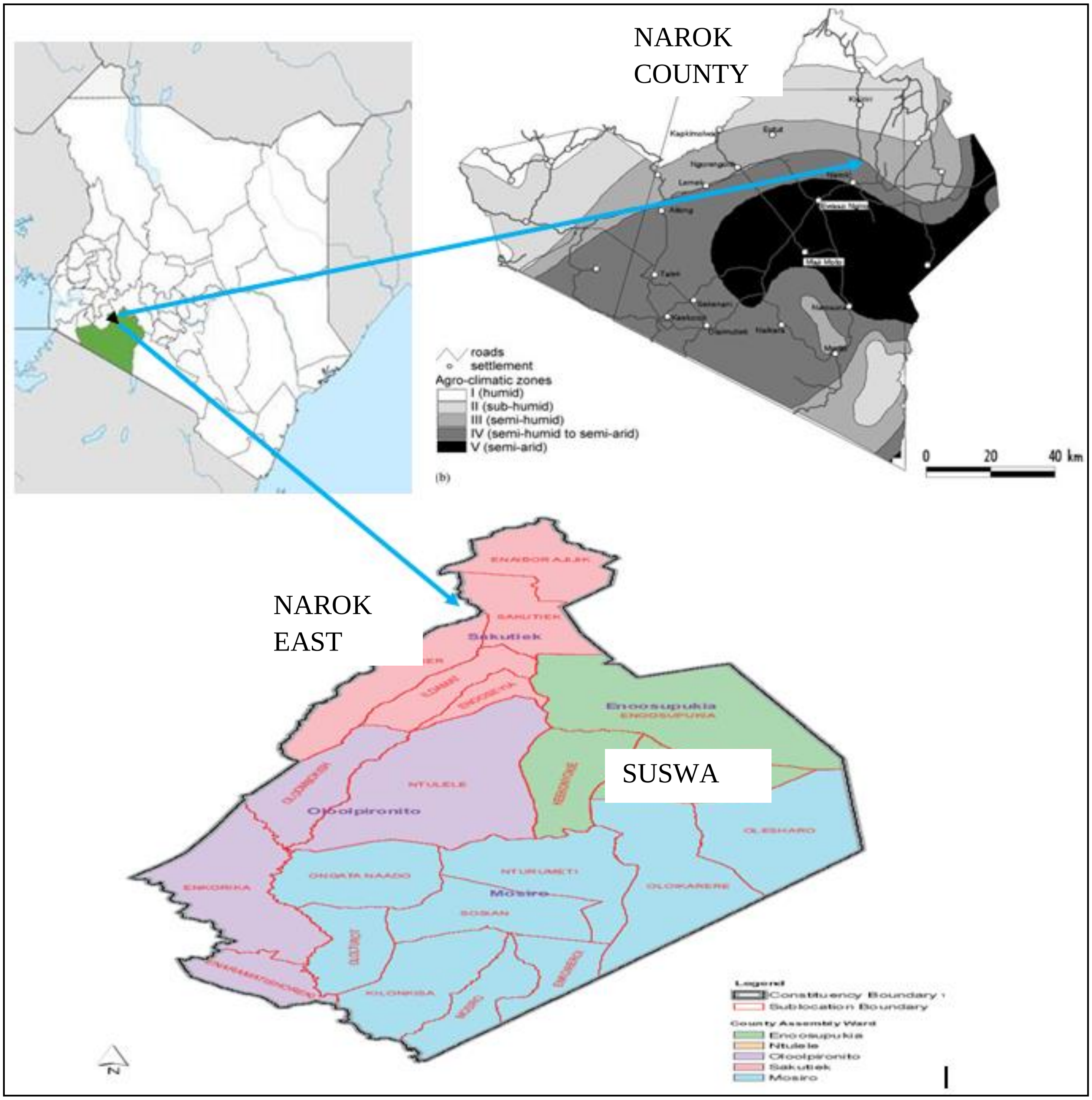

Figure 1.0 Map of the study area, Suswa Narok County (Source: Narok District Environment Action Plan 2009-2013)

1.6 Structure of the Thesis

This thesis is divided into three parts. The **first part** provides an introduction into land degradation, its extent and effects on land productivity (soil and vegetation) and human life in general. It defines the scope of the study (objectives and hypothesis) and describes the study area (Chapter 1). The

second part discusses the effects of land rehabilitation on soil physico-chemical properties and diversity of herbaceous layer (Chapters 2 to 4). The **third part** contained in Chapter 5 provides a general discussion and conclusion from all the chapters, and provides conclusions and recommendations for future research.

1.7 Definition of Key Terms

Dryland is defined as dry sub- humid, semi humid or arid areas where the ratio of mean annual potential evapo-transpiration to mean annual precipitation lies within 0.65 - 0.05 (UNCCD, 1994).

Land degradation is defined as the loss and diminishing of land productivity where it cannot recover unaided due to disturbances such as overgrazing and deforestation (Bai *et al.*, 2008).

Land Rehabilitation is the process of restoring an area of land to its former natural state after some process has resulted in its degradation or damage (Mureithi *et al.*, 2012).

Pastoralism – can be defined as a production system where people keep large herds of livestock and which at least 50 % of their income comes from livestock or its related activities (Swifts, 1998).

Rangelands - are defined as those areas in the world which are unsuitable for conventional crop production but they can be used for pastoralism, agro-pastoralism and wildlife production (Harrington *et al.*, 1984).

Sustainable land management is the adoption of land use practices which gives out optimum output without compromising the ecological integrity of the land (Odini *et al.*, 2015)

CHAPTER TWO

LITERATURE REVIEW

2.1 Definition of Land Degradation

Land degradation is a global challenge affecting approximately 1.5 billion people and a quarter of land area in all agro–ecological zones around the world (Lal *et al.*, 2012). It's a term viewed differently by different stakeholders (Reynolds and Stafford Smith, 2002) and it manifests itself in different forms; including soil erosion, increased sediment loading of water bodies, loss of soil fertility, salinity, reduced ground cove r, and reduced carrying capacity of pastures. The term degradation is generally defined as the long-term loss of ecosystem function and productivity caused by disturbances from which the land cannot recover unaided (Bai *et al.,* 2008). Its effects are profound and negative, and it occurs slowly and cumulatively and has long lasting impacts on rural people who become increasing vulnerable (Muchena *et al.,* 2008); as it deteriorates biological productivity and affects environmental, social, and economic sustainability (Nunes *et al.,* 2012).

2.2 Drivers and Extent of Land Degradation in Kenya

Land degradation is one of the most serious environmental problems of our time. An approximated one fifth of all rangelands are currently suffering from degradation (MA, 2005). According to UNEP, (2002) 30 % of total land mass in Kenya is affected by severe to very severe land degradation and natural pasture degradation has been established as one of the primary problem limiting sustainable livestock production in the rangelands (RoK 2011). Recent studies on spatial and temporal patterns show that land degradation is increasing in severity and extent in Kenya with over 20 % of all cultivated areas, 30 % of forests, and 10 % of grasslands subjected to degradation (Muchena *et al.,* 2008). These findings agree with studies conducted in 1997 which showed that 64 per cent of Kenya's land area was potentially subject to moderate desertification and about 23% was vulnerable to severe to very severe desertification (Macharia *et al.*, 2004). Within the northern rangelands, 12.3 %, 52 % and 33 % suffered from severe land degradation, moderate and slight vulnerability to degradation respectively. In the early 2000, an estimated 30% of Kenya was affected by very severe to severe land degradation (UNEP 2002) and approximately a third of Kenya's population, depended directly on land that is being degraded (Bai *et al.*, 2008).

Nevertheless, according to a report by the National Action Plan to combat desertification in Kenya, land degradation is intensifying and spreading in the country and it is severely reducing productivity of the land, and is threatening millions of people (RoK/UNEP, 2002). This problem is mainly attributed to the growing imbalance between population, resources, development and environment (UNEP, 2008). A situation that is exacerbated by deforestation and charcoal production, overgrazing, unsustainable agricultural practices, lack of defined property rights, poverty and increased population density (Waswa *et al.*, 2013; Nesheim *et al.*, 2014).

Pastoralists such as the Maasai of East Africa, adapted to live in arid lands by designating wet and dry season grazing areas (Butt, 2010). Their use of the range was based on mobility, splitting and dispersing livestock over the landscape during wet and dry seasons (Butt, 2010). This ensured limited dry concentrated continuous grazing (Kioko *et al.*, 2012). However, this has gradually changed as a result of loss in grazing land to agriculture, fencing of rangelands, poor water point management, conflicts and insecurity, boundaries (county, national and regional), and social change necessitated by changing aspirations and economic needs (Helen de Jode, 2009). The situation has been worsened by the current human population saturation in high fertile lands and reliable rainfall areas which has motivated immigration to communal rangelands where people can access land for cultivation (Kideghesho *et al.*, 2013). Under these circumstances aggravated by natural disturbance such as drought and flooding, drylands are getting more and more vulnerable to degradation and desertification in Kenya (GoK, 2002). This current rate and status of environmental degradation calls for more integrated and coordinated intervention actions to rehabilitate degraded lands (Edward, 2000; Kindeya G/Hiwot, 2004).

2.3 Indicators of Land Degradation

Indicators are increasingly becoming important tools for communication to policy makers and the general public in assessing environmental performance and progress made by actions applied to mitigate land degradation and desertification (Kosmas *et al.,* 2003; Salvati *et al.,* 2008). As pointed out by the United Nations Convention to Combat Desertification (UNCCD), indicators are valuable tools for assessing desertification risk and for analyzing the effectiveness of the various lands management practices for combating desertification (Sommer *et al.,* 2011; Ferrara *et al.,* 2012). Use of appropriate set of indicators, the status and trends of complex processes such as soil erosion and desertification may be effectively described without using complex mathematical expressions or models (Salvati and Bajocco, 2011).

Soil indicators that depict land degradation include soil compaction (Soane *et al.,* 1994) and increased soil run offs and erosion, which occurs due to loss of ground cover, thus initiating soil carbon loss (Maraseni *et al.,* 2008). On the other hand, reductions in total vegetation cover and palatable plant species, increases in undesirable and unpalatable plants and depletions in soil quality and nutrients due to various forms of soil erosions (Haileslassie *et al.,* 2005; Mekuria *et al.,* 2007) also characterize degradation.

Social economic indicators include loss of livestock due to feed scarcity and loss of income due to livestock mortalities which negatively impacts on pastoral livelihoods thereof (Vetter, 2005). This in turn increases poverty levels among the pastoralists (Majule, 2003).

2.4 Effect of land Degradation on Floristic Structure

Land degradation due to deforestation, charcoal production, overgrazing, unsustainable agricultural practices, lack of defined property rights, poverty and increased population density (Waswa *et al.,* 2013; Nesheim *et al.*, 2014) disturbs floristic composition (Landsberg *et al.,* 2003), spatial distribution (Metzger *et al.,* 2005) and diversity of herbaceous layers (Brooks et al., 2006). Moreover, heavy grazing coupled with other agents of degradation, alters vegetation composition and decreases primary productivity, especially of palatable species, thus decreasing community resilience, initiating damaging positive feedbacks (Kinyua *et al.,* 2010).

The alteration in species composition affects soil fertility (Scholes, 1990) due to changes in root biomass (Klumpp *et al.,* 2009) and quality of organic matter, thus decreasing the soil's capacity to sequester soil carbon (Klumpp *et al.,* 2009). Nevertheless, land degradation leads to reduction in resilience of host species, reduction of vegetation cover, increase of unpalatable species, decrease of species diversity, and alteration of soil structure and compactness (Kairis *et al.,* 2015; Belgacem *et al.*, 2013). Furthermore, disturbances favors establishment of invader species due to the reduction of native biodiversity (Byers *et al.,* 2002), survival and dominance of short-lived, un-preferred annual plant species rather than the palatable perennial ones (Sahar *et al.*, 2012). Conversion of natural land to farm land exposes soils to erosion and increases abundance of unpalatable grasses and introduction of new species (Maitima *et al.,* 2004). Ultimately, the changes in composition of plant species in savanna ecosystems pose significant influence on the sustainability of livestock production (Sankaran *et al.*, 2005).

