EFFECT OF WATERING POINTS ON VEGETATION AND SOIL PHYSIO-CHEMICAL PROPERTIES AND COMMUNITY BASED WATER RESOURCE CONSERVATION IN KAJIADO COUNTY, KENYA

By

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A Thesis Submitted in to the Board of Postgraduate Studies in Partial Fulfilment for the Requirement of the Degree of Masters of Science in Range Management in the Department of Land Resource Management and Agricultural Technology (LARMAT), University of Nairobi

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DECLARATION

I hereby declare that this thesis is my original work and has not been presented in any other university

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DEDICATION

I dedicate this work to the most important women in my life; my mum Jane Achieng' Omondi, my fiancée' Cynthia Sheila Nanyokia and mentor Judith Mildred Ombok. Your counsel, support and prayers have made this possible.

ACKNOWLEDGEMENTS

First, I thank the Almighty God for His mercies; grace and strength to enable me complete this Master's program. You are good and your mercies endure forever. I sincerely appreciate the University of Nairobi for technical and supervisory support and research fund facilitation. Thanks to my mentors; Dr. Oscar Koech, Dr. George N. Karuku and Dr. Judith S. Mbau for guidance and positive criticism. I cannot pay you enough for the much you put into this work. God bless you. I am also grateful to the International Canopy of Conservation (I-CAN) for financing this research through the African Drylands Institute of Sustainability (ADIS). Heartfelt appreciations also go to Mr. Mopel and management of Mopel Ranch, Kiserian, the Oloolaiser Water and Sewerage Company and the leadership and members of the Kiserian Water Users' Association for facilitating the process of data collection.

I would also like to thank dear classmates, Hillary Rotich and Joseph Ombega for the company and moral support, friends among them Felix Osimbo, Daniel Moseti and Dortea Kangai for their encouragement throughout this journey. Much appreciation also goes to my siblings Eric, Fred, Nelly, Faith, Allan, Evans, Lydia, Stella, Winnie and Rachael for their patience. God bless you all.

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ACRONYMS

GoK	Government of Kenya
IPCC	Intergovernmental Panel on Climate Change
NGOs	Non-Governmental Organizations
RoK	Republic of Kenya
SOC	Soil Organic Carbon
SPSS	Statistical Package for the Social Sciences
WRMA	Water Resource Management Authority
WRUA	Water Resource Users' Association

ABSTRACT

Water crisis in the Kenyan rangelands threatens the sustainability of pastoral livelihoods. The Water Act of 2002 created the Water Resource Users' Associations (WRUAs) to enhance water resource conservation and enhance water access at the local level. Yet, environmental degradation has increased in many areas, further exacerbating water crisis and threatening livelihoods. This study therefore assessed community based water resource conservation in the Southern rangelands of Kajiado, Kenya through a survey. Results showed that access to information on water resource management was significantly associated (χ^2=0.56, p≤0.05) with membership to the WRUA. The main challenge facing the WRUA was lack of funds (93.2%). Public awareness campaigns aimed at increasing WRUA membership should be done to boost water resource conservation. The government should also increase WRUA funding in order to facilitate its conservation efforts.

Water shortage in Kenyan rangelands has also led to introduction of watering points as an intervention measure by government agencies and other stakeholders. This has adversely impacted on vegetation due to increased animal grazing around these watering points. In this study, the effect of watering points on Shannon-Wiener's diversity index, species richness and Pielou evenness in the southern rangelands were also evaluated. Vegetation sampling was done during both the long rains (April) and the dry season (August). Three watering point types (dam, trough and a seasonal river) were studied using 0.25 m^2 quadrats to sample vegetation at intervals of 20 m along 100 m transects. Two-way ANOVA was used to determine if piospheric distance had effect on Shannon-Wiener's diversity index, species richness and Pielou evenness using GenStat 15th edition. A total of 22 grasses and 29 forbs were recorded in the study area. The most abundant grasses near the watering points were *Eragrostis tuneifolia* (12.9%) and

Cynodon dactylon (10.6%) while the most abundant forbs were *Crotolaria brevidens* (37.5%). Shannon-Wiener diversity index significantly increased (F=25.07, p=0.001) with distance from the three watering points and was significantly different between them, being higher (F=10.05, p=0.001) at 20m from the river (1.2±0.1) compared to a similar distance from the dam (0.9±0.1) and the trough (0.8±0.2). We recommend reseeding degraded watering points with perennial species tolerant to high intensity utilization. Further, animals should be herded to reduce grazing near the watering points and allow for plant species regeneration.