2.5 Impact of Land Degradation on Soil Chemical Properties

Soil erosion, land degradation and conversion of land to crop lands characterize most rangelands today (Reid *et al.,* 2003). This has resulted to losses of soil nutrients among them soil organic carbon, soil nitrogen and soil phosphorus, all of which reduce the productivity of the land and reduced pools of soil carbon and nitrogen (Zhou *et al.*, 2005; Dong et al., 2012; Wen et al., 2013a, 2013b). Subsequent changes in soil organic carbon strongly affect soil structure and other soil properties such as hydraulic conductivity and bulk density, which in turn have feedback effects on the soil microbial activity and soil organic carbon dynamics (Boivin *et al.*, 2009).

One of the key roles of soil organic carbon (SOC) is to increase the Cation exchange capacity (CEC) and water holding capacity of the soil (Mureithi *et al.,* 2014). The SOC plays a key role in binding of soil particles into aggregates which improve the structural stability of the soil and it forms part of the soil organic matter (SOM) which holds the nutrient cations and trace elements necessary for plant growth (McClaran et al., 2008). Furthermore, SOC prevents nutrient leaching and produces an organic acid that promotes availability of minerals to plants. SOC also buffers the soil from strong changes in soil pH (Mureithi *et al.,* 2014).

Reduced biodiversity in soils due to degradation impairs numerous ecosystem functions, such as nutrient acquisition by plants and the cycling of resources between above and belowground communities (Vander *et al.,* 2008; Wall *et al.,* 2010). This is mainly attributed to a reduction in ground cover due to severe degradation. A reduction in plant biomass, leads to depletion of existing nutrients among them nitrogen and phosphorus thus resulting in soil fertility reduction (Morgan *et* *al.*, 1995). As vegetation cover declines due to degradation, soil nutrients gets depleted due to increased soil erosion this in turn generates negative consequences on rangeland productivity (Morgan *et al.*, 1995).

The survival and physical condition of plants depend on the regular supply of mineral nutrients from the soil (Badshah *et al.*, 2012). Minerals are essential not only for the normal growth and development of plants but also for the growth, maintenance and productivity of grazing livestock in rangelands (Hussain and Durrani, 2008). Insufficient animal growth and reproductive problems can directly be related to mineral deficiencies caused by low mineral concentration in soils (Tiffany *et al.*, 2000). Therefore, investigation of the temporal and spatial changes in soil nutrients is an essential tool for a sound management skill (Kavianpoor *et al.*, 2012)

2.6 Effect of Degradation on soil Physical Properties

Soil is the foundation resource for nearly all land uses, and the most important component of sustainable agriculture (Mulugeta and Karl, 2010). Degradation reduces vegetation cover, and soil organic matter. Soil organic matter binds mineral particles into granular soil structure thus making the soil resistant to soil erosion, loose and easy to work and also enable greater moisture infiltration (Handayani *et al.*, 2010). Soil organic matter also influences aggregate stability of the soil. Soil aggregate stability is a key factor of soil resistivity to mechanical stresses, including the impacts of rainfall and surface runoff, and thus to soil erosion (Canasveras *et al.*, 2010). Stable aggregates are resilient to any kind of disruption be it from rain drops or movement of water through the soil (Zziwa *et al.*, 2012).

Land degradation enhances soil aggregate disintegration into finer particles making them easily carried away by wind and water flow and which upon re-sedimentation tend to clog soil pores, leading to the formation of soil crusts (Yan *et al.,* 2008) which in turn reduces soil porosity while increasing penetration resistance. A reduction in the volume of macropores directly affects infiltration capacity and soil moisture content negatively thus encouraging soil erosion (Bork, 2006)

The relative amounts of mineral and organic matter determine the physical properties of the soil (Donkor *et al.,* 2002). Therefore, removal of plant cover reduces soil organic in the soil this in turn encourages soil compaction (Soene *et al.,* 1994). Soil compaction influences several other soil properties such as penetration resistance, bulk density and hydraulic conductivity which in turn affect vegetation structure by inducing changes in root growth, availability and movement of air and water, and microbial activity (Lal *et al.,* 2005).

Increased soil compaction increases soil bulk density which is a key determinant of soil health (Maitima, 2009) and an indicator of low soil porosity and compaction (Azarnivand, *et al*, .2010). High bulk density prohibits biomass production thus encouraging soil runoffs and erosion due to lack of cover to protect the soil from agents of degradation.

High soil organic matter lowers the penetration resistance, bulk density and increases water retention (Wilkins *et al.,* 2002; Dobers *et al.,* 2004). High penetration resistance lowers water infiltration reducing soil moisture content which is an important soil component and a major determinant of productivity (Chaichi, 2005). Soil moisture plays a significant role in vegetation restoration and crop production in arid areas (Wang *et al.*, 2008; Ziadat and Taimeh, 2013). Besides, it plays a key role in the establishment, growth and development of vegetation cover in the dry-lands. Amiri *et al.* (2008) reported that the reestablishment of range plants and root development is guaranteed when the management practices adopted in the rangelands ensures adequate moisture holding capacity of the soil. Other studies have also shown that plant biomass and productivity increases significantly with increasing soil infiltration rates, which have close relationships with covered vegetation types (Finley and Glenn, 2010; Zhang *et al.,* 2014; Fu *et al.*, 2015; Zheng *et al.,* 2015

2.7 Ecological Benefits of Land Rehabilitation

Land degradation decreases the capacity of the drylands to provide essential ecosystem services (Irwin and Ranganathan, 2007; Mekuria and Veldkamp, 2011); as it deprives the soil organic matter reducing soil fertility and productivity in drylands (FAO, 2004) thus decreasing the potential benefits soils offer to societies (Keesstra *et al.,* 2012). In addition, loss of biodiversity due to vegetation clearance leads to leaching of nutrients, decline in organic matter and accelerated surface erosion undermining land productivity (Holzel *et al.,* 2002). This in turn adversely affects ecosystem health, resilience, biodiversity and ecological function provision of nature (SER, 2008).

In general, unsustainable utilization of land resources impairs ecosystem functions such as regulation of water supplies and quality, soil fertility maintenance, carbon sequestration, climate change mitigation and food security leading to ecosystem fragmentation as a whole (UNEP, 2010). Restoration of severely degraded rangelands is thus necessary if their potential productivity is to be maintained at optimal levels. This can only be achieved through sustainable utilization of these lands with management strategies that do not compromise the capacity of soil to function over the long-term (Liebig *et al.,* 2006). Moreover, any action taken to aid in rehabilitation should be that mimicking the natural processes of the area (Gendreau *et al.,* 2012)

There are diverse approaches and techniques to land and vegetation restoration (Perrow and Davy, 2002). These techniques include grazing the range with the appropriate animals, balancing number of animals with forage resources, grazing at the correct season of the year and maintaining proper distribution of livestock over the range (Admasu *et al.,* 2014). Besides, range fertilization, reseeding technologies and water conservation techniques are other techniques for range rehabilitation (Ayana and Oba, 2010).

Land rehabilitation is becoming an increasingly significant tool to manage, conserve, and repair the world's degraded ecosystems (Young, 2000; Hobbs and Cramer, 2008). Well planned and implemented rehabilitation strategies improve species diversity, soil quality and ecosystem productivity (UNEP, 2010). Nevertheless, successful restoration of rangeland vegetation cover improves soil water balance and soil fertility, reduces soil erosion and restores the soil biodiversity and ecosystem services (Descheemaecker *et al.,* 2006; Mekuria *et al.,* 2007; Tongway and Ludwig, 2011). Furthermore, vegetation regeneration positively affects biodiversity (Abebe *et al.,* 2006), soil fertility (Mekuria *et al.,* 2007); as it reduces soil erosion (Descheemaecker *et al.,* 2006) and increases water availability (Hongo *et al.,* 1995). Cairns *et al.* (1998), argue that unless ecological rehabilitation and preservation are well practiced, human societies will not survive on this planet for the future.

CHAPTER THREE

EFFECT OF RANGELAND REHABILITATION ON THE HERBACEOUS LAYER CHARACTERISTIC IN SUSWA CATCHMENT, NAROK COUNTY, KENYA

Abstract

Sustainable land management enhances quick vegetation recovery through enhancement of soil fertility and reduction in land degradation. This study investigated the effect of rangeland rehabilitation on diversity of herbaceous layer within Suswa catchment in Narok County, Kenya. Selected herbaceous layer characteristics were determined within the rehabilitated area and reference (degraded area) along a slope (upper, middle and lower slope positions). The results showed that percent cover, aboveground biomass, relative abundance, richness, composition and diversity of perennial grasses significantly ($p \leq 0.05$) increased downslope and was higher in the rehabilitated area than in the degraded area. On the contrary the same attributes for forbs and annual grasses were significantly ($p \leq 0.05$) higher within the degraded site compared to the rehabilitated area and increased upslope. Highest plant biomass production (1,459 kg/ha) and percent cover (74.67 %) were recorded in the lower slope position within the rehabilitated area. The study showed that use of structural soil and water conservation measures has the potential of restoring degraded ecosystems through vegetation recovery.

Key words: Land rehabilitation; Land degradation; Slope; Herbaceous layer; Biodiversity

3.1 Introduction

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

The alteration in species composition affects soil fertility due to changes in belowground biomass and organic matter content, thus reducing soil carbon sequestration (Scholes, 1990; Klumpp *et al.,* 2009). Further, land degradation leads to reduction in resilience of host species, reduction of vegetation cover, decreased species diversity and reduced herbaceous biomass production (Kairis *et al.,* 2015; Belgacem *et al.*, 2013). Moreover, disturbances such as overgrazing favors establishment of invader species, survival and dominance of short-lived, un-preferred annual plant species rather than the palatable perennial species (Byers, 2002; Sahar *et al.,* 2012). Ultimately, changes in plant species composition greatly influences on the sustainability of livestock production within the rangeland ecosystems (Sankaran *et al.,* 2005).

In Kenya, land-use changes due to population increase and migrations from high potential lands have reduced grazing resources in the arid and semi-arid (ASALs) rangelands (Fratkin, 2001; Kirwa, 2009). Loss of grazing resources has influenced change in land use practices from traditional pastoralism to other non-compatible land use enterprises in the rangelands such as crop farming and charcoal production (Kirwa, 2009). The change in land use has further increased shrinkage and degradation in quality of pastures due to proliferation of invasive plant species such as *Lantana camara* and *Opuntia ficus* species (NEMA, 2009; Maina, 2013). The situation has led to severe land degradation (Muchena, 2008) in the Kenyan rangelands. A good example is the Suswa catchment in Narok County with gullies of over 25 m deep and 30 m wide (Khalif, 2014).

To restore the severely degraded Suswa catchment, the Sustainable Land Management (SLM) project rehabilitated the land through the establishment of several soil and water conservation structures as well as planting of trees in degraded areas (Odini *et al.*, 2015). However, despite the various rehabilitation approaches carried out, little research has been conducted to ascertain their effect on successful vegetation recovery. This coupled with the fact that many restoration approaches have failed in East Africa and more especially in Kenya gave drive to the study (Wasonga, 2009; Mureithi *et al.*, 2010). This study therefore, hypothesized that the restoration and rehabilitation measures installed in Suswa catchment has positively contributed to vegetation regeneration and species diversity enhancement, geared towards increased land productivity.

3.2 Materials and Methods

3.2.1 Study design

A Split Plot Design was used for this research with two land management practices (rehabilitated area and degraded areas) forming blocks, plots were the three slope categories (lower, middle and upper positions). Within each plot (slope position) three100 m transects were placed across the hill 30 m apart and 5 m away from the boundaries to avoid edge effects. The three 100 m long transects were replicated three times on each plot within the degraded and rehabilitated areas. To determine the differences in herbaceous layer due to seasons, data was collected during the wet (February) and dry seasons (August) in the year 2016.

3.2.2 Vegetation sampling

To assess the diversity of aboveground herbaceous layer, in the rehabilitated area and degraded areas along a slope (upper, middle and lower), line transect and quadrat count methods were used (Brady *et al.*, 1995). Vegetation was sampled at the peak of the wet and dry seasons in the year 2016. Within each slope position three 100 m transects were placed across the hill and parallel to one another 30 m apart. The species hit, those next to the hit and the hits on bare ground were recorded. Along the same transects 1m² quadrats were laid 25m apart and herbaceous layer aboveground biomass determined by use of the destructive method (T'Mannetje and Jones, 2000). Forb and grass plants rooted within the quadrat were clipped 2 cm above the ground level (clipping at grazing-height to give a more applicable measure of forage biomass). The various plant species clipped were then sorted into their relevant functional groups (perrenial grasses, forbs and annual grasses). Their fresh biomass was immediately weighed to determine their aboveground fresh biomass and later dried to a constant weight at 70°C for 48 hours after which aboveground biomass production was then determined and expressed in kg DMha^{-1}. In determining plant (species richness, composition, diversity and relative abundance) direct visual observation was used to identify, count and record individual plant species along transects at intervals of 1 m. The following equations were used.

Percent cover of a functional group = $\frac{\text{Number of hits of a functional group}}{\text{Total number of hits}} x\ 100\ \%$.................. (1)

Species richness = Number of different species represented in the sample…………………… (2)

Species composition (%) = $\frac{\text{Number of species A}}{\text{Total number of individuals}}$ x 100 %................................ (3)

Species diversity - Shannon-Weiner's (1949) index (H')

$$\textbf{Diversity}(\mathbf{H'}) = -\sum[\left(\frac{n_1}{N}\right) \times \ln\left(\frac{n_1}{N}\right)] \ldots\ldots \quad (4)$$

Where; n_1 = Number of individual species in the area

N = Total number of species in the area

Ln = Natural log of the number

$$\textbf{Relative abundance of functional group} = \frac{\text{Total number of hits of functional grp}}{\text{Total no.of hits of all species}} \times 100\ \% \ldots \quad (5)$$

3.2.3 Data analysis

Data on vegetation attributes was subjected to analysis of variance (ANOVA) using Genstat Discovery 15th edition statistical software at 5% significance level. Two way ANOVA was used in determining if there were significant differences between means of the various herbaceous characteristics with regard to land management practices, slope categories and season. Tukey's HSD *post hoc* was used to separate treatment means where the *F*-values were significant.

3.3 Results

3.3.1 Herbaceous species richness, relative abundance and diversity

The herbaceous species richness, relative abundance and diversity of perennial grasses significantly *($p \leq 0.05$)* increased downslope being higher in the rehabilitated area (4.67, 8.30 and 10.30), (77.97, 93.27 and 99.10 %) and (1.35, 1.55 and 1.91) compared to the degraded area (3.00, 5.00 and 6.67), (67.13, 79.70 and 91.51 %) and (1.07, 1.23 and 1.45) respectively (Table 3.1). Seasonality did not affect species richness *($p = 0.432$)*, relative abundance *($p = 0.065$)* and diversity *($P = 0.740$)* of perennial grasses (Appendix 1). However, higher values were recorded for the same attributes during the wet season than in the dry season (Table 3.1). The corresponding interactions of management*slope* season had no effect on the same attributes (Appendix 1). Generally perennial grass species richness, relative abundance and diversity increased downslope and were significantly higher in the rehabilitated area compared to the degraded area.

Table 3.1: Herbaceous species richness, relative abundance (%) and diversity in rehabilitated and degraded areas of Suswa catchment during wet and dry seasons

Treatment		Management / Slope	Wet season (February, 2016) Rehabilitated area Upper	Middle	Lower	Degraded area Upper	Middle	Lower	LSD	Dry season (August, 2016) Rehabilitated area Upper	Middle	Lower	Degraded area Upper	Middle	Lower	LSD
Abundance	Grasses	Annuals	1.50a	0.60a	0.00a	6.50b	3.70a	2.30a	5.40	0.00a	0.00a	0.00a	0.00a	1.37a	2.73b	2.43
		Perennials	77.97b	93.27c	99.10d	67.13a	79.70b	91.51c	3.10	88.70ab	95.6bc	99.90c	84.90a	85.90a	91.46a	7.88
	Forbs		15.53c	6.07b	0.90a	31.30d	16.57c	6.13b	4.98	11.30bc	1.40a	0.00a	15.10c	12.70bc	2.70ab	8.00
Diversity	Grasses	Annuals	0.11	0.00	0.00	0.11	0.10	0.36	0.31	0.00	0.00	0.00	0.00	0.10	0.20	0.18
		Perennials	1.35c	1.55e	1.91f	1.07a	1.23b	1.45d	0.07	1.30c	1.53d	1.86e	1.05a	1.22b	1.35c	0.02
	Forbs		0.43c	0.09a	0.02a	0.62d	0.46c	0.26b	0.07	0.21	0.33	0.00	0.35	0.25	0.13	0.44
Richness	Grasses	Annuals	0.67a	0.00a	0.00a	0.67a	0.67a	3.33b	2.45	0.00a	0.00a	0.00a	0.00a	0.33a	0.67b	0.59
		Perennials	4.67b	8.30d	10.30e	3.00a	5.00b	6.67c	0.84	4.00b	8.00e	10.00f	2.60a	5.00c	6.00d	0.42
	Forbs		1.60b	1.00ab	0.30a	5.30d	4.00c	2.00b	0.70	1.30bc	0.33a	0.00a	2.00c	2.00c	1.00b	0.94

Means followed by different letters within the same row are significantly different *($p \leq 0.05$)*

The species richness, relative abundance and diversity of forbs significantly *($p \leq 0.05$)* increased upslope being higher in the degraded area (5.3, 4.0, 2.0), (31.3, 16.57, 6.13 %) and (0.62, 0.46, 0.26) compared to the rehabilitated area (1.6, 1.0, 0.3), (15.53, 6.07, 0.90 %) and (0.43, 0.09, 0.02) respectively (Table 3.1). Seasonality significantly affected the species richness *($p = 0.001$)*, relative abundance *($p = 0.001$)* and diversity *($p = 0.010$)* of forbs with higher values recorded in the wet season compared to the dry season. However, interactions due to management* slope and season did not show significant effect on the same attributes (Appendix 1).

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

3.3.2 Aboveground herbaceous biomass and percent ground cover

Aboveground biomass of perennial grasses significantly ($p \leq 0.05$) increased downslope (upper, middle and lower) being higher in the rehabilitated area (284, 701, 1,459 kg/ha) than in the degraded area (229, 453, 635 kg/ha), respectively. The same trend was also observed with percentage cover where rehabilitated area had (42.33, 64.63 and 74.67 %) and degraded (31.33, 45.00 and 57.47 %) respectively (Table 3.2). Seasonality had a significant effect on aboveground biomass of perennial grasses *($p = 0.045$)* with higher values recorded in the wet season than in the dry season (Table 3.2).

Table 3.2: Aboveground herbaceous plant biomass (Kg/ha) and percent cover in rehabilitated and degraded areas of Suswa catchment during wet and dry seasons

Treatment	Management	Wet season (February, 2016)							Dry season (August, 2016)						
		Rehabilitated area			Degraded area				Rehabilitated area			Degraded area			
	Slope	Upper	Middle	Lower	Upper	Middle	Lower	LSD	Upper	Middle	Lower	Upper	Middle	Lower	LSD
Aboveground biomass	Annuals grasses	0.0a	0.0a	0.0a	16.7a	22.0a	56.7b	49.7	0.0a	0.0a	0.0a	0.0a	0.0a	0.0a	*
	Perennials grasses	284.0a	701.0b	1459.0c	229.0a	453.0ab	635b	295.0	223.0c	391.0d	895.0e	114.0b	236.0c	4.2a	20.6
	Forbs	4.0a	4.3a	50.7ab	50.0ab	74.0b	194.7c	57.9	2.0a	4.3a	8.0a	5.0a	14.0a	46.3b	15.1
Percent cover	Annuals grasses	1.6a	0.0a	0.0a	3.3a	3.0a	1.9a	7.0	0.0a	0.0a	0.0a	0.0a	0.7a	1.3b	1.2
	Perennials grasses	42.3b	64.6d	74.7e	31.3a	45.0b	57.5c	2.8	40.0b	58.1c	68.0d	29.0a	42.0b	54.7c	2.7
	Forbs	10.00c	2.67a	1.33a	19.6d	12.0c	7.0b	2.2	4.0ab	0.7ab	0.0a	6.3b	6.0b	2.3ab	3.8

Means with different letters within the row are significantly different *($p \leq 0.05$)*

The forbs aboveground biomass increased downslope, however, higher values were observed in the degraded (50.0, 74.0, 194.7 Kg/ha) area than in the rehabilitated area (4.0, 4.3, 50.7 Kg/ha) (Table 3.2). Percent cover of forbs significantly *($p \leq 0.05$)* increased upslope being higher in the degraded areas (19.67, 12.00, 7.00 %) than in the rehabilitated areas (10.00, 2.67, 1.33 %) respectively (Table 2.2). Seasonality had a significant effect on the aboveground biomass (*$p = 0.001$)* and percent cover *($p = 0.001$)* of forbs (Appendix 2). The corresponding interactions of management*slope*season had no significant effect on the aboveground biomass *($p = 0.268$)* and percent cover *($P = 0.344$)* of forbs (Appendix 2).

Statistically, management practice and slope did not have significant *($p \leq 0.05$)* effect on the aboveground biomass and percent cover of annual grasses. However higher values were recorded within the degraded area compared to the rehabilitated area (Table 3.2). Seasonality had a significant effect on the aboveground biomass *($p = 0.024$)* and percent ground cover *($p = 0.032$)* of annual grasses (Appendix 2), with higher values recorded during the wet season compared to the dry season (Table 3.2). The corresponding interactions of management*slope*season did not significantly affect aboveground biomass *($p = 0.418$)* and percent cover *($p = 0.430$)* of annual grasses (Appendix 2)

3.3.3 Percent herbaceous plant species composition

Rangeland rehabilitation, slope and season had an effect on species composition. Generally, during the wet season *Aristida adoensis* was the most abundant species in the area with abundances of 1.76, 2.82 and 5.52 % in the upper, middle and lower slope positions of the rehabilitated area and 1.13, 2.11 and 3.17 % in the upper, middle and lower slope positions of the degraded area respectively (Table 3.3).

The percentage composition of perennial grasses *Themeda triandra* and *Chloris gayana* was high in the lower slope position (0.59 and 0.70 %) compared to the middle (0.35 and 0.24 %) and upper slope position (0.25 and 0.12 %) within the rehabilitated area during the wet season (Table 2.3). However, *Cymbopogon afranardus* mainly dominated the upper slope position (0.68 %) within the degraded area (Table 3.3). Seasonality did not impact on perennial grasses composition.

High frequencies of forbs such as *Pentanisia ouranogyne, Euphorbia inequilatera* and *Sirene species* were found in upper slope position and mainly within the degraded site. *Hypoestes verticillaris* was the most abundant forb within the upper slope position with percentages of (0.57 %) in the degraded and (0.16 %) in the rehabilitated area respectively (Table 3.3). Forbs such as *Polyghala sphenoptera* disappeared during the dry season.

There were high proportions of annual grasses such as *Aristida keniensis* and *Eragrostis tenuifolia* in upper slope position (0.23 % and 0.35 %) of the degraded area compared to upper slope position (0.12 % and 012 %) of the rehabilitated area (Table 3.3). There were seasonal changes in species composition of annual grasses with some annual grasses such as *Eragrostis tenuifolia* disappearing during the dry season (Table 3.3).

Generally, forbs and annual grasses had a higher percentage composition in upper slope positions within the degraded area compared to the rehabilitated areas. Contrary perennial grasses dominated the lower slope position within the rehabilitated area depicting signs of improved soil productivity.