In order to provide more insights to guide future water interventions, we also determined the effect of watering points on soil physio-chemical characteristics. Soil samples were collected within the $0.25m^2$ plots along the 100 m transects and bulk density, porosity, hydraulic conductivity, moisture content, aggregate stability, soil texture, organic carbon, total nitrogen and pH determined. Data was analysed using GenStat 15th edition. Soil bulk density was significantly different between piospheric distances (F=22.25, P=0.001) and watering points, (F=13.10, P=0.002), being highest at 20 metres from the trough ($1.1\text{-}1.21gcm^{-3}$) relative to a similar distance from the dam ($1.01\text{-}1.20gcm^{-3}$) and the river ($1.1\text{-}1.17gcm^{-3}$). High soil bulk density signified high compaction near the watering points. It is recommended that herding and rest periods be instituted in order to minimize compaction and allow for soil generation near these watering points. Watering points should also be better planned and placed at landscape level to exploit landscape heterogeneity.

Key words: Piospheres, Diversity, Soil Bulk density, Rangelands.

CHAPTER ONE

General Introduction

1.1 Background information

Worldwide, dry lands form 41% of the earth's land total surface area and are inhabited by more than 2 billion people, which is a third of the human population (Reynolds *et al.,* 2007; Lohmann, 2013). In Africa, rangelands make up 43% of the inhabited surface and are home to up to 268 million people, supporting 40% of the continent's population (Mganga *et al.,* 2015). About 250 million pastoralists and agro-pastoralists are estimated to live in rangelands of West and East Africa (de Jode, 2014). In East Africa, 79% of landmass is classified as rangelands: 85%, 56%, 83%, 40% and 20% in Kenya, Ethiopia, Tanzania, Uganda and Rwanda, respectively. Notably, almost the entire country of Somalia, Eritrea and Djibouti are rangelands. These rangelands of East Africa include 26 % desert and semi-desert, 33 % bush lands, 21 % woodlands, 12 % pure forest and about 7 % pure grassland (Nyariki *et al.,* 2005; Miller and Doyle, 2014). Kenya is characterized by 85% of arid and semi-arid lands (ASALs) which host about 14 million people and approximately 70% of the national livestock population (Barrow and Mogaka, 2007; Mganga *et al.,* 2015). The dominant economic activity is pastoralism while agro-pastoralism, rain-fed and irrigated agriculture, tourism and related activities are practiced in the more open, better watered regions (Headey *et al.,* 2014; Nyberg *et al.,* 2015). Livestock sub-sector in the Kenyans rangelands contributes about 40% of the agricultural GDP and 10% of the country's total GDP, contributing to 95% of family income and employing 90% of the population (Otieno, 2013; Syomiti *et al.,* 2015).

Kenyan rangelands have however; witnessed human population growth, drought and famine, loss of common property resources, commoditization, sedentarization and urban migration, political turmoil and resource based inter-tribal wars which put pressure on their viability (Fratkin, 2001; Ouma *et al.,* 2012). Furthermore, ASALs have experienced food insecurity as a result of degraded ecosystems, and climate change (Gichere *et al.*, 2013; Lugusa *et al.*, 2016). Extreme conditions associated with climate change, such as droughts result in adverse impacts including loss of livestock (Mwadalu and Mwangi, 2013; Chege and Kimiywe, 2015). Livestock is a major source of livelihood and food security among pastoralist communities (Huho and Mugalavai, 2010; Mganga *et al.*, 2015). Droughts in northern Kenya, for example, usually have an effect on pastoralism which is manifested in; declining livestock economy, large-scale livestock mortality (Pricope *et al.,* 2013; Mapfumo *et al.*, 2015), drying up of water sources and inadequate pasture (Huho *et al.*, 2011). Because of the high risk experienced by these natural resource-dependent communities, the Kenyan government is partnering with development agencies to help communities adapt to these changes (Jones *et al.*, 2012; Amaru and Chhetri, 2013). Water user associations have emerged in most parts of the world to manage conflicts associated with water access, distribution and use (Marks and Davis, 2012; Aarts and Rutten, 2013). In 2005, such water associations provided drinking water to almost half the rural population in Colombia which comprised of 4.5 million people (Cardenas *et al.*, 2000; Colmenares *et al.,* 2007). Today, these water associations are pressed to adapt to the changing environmental and climate, land use, and water demand changes (Marks and Davis, 2012). Furthermore, water access and use has also been reported to have effects on vegetation species in grazing ecosystems and this has necessitated interventions on water resource management for sustainable ecosystems (Brooks *et al.*, 2006; Shahriary *et al.,* 2012).