Table 3.3: Percent herbaceous plant species composition in rehabilitated and degraded areas of Suswa catchment during wet and dry seasons

		Wet Season (February, 2016)						Dry Season (August, 2016)					
		Rehabilitated area			Degraded area			Rehabilitated area			Degraded area		
Species	**Functional group**	**Upper**	**Middle**	**Lower**	**Upper**	**Middle**	**Lower**	**Upper**	**Middle**	**Lower**	**Upper**	**Middle**	**Lower**
Hyparrhania lintonii	Perennial grass	0.70	1.29	2.23	0.34	0.94	1.29	0.59	1.17	2.11	0.34	0.82	1.17
Harpachne schimperi	Perennial grass	0.59	1.06	1.41	0.23	0.35	0.82	0.47	0.94	1.29	0.23	0.35	0.70
Hyparrhania disoluta	Perennial grass	0.12	0.70	1.29	0.11	0.35	0.94	0.12	0.70	1.29	0.11	0.35	0.82
Aristida adoensis	Perennial grass	1.76	2.82	5.52	1.13	2.11	3.17	1.64	2.70	5.40	0.94	1.88	2.70
Chloris gayana	Perennial grass	0.12	0.24	0.70	NP	0.12	0.23	0.12	0.12	0.70	NP	0.12	0.23
Digitaria scalarum	Perennial grass	0.59	0.82	1.41	NP	0.70	0.94	0.47	0.70	1.41	NP	0.47	0.82
Themeda triandria	Perennial grass	0.35	0.35	0.59	NP	0.12	0.47	0.35	0.35	0.59	NP	0.12	0.47
Cymbopogon afronardus	Perennial grass	0.47	NP	NP	0.68	NP	NP	0.47	NP	NP	0.68	NP	NP
Eragrostis brownie	Perennial grass	NP	NP	0.23	NP	NP	NP	NP	NP	0.23	NP	NP	NP
Ergrostis biflora	Perennial grass	NP	NP	0.35	NP	NP	NP	NP	NP	0.35	NP	NP	NP
Hyparrhania hirta	Perennial grass	0.12	0.59	0.47	0.11	0.23	0.35	0.12	0.47	0.35	0.11	0.23	0.35
Cynodon plectostachyus	Perennial grass	NP	NP	NP	NP	0.12	NP	NP	NP	NP	NP	0.12	NP
Sporobolus fimbriatus	Perennial grass	0.12	0.47	0.23	0.11	0.35	0.23	0.12	0.47	0.23	0.11	0.35	0.23
Eustachyus paspaloides	Perennial grass	NP	0.24	0.35	NP	NP	0.23	NP	0.24	0.35	NP	NP	0.23
Sporobolus discosporus	Perennial grass	NP	0.70	1.64	NP	0.47	1.41	NP	0.59	1.53	NP	0.35	1.17
Satureia biflora	Forb	0.12	0.12	NP	0.45	0.59	NP	NP	NP	NP	0.23	0.35	NP
Borreria stricta	Forb	0.12	NP	NP	0.23	0.12	0.12	0.12	NP	NP	0.12	NP	0.12
Euphorbia inequilatera	Forb	0.12	NP	NP	0.23	0.12	NP	0.12	NP	NP	0.12	0.12	NP
Polyghala sphenoptera	Forb	NP	NP	NP	0.11	NP	NP	NP	NP	NP	NP	NP	NP
Sirene SPP.	Forb	0.12	NP	NP	0.23	NP	NP	NP	NP	NP	0.23	NP	NP
Hypoestes verticillaris	Forb	0.16	NP	NP	0.57	0.12	NP	0.12	NP	NP	0.35	0.12	NP
Pentanisia ouranogyne	Forb	NP	NP	NP	0.45	NP	NP	NP	NP	NP	0.23	NP	NP
Fuerstia Africana	Forb	NP	NP	NP	0.23	0.35	NP	NP	NP	NP	NP	0.12	NP
Eragrrostis tenuifolia	Annual grass	0.12	NP	NP	0.35	0.23	0.12	NP	NP	NP	NP	NP	NP
Aristida keniensis	Annual grass	0.12	NP	0.12	0.23	0.11	0.12	NP	NP	0.12	NP	0.12	0.12

KEY: NP – Not Present, N – 852 Species

3.4 Discussions

3.4.1 Species richness, Relative abundance and Diversity

The significantly higher species richness, relative abundance and diversity of perennial grasses compared to forbs and annual grasses in the rehabilitated area could be attributed to improved soil fertility as a result of reduced runoff and erosion due to the establishment of soil and water conservation structures (Singh *et al.,* 2011). Restoration of severely degraded areas have been shown to enhance vegetation recovery which in turn reduces soil erosion, enhances soil fertility and hence increased soil productivity and plant biodiversity (Tongway and Ludwig, 2011). The rehabilitation activities in the study area could have achieved this and hence the observed improvement in plant species diversity and land cover. The findings of this study are consistent with those of Mureithi *et al.* (2014) who while working in Laikipia, reported a higher species richness and diversity in areas under community conservation than in open communal grazing areas. Similarly, Singh *et al.* (2011) working in the degraded Aravalli hills in Western India found a higher species diversity in areas with soil and water conservation structures.

Further, the higher species richness, diversity and relative abundance of perennial grasses compared to that of forbs and annual grasses downslope could be attributed to improved fertility as a result of the transportation and accumulation of soil sediments from the upper slopes. Slope gradient influences the accumulation and export of soil nutrients downslope thereby directly or indirectly affecting vegetation distribution (Zuo, 2012). Slope also affects the physical chemical properties of the soil which in turn affects the distribution and diversity of species (Enright *et al.,* 2005). Soils in higher altitudes are frequently washed of their nutrients which are then deposited in the lower slopes (Sohrabi, 2003). These findings corroborates with those of (Sohrabi, 2003; Heidari *et al.,* 2010; Zheng *et al.,* 2014) who reported a decreasing species diversity and richness with increasing altitude. Contrary to these findings, Baldock and Smith, (2009) in their study in Nubra valley region in Ladakh reported an increasing herbaceous species diversity and abundance with up the slope, a fact they attributed to increased grazing pressure on lower positions from the inhabitants.

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

3.4.2 Herbaceous plant biomass yield and ground cover

Higher biomass production and ground cover of perennial grasses in the rehabilitated area compared to the degraded area could be attributed to improved land management through the establishment of soil and water conservation structures such as semi-circular bands, cut-off drains and terraces. Terraces have been shown to improve soil physico-chemical properties such as soil moisture content and soil organic carbon (Ruto, 2015). Aboveground biomass and ground cover are positively correlated with the amount of water and nutrients in the soil which are the main limiting components in severely degraded areas (Singh *et al.,* 2011). Furthermore, improved ground cover and above ground biomass of perennial grasses compared to forbs and annual grasses in the rehabilitated area could be attributed to reduced grazing pressure in the rehabilitated sites. The area under study was under planned grazing with animals only allowed to graze on the site when there was severe drought. Proper grazing management through livestock exclusion at certain times has been found to enhance the range condition in areas that are severely degraded (Allen *et al.*, 1995; Wasonga *et al.*, 2011). Moreover, lower biomass production and percentage cover of perennial grasses in the degraded area could be attributed to year round grazing which could not allow quick vegetation recovery in the study area (Verdoodt *et al.*, 2010). These findings corroborates with those of Singh *et al.*, (2011) who reported higher biomass production and percent cover in areas rehabilitated through rainwater harvesting. Similarly, Monsour *et al.* (2013) found a higher ground cover and biomass yield in areas rehabilitated with stone terraces compared to those with no terraces.

The higher aboveground biomass and percent cover of perennial grasses in the lower slope position compared to forbs and annual grasses could be attributed to improved soil fertility downslope (Chapter 4 & 5). This is in agreement with previous studies which have indicated that vegetation growth is directly related with phosphorus, soil organic carbon, potassium and total nitrogen (Marcuzzo *et al.*, 2013). Singh *et al.*, (2011) in his study on Aravalli hills in western India found higher herbaceous biomass production and percent cover on lower slopes than in upper slopes.

The significantly higher aboveground biomass and percent cover between seasons could be attributed to rainfall variability. Sufficient soil moisture content generally increases plant biomass (Robinson *et al.*, 2013). O'Connor and Roux, (1995) working in a semi-arid shrubland of Karoo in South Africa also reported higher aboveground herbaceous biomass production and percent cover during the wet season.

3.4.3 Herbaceous species composition

The results of this study indicated differences in species composition between sites, seasons and among slope positions. The dominance of forbs and annuals in the degraded area compared to the rehabilitated area could be attributed to depleted soil fertility due to erosion. Abundance and dominance of forbs and annual grasses is an indication of poor range condition due to mismanagement or change in plant composition within the site (Camp, 1997). Stohlgren *et al.* (1999) and Anderson and Hoffman, (2007) noted that poorly managed communal rangelands had lower proportion of perennial grasses compared to forbs and annual grasses.

Increase in number of perennial grasses compared to forbs and other annuals in the rehabilitated area could also be an indication of reduced runoff, a fact attributable to improved ground cover. This is in agreement with Everson *et al.*, (2007) who noted reduced runoff rates in the rehabilitated areas than in the degraded areas. The observed pattern of species composition with large number of perennial grasses in the lower slopes compared to the upper and mid slope positions within the rehabilitated area could be attributed to improved fertility, drainage and depth of the soils downslope. Slope impacts on soil drainage, depth and chemical fertility (Boll *et al.*, 2005; Enright *et al.*, 2005).

Reduced frequency and dominance of annual grasses and forbs during the dry season may be attributed to low soil moisture content (Chapter 5). Annuals and forbs are generally shallow rooted and therefore slight changes in soil moisture content with high temperatures affects their growth. Annuals also respond to moisture variations faster than perennial species because of their fast growth and early completion of life cycle (Miranda 2009).

3.5 Conclusion and Recommendation

This study confirms that land management, slope position and season have a significant effect on floristic composition and vegetation structure. This is demonstrated by the significant differences in the various vegetation attributes between management practices, slope positions and seasons. In general, herbaceous plant species diversity, species richness, relative abundance, percent composition, biomass production and percent cover of perennial grasses significantly increased downslope being higher in the rehabilitated area compared to the degraded area. On the contrary, the same attributes for forbs and annual grasses were higher in the degraded area and increased upslope. Seasonal variations were also observed mainly on forbs and annual grasses for the same attributes with low values recorded during the dry season. The phenomenal differences clearly indicate that slope, management practice and season influences vegetation structure and should be considered for sustainable land management. In heavily degraded lands, the use of water and soil conservation structures such as water retention ditches, terraces, semi-circular bands should be encouraged for soil erosion control and vegetation recovery. Nonetheless, grasses such as *Cymbopogon afranardus* which can withstand severe degradation and were naturally occurring should be used in restoration of heavily degraded systems.

CHAPTER FOUR

EFFECT OF RANGELAND REHABILITATION ON SOIL CHEMICAL PROPERTIES IN SUSWA CATCHMENT, NAROK COUNTY, KENYA

Abstract

A large percentage of land in Kenya is currently experiencing severe land degradation. This has therefore, called for proper land use and improved land rehabilitation techniques. This study investigated the effects of land rehabilitation on soil chemical properties (SOC, N, P, K and pH) in Suswa Catchment, Narok County. The soil parameters were determined within the rehabilitated and degraded areas at different slope positions (Lower, middle and upper) during the wet and dry seasons in the year 2016. Within each slope position three 100 m long transects were laid along the slope categories 30 m apart and soil sampled at 25 m intervals along the transect using a soil auger. The results indicated that soil organic carbon, total nitrogen, potassium, phosphorus and pH significantly ($p \leq 0.05$) increased downslope and were significantly ($p \leq 0.05$) higher in the rehabilitated areas than the degraded areas. Highest soil organic carbon (3.82 %), total nitrogen (0.38 %), phosphorus (36.34 ppm), potassium (2.50 Cmol+/kg) and pH (6.41) were observed within the lower parts in the rehabilitated sites. Seasonality did not significantly *($p > 0.05$)* affect the above soil attributes. The study demonstrates that proper land rehabilitation restores soil fertility and thus rangeland productivity in general. Therefore, these interventions should be employed on areas undergoing severe land degradation

Key words: Land degradation, land rehabilitation, soil chemical properties, slope categories

4.1 Introduction

Soil is a very important natural resource and its quality is due to net effects of all its soil forming factors and management (Muya *et al.,* 2011). Despite the various ecosystem services derived from soils its mismanagement continues unabated leading to severe land degradation. Approximately 20 to 30 % of total land area in the world has already been degraded (Stavi and Lal, 2015; Le *et al.* 2014). In Sub-Saharan Africa, about 28 % of the population (UN, 2014) lives in areas that are currently experiencing severe land degradation. Moreover, approximately 40 % of Sub-Saharan's grasslands are severely degraded (Le *et al.*, 2014). Land degradation in Kenya is increasing rapidly with over 30 % of forests 20 % of croplands and 10 % of rangelands experiencing degradation (Muchena *et al.,* 2008).

Soil erosion, land degradation and conversion of grasslands to crop lands characterize most rangelands today (Reid *et al.*, 2003). This has resulted to loss of micro and macro nutrients such as soil organic carbon, nitrogen and zinc. The loss of these nutrients in turn negatively impacts land productivity (Dong *et al.*, 2012) due to the reduced levels of soil organic carbon (Zhou *et al.*, 2005) and nitrogen (Wen *et al.*, 2013). The alterations in soil organic carbon strongly influence other soil properties such as hydraulic conductivity and aggregate stability, which also affects soil organic carbon dynamics and microbial activity (Boivin *et al.,* 2009).

One of the many roles of soil organic carbon (SOC) is to enhance the capacity of the soil to hold water as well as improve the cation exchange capacity (Mureithi *et al.,* 2014). Moreover, SOC plays a major part in binding of soil particles into aggregates which improve the structural stability of the soil. It also forms part of the soil organic matter content (SOM) which holds the nutrient cations and trace elements necessary for plant growth (McClaran *et al.*, 2008). Reduced biodiversity in soils due to degradation impairs numerous ecosystem functions, such as nutrient uptake by plants and the cycling of resources between above and belowground communities (Vander *et al.,* 2008; Wall *et al.,* 2010). This is mainly attributed to a reduction in ground cover as a result of land degradation. Reduced ground cover leads to frequent runoffs and hence depletion of soil nutrients (Morgan *et al.,* 1995).

The survival and physical condition of plants is dependent on the regular supply of nutrients from the soil (Badshah *et al.,* 2012). Nutrients are not only vital for plant growth and development but they also provide forage and fodder for grazing livestock (Hussain and Durrani, 2008). Any successful rehabilitation therefore, needs to improve the depleted soil seed bank, control soil erosion and runoff as well as promote sustainable land use (Kinyua *et al.,* 2009; Opiyo *et al.,* 2011). Successful land rehabilitation techniques enhance soil fertility, ecosystem services and biodiversity in general (Descheemaecker *et al.,* 2006; Tongway and Ludwig, 2011).

There has been a tremendous change in land use from pure pastoralism to agro-pastoralism and crop production in most rangelands of Kenya. Suswa Catchment in Narok County is an example where previously large communal grazing lands have been fenced and sub divided a situation that has restricted livestock mobility. This has resulted in concentrated grazing and change in livelihood a situation that has led to loss of soil fertility due to frequent runoffs and erosion. Frequent runoffs in the area have resulted to formation of deep gullies (25 m deep and 30 m wide) (Khalif, 2014). Increasing land degradation in the area demanded for land rehabilitation efforts. The Sustainable Land Management (SLM) team through its donor agencies took the initiative of rehabilitating the land through construction of structural soil and water conservation structures in the year 2013 (Odini *et al.,* 2015). Community sensitization was also conducted on the importance of controlled grazing and charcoal burning. Despite the initiatives carried out in Suswa in restoring land productivity, limited research has been done to examine the effectiveness of the rehabilitation process on soil fertility. This study thus sought to investigate how the land rehabilitation process has impacted on rangeland productivity through assessment of selected soil chemical properties. The study hypothesized improved soil fertility due to rehabilitation efforts done in the study area.

4.2 Materials and Methods

4.2.1 Study design

A Split Plot Design was used for this research with two land management practices (rehabilitated area and degraded area) forming blocks, plots being the three slope categories (lower, middle and upper positions). Within each plot (slope position) three100 m transects were placed across the hill 30 m apart and 5 m away from the boundaries to avoid edge effects. The three 100 m long transects were replicated three times on each slope position. Disturbed soil was then sampled along transects at 25 m intervals. Season was also considered as an experimental factor to test for the changes in soil chemical properties within the wet (February) and dry seasons (August) in the year 2016.

4.2.2 Soil sampling

Along the transects 1- m^2quadrats were laid 25 m apart and soil sampled at a depth of (0 – 20 cm) from each quadrat using a soil auger. Soil samples along each transect were mixed to a 1kg composite soil sample per transect. This resulted to 3 composite samples per slope position giving to a total of 9 soil samples per management practice per season.

4.2.3 Laboratory analysis

Air-dried soil samples ground and passed through a 2-mm sieve were used in determination of soil organic carbon (SOC), total nitrogen (N), available Phosphorus (P), potassium (K) and soil pH. Total soil organic carbon was determined by the wet oxidation method of Walkley and Black and soil organic matter content calculated by multiplying soil organic carbon by a factor of 1.724 (Nelson and Sommer, 1982). Determination of total nitrogen followed Kjeldahl method (Bremmer and Mulvaney, 1982). Available Phosphorus was extracted by the Mehlich method and determined spectrophotometrically (Murphy and Riley, 1962). Exchangeable base K^+ was extracted by saturating the soil with neutral 1M NH_4OAc (ammonium acetate) (Thomas, 1982). The base K^+, displaced by NH_4^+ was then measured by atomic absorption spectrophotometer (AAS). In the determination of soil pH 1M KCl and water were used. Soil was then mixed with the solution in a ratio of 1: 2.5 and pH determined by glass electrodes after subsequent shaking (McLean, 1982)

4.2.4 Data analysis

Data on soil properties was subjected to analysis of variance (ANOVA) using Genstat Discovery 15th edition statistical software. Tukey's HSD *post hoc* was used to separate treatment means where the *F*-values were significant.

4.3 Results

Table 3.1 presents means for soil pH, organic carbon (C), total nitrogen (N), available phosphorus (P) and potassium (K) among treatments. Soil pH values ranged from slightly acidic (6.41) in the rehabilitated area to moderately acidic (5.73) in the degraded area and significantly ($p \leq 0.05$) increased downslope. There were no significant differences in terms of soil pH due to season ($p = 0.719$) and in the corresponding interactions of management practice*slope*season ($p = 0.997$) (Appendix 3).

Soil organic carbon levels ranged from moderate to high (1.40 to 3.82 %) (Landon, 1991) and significantly ($p \leq 0.05$) increased downslope. Higher values were recorded in the rehabilitated area (2.06 to 3.82 %) than in the degraded area (1.40 to 2.61 %) respectively (Table 4.1). There were no significant differences in terms of soil organic carbon due to season ($p = 0.662$) and in the corresponding interactions of management*slope*season ($p = 0.988$) (Appendix 3).

Table 4.1: Soil chemical properties in rehabilitated and degraded areas of Suswa catchment during wet and dry seasons

Treatment		Wet season (February, 2016)							Dry season (August, 2016)						
Management		Rehabilitated area			Degraded area				Rehabilitated area			Degraded area			
Slope		Upper	Middle	Lower	Upper	Middle	Lower	LSD	Upper	Middle	Lower	Upper	Middle	Lower	LSD
pH		5.95bc	6.13c	6.41d	5.73a	5.91b	6.03bc	0.18	5.92b	6.11b	6.40c	5.72a	5.90a	6.03b	0.19
SOC	%	2.06b	2.70c	3.82d	1.40a	1.82b	2.61c	0.25	2.04b	2.67c	3.79d	1.40a	1.81b	2.57c	0.24
SOM	%	3.55c	4.66d	6.58e	2.41a	3.14b	4.50d	0.40	3.53c	4.61d	6.53e	2.41a	3.12b	4.43d	0.41
N	%	0.21c	0.27d	0.38e	0.14a	0.17b	0.26d	0.02	0.21c	0.26d	0.38e	0.13a	0.16b	0.25d	0.02
P	Ppm	20.47b	28.67d	36.34e	12.83a	20.22b	24.33c	2.43	20.37b	28.87d	36.24e	12.73a	20.12b	24.23c	2.38
K	Cmol+/kg	1.88b	2.07bc	2.50d	1.77a	1.93bc	2.13c	0.13	1.85b	2.03bc	2.47d	1.74a	1.90bc	2.11c	0.13

Key: SOC = Soil Organic Carbon, SOM = Soil Organic Matter, N = Nitrogen, P = Phosphorus, K = Potassium
Means with different letters within the same row are significantly different ($p \leq 0.05$)

The mean values for soil organic matter (SOM) ranged from medium to very high (2.41 to 6.58) (Landon, 1991) and significantly ($p \leq 0.05$) increased downslope. Statistically higher values were recorded in the rehabilitated area compared to the degraded area (Table 4.1). There were no significant differences due to Season *(p = 0.662*) and the corresponding interactions of management*slope*season *(p = 0.988)* on SOM.

The mean values for total soil nitrogen (N) ranged from low to moderate (0.14 to 0.38 %) (Landon, 1991) and significantly increased ($p \leq 0.05$) downslope. Statistically higher values were recorded in the rehabilitated area (0.21 to 0.38 %) than in the degraded area (0.14 % to 0.26 %) (Table 4.1). Soil nitrogen content was not significantly affected by season *(p = 0.472)* and the corresponding interactions of management*slope*season *(p = 0.968)* (Appendix 3).

Available P in the soil ranged from moderate to high (12.73 to 36.34 ppm) while that of available K ranged from 1.74 to 2.50 Cmol+/kg which were generally high (Landon, 1991). Soil P and K significantly ($p \leq 0.05$) increased downslope and were higher in the rehabilitated area (20.47 to 36.34 ppm) and (1.88 to 2.5 Cmol+/kg) than in the degraded area (12.83 to 24.33 ppm) and (1.77 Cmol+/kg to 2.13 Cmol+/kg) respectively (Table 4.1). Season did not significantly affect soil P *(p = 0.913)* and K *(p = 0. 225)* levels (Appendix 3). The corresponding interactions of management*slope*and season did not have any significant effect on soil P *(p = 0.988)* and K *(p = 0.999)* amounts (Appendix 3).

4.4 Discussion

The significantly higher soil C and N values in the rehabilitated area than in the degraded area could be attributed to improved ground cover (Chapter 3) that reduced the amount and rates of soil erosion and runoff. Thick vegetation cover reduces loss of soil nutrients among them soil organic carbon and nitrogen which are essential for plant growth (Iwara *et al.*, 2011). Further, restoration of degraded areas enhances vegetation recovery and biomass production which in turn provide litter and organic matter into the soil. The quality and quantity of soil organic matter determines the levels of soil organic carbon (Verdoodt *et al.,* 2010) and nitrogen (Mekuria and Veldkamp, 2012). Moreover, the high ground cover (Chapter 3) within the rehabilitated area could have improved soil moisture content through increased infiltration and reduced evaporation. Soil moisture content, in turn, enhanced root growth and above ground biomass production which is a key component of soil organic matter (Verdoodt *et al.*, 2010). Soil organic matter enhances the soil aggregate stability which in turn decreases loss of soil carbon, nitrogen, and phosphorus (Kasper *et al*., 2009).

On the other hand, the lack of sufficient ground cover in the degraded areas could be the most cause of low SOC and N compared to the rehabilitated area. This can be attributed to too much exposure of soil to high temperature that might have resulted to volatilization of N and also quick decomposition of organic matter in the soil. High temperatures enhance quick disintegration of soil organic matter resulting in higher losses of soil organic carbon (Southorn, 2002). Similarly, very high temperatures cause quick dissociation of NH_4^+ to NH_3 and conversion of Nitrogen to NH_3 which is easily lost through volatilization (Frank *et al.,* 2004).

Use of structural soil and water conservation techniques such as infiltration trenches and water retention ditches in the study area improved soil moisture content (Chapter 5) in the rehabilitated area which in turn improved biomass production and consequently soil organic matter. Mupangwa *et al*. (2006) working in semi-arid Mzingwane Catchment, Limpopo Basin, Zimbabwe found that rainwater harvesting using water retention ditches improved water infiltration, increased the duration of soil moisture availability and reduced runoff. Nonetheless, when the soil moisture content is high the rate of microbial breakdown of dissolved organic carbon is low (Deressa *et al.,* 2015).