Grazing animals affect vegetation and soil physical and chemical characteristics (Amiri *et al.*, 2008; Azarnivand *et al.*, 2010). Grazing livestock and wildlife alter species composition, richness and diversity (Todd, 2006; Brooks *et al.*, 2006). According to Todd (2006), continuous grazing leads to proliferation of shrubs and forbs of low palatability whereas areas grazed mildly to moderately have a larger proportion of species of high palatability. Increased defoliation and trampling affects plant growth and establishment because of reduced hydraulic conductivity which causes soil moisture deficiency (Chaichi *et al.*, 2005; Amiri *et al.*, 2008). Trampling by grazing animals causes soil compaction which increases soil bulk density, decreases soil porosity and impedes water infiltration into the soil, further influencing the available water capacity, soil microbial activity and nutrient availability (Gomez *et al.*, 2006; Maitima *et al.*, 2009; Azarnivand *et al.*, 2010). Overgrazing reduces the stability of soil particles through reduction of plant cover and exposure to wind and rain impact, disintegrating them and making them vulnerable to erosion (Haynes *et al.*, 2014). When erosion succeeds loss of ground cover, carbon and nitrogen are lost (Maraseni *et al.*, 2008). Land degradation reduces carbon storage capacity and can only be reversed by investing in restorative land use practices that increase species diversity and plant cover (Lal, 2001; Vogel *et al.*, 2012; Berendse *et al.*, 2015).

The Southern rangelands of Kenya mainly comprise grasslands where both livestock and wildlife interact during grazing (Ogutu *et al.*, 2014). Water resource use in these areas is a major challenge that is exacerbated by climate change and variability effects. Pastoralists in these areas, like their counterparts in East Africa, rely on native forage resources to facilitate livestock production (Egeru *et al.*, 2014; Egeru *et al.*, 2015). This study sought to establish the status of water access and community based water resource management and the impact of these water sources on vegetation and soils.

1.2 Problem statement

Water scarcity is a perennial problem in the Kenyan rangelands (Wahome *et al.*, 2014; Kiringe *et al.*, 2016). During the dry seasons, water shortage becomes acute, leading to death of livestock and subsequent loss of livelihoods by the pastoral communities (Huho *et al.*, 2011; Opiyo *et al.*, 2014). In order to improve water resource conservation and enhance water access in these regions, the government through the Water Resource Management Authority (WRMA) introduced Water Resource Users' Associations (WRUAs). WRMA is a government agency (in the Ministry of Water) tasked with management of water resources in Kenya. WRUAs (formed by WRMA) are community based water resource management organizations mandated to design water resource management through catchment conservation at the local level (Mathenge *et al.*, 2014). Kajiado County being one of the ASALs most hit by water shortage and land degradation, has been having WRUAs and yet, the catchments degradation in the County has continued to happen, further exacerbating water crisis and adversely affecting livelihoods (Okello *et al.*, 2014; Ogutu *et al.*, 2014). Daily household water demand in Kajiado has also been reported to outstrip the supply (Okello *et al.*, 2014; Wahome *et al.*, 2014). Catchment degradation has been worsened by deforestation a result of increased population and urbanization (Homewood, 2009; Wahome *et al.*, 2014).

In order to make water accessible to pastoral households, watering points were introduced to enhance water availability in Kajiado County (Omondi *et al.*, 2014). These watering points, however, have adversely affected vegetation and soils, reducing land productivity and diminishing its potential to support pastoral production systems. This is because watering points concentrate grazing around them, altering species composition and diversity (Brooks *et al.*, 2006; Todd, 2006) and adversely affecting soil physio-chemical properties (Smet and Ward, 2006;

Egeru *et al.,* 2015). With land acreage available for grazing and livestock mobility shrinking, decrease in quality of vegetation and soils has hampered livestock production and negatively affected pastoral communities' livelihoods (Awa *et al.,* 2002; Homewood, 2009). This worsened state is evidenced by the fact that pastoralism is a low input productive system, majorly depending on natural forage (Manyeki *et al.,* 2015; Abioye and Adegoke, 2016). Increase in forbs and unpalatable grass species in overgrazed areas has therefore reduced the quantity and quality of forage available to grazing animals (Mugasi *et al.,* 2000; Kamau, 2003). Further, highly compacted areas occasioned by animal trampling reduces soil porosity and hydraulic conductivity, hampering water percolation and seed germination in most parts of Kajiado County (Ntiati, 2002; Ogutu, 2014). There is insufficient knowledge of piospheric effect as a water intervention on the productivity of vegetation and soil components of rangeland habitats where they are located. This study seeks to fill this knowledge gap to enhance sustainable water resource management.