The higher levels of SOC and N in the rehabilitated area than in the degraded area agree with those of Offiong *et al. (*2009) in South-Southern Nigeria. The study showed that organic matter, total nitrogen and SOC levels were significantly ($p \leq 0.05$) higher in the undisturbed secondary forest than in disturbed areas. Mureithi *et al.* (2014) working in Laikipia also reported significantly ($p \leq 0.05$) higher SOC and N levels in community conservancies than in open and highly disturbed areas. Similarly, Mulugeta and Stahr, (2010) also noted significantly ($p \leq 0.05$) higher soil organic matter in a conserved catchment compared to non-conserved ones in South Gondar, Ethiopia.

The significantly higher SOC and N content in the lower slope position than in the upper slope position could be attributed to sedimentation and higher organic matter content down slope. These findings are consistent with those of Malgwi and Abu, (2011), whose work in a SW savannah, Nigeria showed that soils in the lower slope position had significantly higher moisture content than those in upper slopes. Higher moisture content in lower slope positions reduces the rate of organic matter microbial disintegration and mineralization (Lopez *et al*., 2003 and Gao *et al*., 2009). Additionally, slope elevation, its length and configuration influence runoff, drainage, and soil erosion (Aandahl *et al.,* 1948) this in turn causes a significant difference in soil physico-chemical properties along the slope positions (Brubaker *et al*., 1993). However, contrary to this study, Lawal *et al.* (2014) reported a downslope decrease in SOC while working within the Southern Guinea Savanna in Nigeria a fact he attributed to overgrazing in the lower parts.

The observed higher N values at the lower slope position than in the middle and upper slope positions could also be due to continuous washing of nitrogen from upper and mid slope positions through run off and erosion which accumulated or deposited on the lower parts of the catchment. Ofori *et al.* (2013) working in Sawah, Ghana reported a significantly *($p \leq 0.05$)* higher amounts of N in the lower slope than in the upper slope position. Similar findings were reported by Siriri *et al*. (2005) working in south west region of Uganda. The non-significant differences in soil C and N amounts between seasons could be attributed to low rates of mineralization of soil nutrients (Marrs *et al.*, 1989, Karuma *et al*., 2015).

Higher values of soil P and K in the rehabilitated area than in the degraded area could be attributed to improved ground cover which probably reduced soil erosion and nutrient loss. Highly disturbed soils lose high amounts of phosphorus unlike soils that are undisturbed and densely covered with vegetation (Brady and Weil, 1996). A reduction in the quantity of plant biomass and ground cover leads to loss of soil nutrients among them soil phosphorus and potassium (Morgan *et al.*, 1995).

The observed higher P and K amounts in the rehabilitated area compared to the degraded area could probably be due to increased organic matter that stimulated the adsorption of potassium cations (Evans *et al.*, 2012). The other possibilities of the observed higher P and K could be a result of improved vegetation cover (Chapter 3) which acted as nutrient pumps for these elements from deeper soil profiles to the upper or surface horizons in litter form (Azarnivand *et al.*, 2011). These findings corroborates those of Matano *et al.* (2015) working in Trans-Mara Kenya who reported significantly higher P and K values in less disturbed areas than in highly disturbed areas.

The significantly higher P and K amounts in lower slope positions could be as a result of reduced run off and deposition of eroded minerals from higher elevations. This is in tandem with the findings of Ovuka (2000) who while working in Murang'a found higher concentration of nutrients in the lower slopes than in the upper and middle slope positions; an indication of erosion of top fertile soils in higher slope elevations.

Similarly, the observed higher P and K could probably be due to increased biomass production down slope (Chapter 3) which in turn improved soil organic matter that enhanced the levels of soil P and K through microbial activities. Higher biomass production increases soil organic matter which is a store of phosphorus. Tadele *et al.* (2011) working in Absela in Ethiopia reported increased amounts of P and K with improved biomass production. Pruess *et al*. (1992) on the other hand argued that soil organic matter content is the main factor determining the levels of soil P, K and other soil properties in semi-arid regions.

The slightly acidic soil pH within the rehabilitated area compared to the moderately acidic in the degraded area could be attributed to high soil organic matter as a result of improved ground cover and biomass production (Chapter 3). Soil organic matter enhances soil structure and hence traps base cations such as Na^+ and $Ca^{2+,}$ which are responsible for the slightly acidic soil pH in the rehabilitated area (Abayneh, 2001). Highly alkaline soils or soils with higher soil pH are highly saturated with base cations (i.e. K^+, Ca^{2+} Mg^{2+} and $Na^{+)}$. Soil pH for instance influences nitrogen levels in the soil through the processes of nitrification and volatilization (Miller, 2016). Further, the decreasing acidity of soil pH downslope could be due to the washing of soil solutes such as Na^+ downslope due to the influence of gravity and soil erosion (Mohammed, 2005). The findings of this study corroborate with those of Lawal *et al.* (2014) working in the Southern Guinea Savanna of Nigeria who reported an increasing pH downslope.

4.5 Conclusion and Recommendation

Land restoration does not only enhance vegetation recovery but improves soil fertility through reduced soil erosion and runoff. The results of this study indicated that land rehabilitation and slope influences soil chemical properties and hence rangeland productivity. This is demonstrated by the significantly higher soil organic carbon, total nitrogen, phosphorus and potassium levels within the rehabilitated area and within the lower slope positions compared to the degraded areas and higher slope positions. The observed higher values in the rehabilitated area compared to the degraded area could be an indication of restoration success through the use of structural soil and water conservation techniques such as retention ditches, terraces and cut off drains. From the study use of structural soil and water conservation measures on severely degraded areas is recommended.

CHAPTER FIVE

EFFECT OF LAND REHABILITATION ON SOIL PHYSICAL PROPERTIES IN SUSWA CATCHMENT, NAROK COUNTY, KENYA

Abstract

Land degradation is a serious problem which is affecting millions of people globally. Its severity and magnitude, especially on soil fertility is high in sub-Saharan Africa. In Kenya recent studies have shown that land degradation is on the rise. In the wake of increased land degradation in Kenya, various land rehabilitation approaches have been developed. This study investigated the effect of land rehabilitation on soil physical properties within Suswa catchment, Narok County, Kenya. Soil texture, penetration resistance, bulk density, moisture content and hydraulic conductivity were determined in the rehabilitated and degraded areas along a slope (upper, middle and lower slope position) during the wet and dry seasons in the year 2016. The results of the study indicated that soil moisture content, hydraulic conductivity, silt and clay content significantly ($p \leq 0.05$) increased downslope being consistently higher in the rehabilitated area than in the degraded area. On the other hand, soil bulk density, penetration resistance and percent sand significantly ($p \leq 0.05$) increased upslope and were higher in the degraded areas than in the rehabilitated areas. Highest moisture (23.4 %) content and soil aggregate stability (46.6 %) were recorded in the lower slope rehabilitated area. In general, management practice and slope influenced the soil physical properties and thus should be considered for sustainable land use and management.

Key words: Land degradation, slope categories, soil fertility and management practice.

5.1 Introduction

Human security, food security and climate greatly depend on sustainable land use and management of soils (Lal *et al.* 2014; Amundson *et al.*, 2015). However, the effects of land degradation are diverse and negative. Approximately 24 % of the world's land surface supporting about 1.5 billion people is currently suffering from land degradation (Lal *et al.,* 2012). In response to these challenges, the United Nations as part of global mandate has set 17 sustainable development goals (SDGs). One such target aims at protecting, reinstating and supporting sustainable use of terrestrial ecosystems, management of forests sustainably, reduce land degradation and combat desertification as well as prevent biodiversity loss (UNDP, 2015). Despite, land degradation being a global agenda, Africa's drylands and specifically sub-Saharan Africa are worst hit by land degradation (UN, 2011). In Kenya, land degradation is increasing drastically with over 30 % of forests 20 % of croplands and 10% of rangelands being degraded (Muchena *et al.,* 2008).

The indicators of land degradation include loss of soil fertility, loss of ground cover and decreased carrying capacity of pasture lands. Land degradation reduces soil organic matter which binds mineral particles into granular soil structure thus making the soil resistant to soil erosion, loose and easy to work and also enable greater moisture infiltration (Handayani *et al.,* 2010). Land degradation enhances soil aggregates disintegration making them susceptible to erosion and which upon sedimentation clog soil pores causing soil crusts (Yan *et al.,* 2008). A reduction in the volume of macropores directly affects soil hydraulic conductivity, infiltration capacity and soil moisture content resulting to loss of organic matter and soil erosion (Bork, 2006). Soil organic matter directly influences soil aggregate stability which is a key factor of soil resistivity to mechanical stresses (Canasveras *et al.,* 2010). Stable aggregates are resilient to any kind of disruption whether from rain or wind (Zziwa *et al.,* 2012).

The organic matter content in the soil and the relative amounts of minerals influences the soil physical properties (Donkor *et al.,* 2002). Therefore, removal of plant cover reduces organic matter in the soil and this in turn encourages soil compaction (Soene *et al.,* 1994). Soil compaction influences other soil properties such as penetration resistance, bulk density and hydraulic conductivity, which in turn have a direct effect on microbial activity and availability of air and water in the soil (Lal *et al.,* 2005).

High soil compaction increases soil bulk density which is a key determinant of soil health (Maitima, 2009) and an indicator of reduced water infiltration rate due to compaction (Azarnivand, *et al.,* 2010). High bulk density prohibits biomass production thus encouraging soil runoffs and erosion due to lack of cover to protect the soil from agents of degradation. High penetration resistance lowers water infiltration reducing soil moisture content which is an important soil component and a major determinant of productivity (Chaichi, 2005). Soil moisture is the most important component for plant growth and development. However; it is the most limiting in arid lands (Wang *et al.,* 2008; Ziadat and Taimeh, 2013). Amiri *et al.* (2008) working in Isfahan, Iran reported that rangeland plants recovered faster from disturbances when there was adequate moisture in the soil. Other studies have also indicated that rangeland productivity is greatly enhanced with increased soil infiltration (Fu *et al.,* 2015; Zheng *et al.,* 2015).

Land use change due to migrations and spill-over effects from high potential areas has greatly affected forage productivity in Kenyan rangelands (Kirwa *et al.,* 2009). This has reduced grazing resources (Fratkin *et al.,* 2001) and negatively impacting on pastoral livelihoods. A case study of highly degraded areas is the Suswa catchment in Narok County, Kenya which has been depleted of vegetation from the increasing soil erosion where frequent runoff has led to deep gullies of over 25 m deep and 30 m wide (Khalif, 2014).

In response to the increasing land degradation in the Kenyan rangelands and in particular Suswa Catchment several restoration approaches have been developed (Mureithi *et al.,* 2010). The Sustainable Land Management (SLM) team through its donor agencies took the initiative of rehabilitating the land through construction of several soil and water conservation structures such as cut off drains, water pans, semi-circular bands and check dams. Community education was also done on the importance of controlled grazing and charcoal burning (Odini *et al.,* 2015). However, despite the various rehabilitation approaches employed; limited research has been conducted to ascertain their effectiveness on soil physical attribute that negatively impact land productivity. In reference to Suswa Catchment this study examined the effect of rangeland rehabilitation on selected soil physical properties. The study findings seek to inform on future interventions on rangeland rehabilitation and restoration efforts in degraded areas.

5.2 Materials and Methods

5.2.1 Study design

A Split Plot Design was used for this research with two land management practices (rehabilitated area and degraded area) forming blocks and plots being the three slope categories (lower, middle and upper positions). Within each plot (slope position) three100 m transects were placed across the hill 30 m apart and 5 m away from the boundaries to avoid edge effects. The three 100 m long transects were replicated three times on each slope position. Soil was sampled along transects at 25 m intervals. Season was also considered as an experimental factor to test for the changes in soil physical properties within the wet (February) and dry seasons (August) in the year 2016.

5.2.2 Soil sampling

Along the transects 1- m^2quadrats were placed at intervals of 25 m and soil sampled to a depth of (0 – 20 cm) in each quadrat using a soil auger. Soil samples from the various points within each transect were composited to a 1kg soil sample per transect. This resulted to 3 composite soil samples per slope position and thus a total of 9 soil samples per management practice. Similarly at the centre of each quadrat along transects at 25 m intervals core rings of known volume (98.187 cm^3) were used in collecting undisturbed soil samples for bulk density and saturated hydraulic conductivity determination.