1.3 Justification

Limited research has been done on the status of community based resource management in Kenya. An understanding of the status of community based water resource management is vital if water conservation through locally formulated solutions is to be realized. Information is also deficient on the effect of watering points on plant composition, diversity and richness and soil physio-chemical characteristics especially in the southern rangelands of Kenya. Most research on watering points' effects on ecosystems have been done in Uganda (Egeru *et al.,* 2014; Egeru *et al.,* 2015), Southern Africa (Todd, 2006), Northern Africa (Tarhouni *et al.,* 2010) Australia and Iran (Landsberg, 2003; Shahriary *et al.,* 2012. Besides, study on piospheric effects will provide range managers with a means of monitoring range condition and trend, because watering points ecologically impact the rangelands in a manner distinct from other environmental factors (Brooks *et al.*, 2006; Todd, 2006). The findings of this study will guide the stakeholders in the Kenyan rangelands to enhance community based natural resource management for improved access to water resources and ecosystem management. This will allow design of sustainable water interventions for improved environments and livelihoods.

1.4 Study Objectives

1.4.1 Broad objective

The broad objective of this study was to contribute to sustainable rangeland management by determining the organization and performance of Kiserian Water Resource Users' Association and the effect of watering points on vegetation and soil physio-chemical properties in the Southern rangelands of Kajiado County to inform future interventions.

1.4.2 Specific objectives

The specific objectives were to;

1. Evaluate the organization and performance of the Kiserian Water Resource Users' Association.
2. Determine the effect of watering points on plant species composition, diversity and richness in the Southern rangelands of Kajiado County.
3. Determine the effect of watering points on soil physio-chemical properties in the Southern rangelands of Kajiado County.

1.5 Research questions

1. What is the organization and performance of the Kiserian Water Resource Users' Association?
2. What is the effect of watering points on plant species composition, diversity and richness in the Southern rangelands of Kajiado County?
3. What is the effect of watering points on soil physio-chemical properties in the Southern rangelands of Kajiado County?

1.6 Outline of the Thesis

This thesis has seven chapters. Chapter one presents the general introduction, problem statement, justification, broad and specific objectives, outline of the thesis and key definitions. Chapter two discusses the general literature review while Chapter three contains the general materials and methods. In Chapter four, the status of water access and community based water resource management is presented and discussed. Chapters five and six outline the effect of watering point on species diversity, richness and composition, and soil physio-chemical properties, respectively. The general conclusions and recommendations are listed in Chapter seven.

1.7 Definition of key terms in this thesis

Agro-pastoralists: People deriving above 25% but less than 50% of their gross income from livestock and more than 50% from cropping activities (Ellis and Swift, 1988). This definition, however, excludes destitute herders who relying on alternative income sources due to decimated herds (Morton and Meadows, 2000; Heffernan *et al.*, 2004).

Drylands: Regions where the mean annual precipitation to potential evapotranspiration ratio is less than 0.65 (Middleton and Thomas, 1997).

Piospheres: Ecological systems of interactions between a watering point, their surrounding vegetation and the grazing animal. In the simplest case of an isolated watering point in one uniform rangeland type, a gradient of utilization pressure develops which is greatest near the watering point and decreases as a function of distance from it (Lange, 1969).

Rangeland: Land with renewable, multiple use natural resources to both animals and humans and on which native vegetation, predominantly grasses, grass-like plants, forbs, or shrubs which are suitable for grazing or browsing use grow (Moghaddam, 2000).

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CHAPTER TWO

Literature Review

2.1. Background information

Pastoralism is the main source of livelihood to about 120 million people worldwide and is practiced in the drylands that are characterized by low erratic rainfall and frequent droughts (Mganga *et al.*, 2015). Pastoralists primarily depend on keeping different types of livestock; cattle, donkeys, shoats and camels as a risk aversion strategy (Lugusa *et al.*, 2016). Livestock types kept are mainly dependent on climatic conditions and the cultural values attached therein (Huho *et al.*, 2011). Mobility is a key feature of Kenyan pastoralism, often depending on availability of pasture and water resources (Nkedianye *et al.*, 2011). Pastoralism is dynamic, comprising people, livestock, natural resources including vegetation, soil, water, temperature, wind; economic characteristics including markets and indigenous knowledge (Egeru *et al.*, 2015; Ermon *et al.*, 2015) and is thus prone to changes occasioned by climate variability and change.