5.2.3 Laboratory analysis

Soil bulk density and saturated hydraulic conductivity were determined using undisturbed soil core samples. For bulk density the core sample method (Blake, 1964) was used. The constant head method was used in determination of saturated hydraulic conductivity (Ksat) (Wessolek *et al.*, 1994). Determination of soil texture followed the Bouyoucos hydrometer method (Nelson and Sommers, 1982) after the soil was dispersed with sodium hexametaphosphate. The standard method described by the NRCS Soil Survey Laboratory was used to determine soil aggregate stability (USDA, 1996). Soil moisture content was determined using the gravimetric method described by Okalebo *et al.* (2002). Penetration resistance was determined using a hand penetrometer (Okalebo *et al.*, 2002). The penetrometer was pushed through the soil profile (0 to 6") to assess surface compaction in the field. An even pressure was applied to the penetrometer aimed at exerting penetration pressure of 1.5"/s. The highest pressure reading measured was recorded.

5.2.4 Statistical Data analysis

Data on soil properties was subjected to analysis of variance (ANOVA) using Genstat Discovery 15th edition statistical software. Tukey's HSD *post hoc* was used to separate treatment means where the F-values were significant.

5.3 Results

The mean soil bulk density ranged from 0.91 to 1.21 g/cm^2 and significantly *($p \leq 0.05$)* decreased downslope with slightly higher values recorded in the degraded area (0.95 to 1.21 g/cm^3) than in the rehabilitated area (0.91 to 1.02 g/cm^3) (Table 5.1). Penetration resistance ranged from 14.8 to 29.0 Kgf/cm^2 and significantly ($p \leq 0.05$) decreased downslope with higher values recorded in the degraded area (26.9 to 21.8 Kgf/cm^2) than in the rehabilitated area (25.8 to 14.8 Kgf/cm^2) (Table 5.1). Season did not significantly affect soil bulk density *($p = 0.553$)* and penetration resistance *($p = 0.070$)* (Appendix 4). The corresponding interactions between management practice*slope*season did not significantly influence soil bulk density *($p = 0.949$)* and penetration resistance *($p = 0.621$)* (Appendix 4)

The average soil aggregate stability ranged from 16.7 to 46.7 % and significantly *($p < 0.05$)* increased downslope with statistically higher values recorded in the rehabilitated area (22.77 to 46.6 %) than in the degraded area (16.97 to 38.4 %) respectively (Table 5.1). Season did not significantly *($p = 0.251$)* affect soil aggregate stability. Moreover, the corresponding interactions of management practice *slope* season did not significantly *($p = 0.997$)* influence soil aggregate stability (Appendix 4)

Table 5.1: Soil physical properties in rehabilitated and degraded areas of Suswa catchment during wet and dry seasons

			Wet season (February, 2016)							Dry season (August, 2016)						
	Management		Rehabilitated area			Degraded area				Rehabilitated area			Degraded area			
Treatment	Slope		Upper	Middle	Lower	Upper	Middle	Lower	LSD	Upper	Middle	Lower	Upper	Middle	Lower	LSD
	Sand	%	79.60d	69.00b	63.60a	85.00e	79.00d	74.00c	0.50	79.80d	69.47b	63.78a	85.10e	78.87d	74.02c	0.73
	Clay	%	13.00b	21.00e	27.30f	9.60a	15.00c	18.00d	1.40	12.77b	20.43e	27.27f	9.53a	15.07c	17.98d	1.57
	Silt	%	7.30b	10.00d	9.00c	5.30a	6.00a	8.00b	0.90	7.10c	9.43d	8.97d	5.37a	6.06ab	8.00c	0.92
	SCR		0.56b	0.48b	0.33a	0.58b	0.40ab	0.44a	0.13	0.57b	0.46ab	0.33a	0.56b	0.40ab	0.45ab	0.13
	Textural class		LS	SCL	SCL	S	LS	SL		LS	SCL	SCL	S	LS	SL	
	Aggregate stability	%	22.77b	34.27d	46.60f	16.97a	27.01c	38.40e	0.98	22.5b	34d	46.37f	16.70a	26.80c	38.27e	0.94
	Bulk density	g/cm^3	1.02b	1.04b	0.91a	1.21c	1.07b	0.95ab	0.09	1.02b	1.04b	0.91a	1.21c	1.04b	0.93b	0.09
	Ksat	cm^3/hr	0.04b	0.07c	0.12d	0.01a	0.02a	0.03b	0.01	0.03b	0.07c	0.14d	0.01a	0.02a	0.03b	0.01
	Moisture	%	18.20b	27.50e	29.80f	16.60a	20.20c	23.40d	1.40	15.20ab	24.50d	26.80e	13.60a	17.20b	20.40c	1.40
	Penetration Resistance	Kgf/cm^2	25.80cd	21.00b	14.80a	26.90d	24.40cd	21.80bc	3.00	28.10de	23.00bc	16.80a	28.97e	25.40cd	21.10b	2.20

Key: SCR = Silt/Clay Ratio, LS = Loamy sand, SCL = Sandy clay loam, S = Sand, SL = Sandy loam

Means followed by different letters within the same row are significantly different *($p \leq 0.05$)*

Soil moisture content ranged from 13.6 to 29.8 % and significantly *($p \leq 0.05$)* increased downslope with higher values occurring in the rehabilitated area (18.2 to 29.8 %) than the degraded area (16.6 % to 23.4 %), respectively (Table 5.1). Season significantly *($p <0.001$)* influenced soil moisture content with higher values occurring in the wet season than in the dry season (Appendix 4). The corresponding interactions of management practice*slope*season did not have any significant *($p = 1.000$)* effect on soil moisture content (Appendix 4).

The soil hydraulic conductivity (Ksat) values ranged from very slow (< 0.8 cm^3/hr) to slow (0.8 – 2.0 cm^3/hr) in the rehabilitated area compared to very slow (< 0.8 cm^3/hr) in the degraded areas (Table 5.1) **(**Landon, 1991). Season and the corresponding interactions of management practice*slope*season did not significantly *($P > 0.05$)* affect soil hydraulic conductivity (Appendix 4).

The mean clay content ranged from 9.6 to 27.3 % and significantly *($p <0.05$)* increased downslope being higher in the rehabilitated area (13.0 to 27.5 %) than in the degraded area (9.5 to 18.0 %) respectively (Table 5.1). The silt content of ranged from 5.30 to 9.0 % and significantly *($p <0.05$)* increased downslope with statistically higher values recorded in the rehabilitated area (7.5 % to 9.0 %) compared to the degraded area (5.5 to 8.0 %) respectively. On the contrary, sand content ranged from 63.6 to 85.0 % and significantly *($p \leq 0.05$)* decreased downslope with higher values recorded in the degraded area (74 to 85 %) compared to the rehabilitated area (63.5 to 79.5 %) respectively (Table 5.1). Season and the corresponding interactions of management practice *slope*season did not significantly *($p \leq 0.05$)* affect percent sand, clay and silt of the soil (Appendix 4). Overall, soil texture ranged from sand in the upper slope degraded area to sandy clay loam in the lower slope rehabilitated area. The silt to clay ratio was lowest (< 0.4) in the lower slope rehabilitated area and increased upslope and highest in the upper slopes (> 0.4) (Karuma *et al.,* 2015).

5.4 Discussion

The significantly higher bulk density in the degraded area than in the rehabilitated area could be an indication of low soil organic matter hence poor soil structure due to lack of sufficient ground cover. Low soil organic matter increases soil compaction and hence soil bulk density and penetration resistance (Lal *et al.,* 2005). Soil compaction in turn affects availability and movement of air and water as well as root growth which in turn influences other soil physical properties like bulk density and porosity (Lal *et al.*, 2005, Tufour, 2014). High bulk density decreases the pore space and hence reduces the amount of air and water within the soil (Froese, 2004). Low soil bulk density is critical for plant growth since it increases infiltration rates and hence minimizes soil erosion and runoff (Catherine, 2007; Sakin, 2011).

Low penetration resistance in the rehabilitated area may be as a result of increased moisture content due to improved ground cover that reduced rates of evapotranspiration and increased soil organic matter. Soil penetration resistance decreases with increased soil moisture content (Gomez *et al*., 2005). Soil moisture content decreases the solid fraction in the soil as it reduces the forces between small particles; especially the cohesive forces. This in turn influences soil penetration resistance (Aksakal 2011). The findings of this study with corroborates those of Aksakal, (2011) who reported higher bulk density and penetration resistance in heavily denuded rangelands compared to less disturbed rangelands of Turkey. Wasonga (2009) working in the Njemps flats of Baringo, Kenya, reported higher bulk density in areas heavily degraded compared to areas properly managed.

Further, the significantly ($p \leq 0.05$) low bulk density and penetration resistance in the lower slope position could be attributed to increased ground cover and reduced runoff downslope. Slope has been shown to directly influence the processes of drainage, runoff and soil erosion thereby affecting soil physico-chemical properties (Farmanullah, 2013) within a hilly landscape. Moreover, this could also be due to improved soil aggregate stability and organic matter downslope which has also been reported to influence soil quality and structure (Josa *et al.,* 2010). Achalu *et al.* (2012) working in Western Oromia, Ethiopia found that organic matter decreases the soil bulk density through its positive effect on soil aggregation. The findings of this study corroborates with those of Aytenew and Gebrekidan, (2015) who while working on Dawja Watershed in Ethiopia reported higher bulk density and penetration resistance on steep slopes than in gentle slopes.

The significantly ($p \leq 0.05$) higher soil aggregate stability in the rehabilitated area than in the degraded area could be associated with improved ground cover and the binding effect of plant roots. Organic compounds and minerals that are exuded by roots promote the production of binding agents which support soil aggregation (Paudel *et al.,* 2011). This could also be attributed to increased organic matter as a result of improved ground cover and aboveground biomass (Chapter 3). Soil organic matter and microbial population affects soil aggregate stability (USDA, 2001; Igwe and Nwokocha, 2006). Moreover, improved aggregate stability in the rehabilitated area could be associated with the significantly high clay levels observed. Clay soils are mostly associated with aggregation due to their arrangement and flocculation. However; swelling clay can disrupt soil aggregates (Bronick and Lal, 2005). The significantly ($p \leq 0.05$) higher soil aggregate stability on the lower slope position compared to the upper slopes could be attributed to the observed improved ground cover and above ground biomass downslope (Chapter 3). Cover and biomass production enhances soil organic matter content which is positively correlated with soil aggregate stability (Canasveras *et al.*, 2010). Moreover, soil aggregate stability increases with increase in soil organic matter, surface area of clay and the CEC (Bronick and Lal 2005).

The significantly higher soil moisture content in the rehabilitated area compared to the degraded area could be due to improved ground cover (Chapter 3) that enhanced infiltration and reduced water loss through evaporation and soil runoffs. The amounts of soil runoff and soil loss are controlled by several factors including vegetation cover, land use and soil conditions (Al-Kharabsheh, 2004). Further, higher moisture amounts could be attributed to the establishment of the various conservation structures such as terraces, water retention ditches and semicircular bands that conserved soil moisture through reduced runoffs and improved water storage within the rehabilitated area. According to Xiang (2004) water and soil conservation structures such as terraces and retention ditches conserve soil moisture content, reduce runoff and sedimentation as well as improve soil water storage. Further, Al-Seekh, (2009) working in the Southern West Bank reported higher moisture content in areas with stone terraces over the un-terraced areas.

The soil moisture variations observed along the slope positions with significantly ($p \leq 0.05$) higher values in the lower slope compared to the mid and upper slope positions could be associated with the downward movement of water under the influence of gravity. The downward movement of water carries with it sediments which accumulate in the lower slope position resulting in deeper soils which store more water while the upper and mid slope positions have shallow soils and therefore less water retention. Bezuayehu *et al*. (2002) working in Oromiya region of Ethiopia reported that soils on steep slopes are generally shallower and their nutrient and water storage capacities are limited than those of gentle slopes. Similarly, results by Ruto, (2015) in her field study in Suswa catchment, Narok County reported higher moisture content in the lower slopes compared to the upper slopes a fact she attributed to the establishment of soil conservation terraces.

The higher moisture content during the wet season compared to the dry season could be as a result of the variations in the amount of rainfall and temperature. Findings by Qiu *et al*. (2001) working in the Hillslope catchment of the Loess Plateau in China showed that season and topography influence the spatial variability of soil moisture due to runoff, rainfall and temperature changes across seasons.

The significantly higher soil hydraulic conductivity (Ksat) downslope being higher in the rehabilitated area could be attributed to improved ground cover and reduced soil erosion and runoff which enhanced other soil properties such as bulk density and texture. Increased bulk density due to compaction reduces soil hydraulic conductivity (Celik, 2005). Soil aggregate stability affects water flow within the soil hence affecting soil hydraulic conductivity (Six *et al.*, 2004). Neris *et al.* (2012) working in the Andosols of Tenerife in Spain found that the soil aggregate stability, bulk density and organic matter significantly affected soil hydraulic conductivity and infiltration rates. Gonzales-Sosa *et al.* (2010) noted that organic matter content in the soil, bulk density and porosity influenced soil hydraulic conductivity while working on the effect of land use on a French catchment. Findings of this study also corroborates those of Ren *et al.* (2016) who reported higher soil hydraulic conductivity in restored areas of Loess Plateau in China over time.

The significantly higher clay and silt content with low sand in the rehabilitated area compared to the degraded area may be a result of low soil erosion and runoffs. Reduced soil runoff was attributed to the construction of the various water and soil conservation structures as well as improvement in vegetation cover in the study site. A study by Li *et al.* (2014) while working in Loess plateau of China revealed that the establishment of terraces and other conservation structures combined with planting of vegetation effectively controlled runoff and soil erosion. Storm flows and runoffs affect soil texture patterns through accumulation of solutes and particles (Khomo, 2011). Mismanagement and lack of appropriate conservation measures have a direct influence on soil particle size distribution through removals by sheet and rill erosion. These are the effects of ground cover depletion and increased runoff (Toy *et al.*, 2002). The higher silt content in the rehabilitated area could be due to improved biomass production in the area (Chapter 3), which in turn influenced the amount of organic matter. Soil organic matter influences soil organic carbon accumulation which improves soil structure and increases soil micro aggregate and fine particle fractions (Xie *et al.*, 2013).

The significantly higher clay and silt content downslope could be due to the process of soil erosion and runoff. When soil erosion takes place, the finer soil particles are washed by running water and transported downslope where they accumulate increasing the clay and silt content. Movement of water downslope affects soil texture through accumulation of sediments (Khomo, 2011). Moreover, higher silt and clay downslope could be associated with the improvement of soil organic matter downslope (Chapter 4). Laurance *et al.* (2011) working in the Amazon forest realized that above ground biomass was positively correlated with the clay content in the soil. The findings of this study are consistent with those of Khan *et al.* (2013) who found significantly ($p \leq 0.05$) higher clay and silt content in the lower altitudes. Similar studies by Khomo *et al.* (2011) and Schimel *et al.* (1985) show an increasing trend of soil organic matter, clay and silt content downslope.

The observed pattern of soil texture ranging from sand in the upper degraded area to sand clay loam in the lower slope rehabilitated area could be due to improved ground cover in the rehabilitated area (Chapter 3) which enhanced the organic matter content of the soil and reduced soil erosion and runoff. Higher silt to clay ratio (> 0.4) (Landon, 1991) in the upper slope degraded area compared to the lower slope rehabilitated area could be an indication of high erosion rates within the degraded area due to insufficient ground cover and organic matter and hence poor soil structure (Chapter 4).

5.5 Conclusion and Recommendation

Results of this study demonstrated that land management and slope influences soil physical properties. Soil hydraulic conductivity, moisture content, aggregate stability silt and clay content were significantly higher in the rehabilitated area compared to the degraded area and increased downslope. On the contrary, the soil bulk density, penetration resistance and sand content were significantly higher in the degraded area and increased upslope. Even though, seasonality did not significantly affect most of the soil physical properties it had a significant effect on soil moisture content with higher values recorded in the wet season. Therefore, sustainable land management requires consideration of the two factors if successful restoration of heavily degraded lands is to be achieved. Areas with very steep topographical gradient where soil erosion and runoffs is common phenomenal appropriate rehabilitation techniques such as cut off drains, terraces and semicircular bands should be constructed to reduce soil and nutrient losses.

CHAPTER SIX

GENERAL CONCLUSION, SCOPE FOR FUTURE RESEARCH AND IMPLICATIONS FOR PRACTICE

6.1 Conclusions

To understand the effect of land rehabilitation and slope on plant biodiversity and hence people's livelihoods. The effect of land management on the herbaceous layer characteristics (species richness, relative abundance, composition, percent cover, diversity and aboveground biomass) within the rehabilitated and degraded areas along a slope (upper, middle and lower slope positions) was assessed. The results showed that land rehabilitation and slope had a significant effect on vegetation structure. Generally, aboveground biomass, percent cover, species richness, relative abundance, diversity and composition of perennial grasses increased downslope and were higher in the rehabilitated area compared to the degraded area. On the contrary the same attributes for forbs and annual grasses increased upslope and were higher within the degraded area compared to the rehabilitated area. Seasonality had a significant effect on herbaceous layer however its effect was more profound on forbs and annual grasses. Generally, this study concluded that proper land rehabilitation approaches can enhance quick vegetation recovery and hence quick forage production. On the same note it concluded that slope and management practice are not the only factors affecting vegetation distribution but, seasonality also influences their spatial and temporal arrangement.

Further, to determine the effect of land management on soil fertility and hence general rangeland productivity, soil physico-chemical properties (C, N, P, K, Texture, Aggregate stability, Bulk density, Moisture content, Penetration resistance and Hydraulic conductivity) were determined. The results indicated that land management practice and slope had a significant effect on soil physico-chemical properties. Generally, C, N, P, K and pH significantly increased downslope and were higher in the rehabilitated area compared to the degraded area. Similarly, soil moisture content, aggregate stability, hydraulic conductivity, percent clay and percent silt significantly increased downslope being higher in the rehabilitated area compared to the degraded area. On the contrary, soil bulk density, penetration resistance and percent sand significantly increased upslope being higher in the degraded area compared to the rehabilitated area. Seasonality did not significantly affect soil properties however; there were significant differences in the amount of soil moisture content between seasons with higher values recorded in the wet season compared to the dry season.

Generally, the study demonstrated that with proper land management both soil and vegetation biodiversity can be enhanced. However, in areas with steep topographical gradient including Suswa catchment Narok County, the effect of slope and management on soil and vegetation biodiversity should be considered. This can be achieved by embracing proper land rehabilitation techniques such as semi-circular bands, cut off drains and terraces in areas with steep topographical gradient.

6.2 Scope for Future Research

The study concluded that land rehabilitation and slope significantly influenced soil and vegetation diversity however there is need for more research. Some of the areas recommended for future research include:

a) Long term monitoring of the effects of land rehabilitation on soil and vegetation biodiversity on the area would be helpful. This was a short term study, which revealed that land management and slope gradient influences both soil and vegetation diversity and that the process of land rehabilitation greatly improved the soil physico-chemical properties and diversity of herbaceous layer.

b) This study only looked at the soil physico-chemical properties and diversity of herbaceous layer, a detailed study incorporating other soil and plant diversity parameters would give a clear indication of the rehabilitation process.

c) There is need to carry out a detailed study on the appropriate grass species that are suitable for land rehabilitation in the area so that they can be introduced to curb soil erosion and hence degradation. The current study showed that grasses like *Cymbopogon afranardus* can do better in areas with severe degradation and therefore, should be used in rangeland restoration.

d) Lastly a study should be conducted to determine the effect of the rehabilitation on the ground water table.

6.3 Implications for Research

In an attempt to improve land productivity and hence livelihoods, the people of Suswa are gradually adopting the various land rehabilitation approaches such as construction of soil and water conservation structures. However, there exist other practices that can be recommended to enhance land productivity within the area. These include:

a) There is need for integrated use of the various soil and water conservation structures to enhance productivity at all times. Moreover, to improve on land productivity rotational grazing should be adopted to avoid the adverse effects of continuous grazing on soil and plant biodiversity.

b) The current study demonstrated that management practice, slope, season impact on vegetation structure and soil physico-chemical properties. Therefore, there is need for community conservation taking into consideration the above factors. This can be achieved through a holistic approach that integrates local knowledge and other land rehabilitation techniques such as use of cut-off drains, terraces and water retention

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APPENDICES

Appendix 1: herbaceous species richness, diversity and relative abundance vs. management, slope, season and their interactions

	Relative Abundance			Diversity			Richness		
	Grasses			Grasses			Grasses		
Treatment	**Annual**	**Perennial**	**Forbs**	**Annual**	**Perennial**	**Forbs**	**Annual**	**Perennial**	**Forbs**
Management	0.340	<.001	<.001	0.012	<.001	0.011	0.020	<.001	<.001
Slope	0.719	<.001	<.001	0.240	<.001	0.001	0.154	<.001	<.001
Season	0.032	0.065	<.001	0.018	0.73	0.010	0.040	0.043	<.001
management*slope	0.026	0.157	0.070	0.067	<.001	0.969	0.056	<.001	0.035
management*season	0.447	0.064	0.081	0.582	0.161	0.106	0.147	0.056	<.001
slope*season	0.106	<.001	0.039	0.611	0.007	0.219	0.373	0.062	0.020
management*slope*season	0.23	0.673	0.118	0.742	0.057	0.383	0.226	0.461	0.067

Probability (significance detected at *p<0.05*, highly significant at *p<0.01*)

Appendix 2: Aboveground biomass production and percent cover vs. management, slope, season and their interactions.

	Aboveground Biomass			Percent Cover		
	Grasses			Grasses		
Treatment	**Annual**	**Perennial**	**Forbs**	**Annual**	**Perennial**	**Forbs**
Management	0.024	<.001	<.001	0.025	<.001	<.001
Slope	0.418	<.001	<.001	0.411	<.001	<.001
Season	0.024	0.025	<.001	0.032	0.056	<.001
Management*slope	0.418	<.001	0.006	0.190	<.001	0.085
Management*season	0.024	0.120	<.001	0.103	0.024	<.001
Slope*season	0.418	0.014	0.002	0.654	0.106	<.001
Management*slope*season	0.418	0.137	0.268	0.43	0.254	0.344

Key: Probability (significance detected at *p<0.05*, highly significant at *p<0.01*)

Appendix 3: Soil C, N, P and K vs. management, slope, season and their interactions in Suswa Catchment

Treatment	C	SOM	N	P	K	Ph
Management	<.001	<.001	<.001	<.001	<.001	<.001
Slope	<.001	<.001	<.001	<.001	<.001	<.001
Season	0.662	0.662	0.472	0.913	0.225	0.719
management*slope	<.001	<.001	<.001	0.002	<.001	0.111
management*season	0.950	0.950	0.757	0.913	0.895	0.888
slope*season	0.970	0.970	0.927	0.988	0.997	0.993
management*slope*season	0.988	0.988	0.968	0.988	0.999	0.997

Probability (significance detected at *p<0.05*, highly significant at *p<0.01*)

Appendix 4: Soil physical properties vs. management, slope, season and their interactions

Treatment	% sand	%clay	% silt	% aggregate stability	Bulk density g/cm3	Ksat Cm^3/hr	% moisture	Penetration resistance kg/cm^2
Management	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Slope	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Season	1.000	1.000	1.000	0.251	0.553	0.059	<.001	0.070
management*slope	<.001	<.001	<.001	<.001	<.001	<.001	<.001	0.003
management*season	1.000	1.000	1.000	0.862	0.63	0.879	1.000	0.193
slope*season	1.000	1.000	1.000	0.992	0.949	0.980	1.000	0.478
management*slope* season	1.000	1.000	1.000	0.997	0.949	0.993	1.000	0.621

Probability (significance detected at *p<0.05*, highly significant at *p<0.01*)