Rainfall extremes leading to droughts and occasionally floods worsen the vulnerability of pastoralists since their livelihood is weather dependent (Schimmer *et al.*, 2012; Ide *et al.*, 2014). In order to mitigate the effects of water scarcity for sustainable pastoralism in East Africa, water intervention is a key priority (Okello *et al.*, 2014). In a study conducted in Samburu County, Kenya, Kiringe *et al.* (2016) reported that boreholes provided about 197.72m^3 of water per day to both humans and livestock. While conducting a related survey in the Southern Maasai rangelands of Kenya, Omondi *et al.* (2014) observed that 52% of the respondents cited water interventions as a priority need. Water management is greatly rewarding to the economy of drylands supporting 80% of the country's ecotourism interests and a home to 75% of its wildlife (Wade, 2013).

2.2. Water situation in Kenya

Water scarcity and shortage are global concerns with about 35% of the world population currently unable to meet their daily water demands, which is estimated to be about 2000m^3 per year per capita (Shivoga *et al.,* 2007; Okello *et al.,* 2014). By 2025, a majority of the countries in the globe will be surviving with below 1000 m^3 per capita per year (Mogaka *et al.,* 2006). Kenya was withdrawing about 10% of fresh water in 1995. It is however projected that by 2025, the nation will have one of the highest withdrawal rates globally, at about 40%. As such, Kenya will be among the 17 countries in the Middle East and in Africa that will witness acute water scarcity, thus massive livelihood, health and economic growth declines (Okello *et al.,* 2014). The current Kenya's natural water endowment is 7.4 billion m^3 of surface water and 1 billion m^3 of underground water resources (Mogaka *et al.*, 2006). The per capita water available in Kenya is 650m^3 of fresh water yearly. Due to recurrent droughts, high rates of deforestation, climate change and increased human population, the capita endowment is fast decreasing (Okello *et al.*, 2014). Most water resources in Kenya are found in the highland areas mainly Mts. Aberdares, Elgon, Kenya, Cherangani Hills and the Mau Complex (Mogaka *et al.,* 2006). However, these key water catchment areas have recently experienced extensive and severe environmental degradation which compromise their water resource potential and production (Luwesi, 2010; Luwesi *et al.,* 2012). This scenario has immensely limited rain-fed agricultural production and necessitated irrigated crop production to feed the growing population.

Constraints to water resource management have been policy deficiency, inadequate funding, improper research and support programs, weak water resource users' associations and inadequate public awareness and sensitization (Mathenge *et al.,* 2014; Kanyuuru *et al.,* 2015). Economic growth and sustainability of livelihoods will rely on efficient land and water use within medium to high potential areas and innovative water resource management with arid and semi-arid regions through efficient national policies, support systems and objective irrigation interventions (Gichuki, 2004; Opiyo *et al.*, 2014)

2.3. Natural resource governance in the rangelands of Kenya

Kenyan rangelands have been marginalized due to inappropriate policies which emanate from an inadequate level of understanding of their value and economic potential (Kanyuuru *et al.,* 2015). Therefore, the ecological and socio-economic challenges of these areas have remained unaddressed; acute poverty, low literacy, high unemployment, drought, insecurity and degradation of natural resources (Opiyo *et al.*, 2011; Kanyuuru *et al.,* 2015). In order to address marginalization, enhance public participation under devolved governance units and reverse the socio-economic and ecological challenges, a strategy of ASAL development that is informed that rangelands are complex and multifaceted should be employed (Odhiambo, 2013). Key aspects of rangeland resilience will encompass the ability of the systems to withstand change and improve in its capacity to learn and adapt, through ecosystem diversity and resource management shared by various development agencies (Holling and Walker, 2003; Folke, 2006). Because of a changing climate and market dynamics, natural resource management in the Kenyan rangelands should link ecology and economy with the society and share allocation and use of resources among many stakeholders. Co-management of natural resources within these fragile ecosystems creates synergy that yields a community system that is able to adapt to change (Nadasdy, 2003; Bahadur *et al.,* 2010). This new approach is based on the fact that Kenyan rangelands are shifting from entire dependency on customary institutions while addressing socio-economic issues. The need for community participation in development is vital because the development strategies formulated locally target the real needs that the beneficiaries are able to identify with (Mcpeak *et* *al.*, 2009). Indigenous knowledge possessed by local people is imperative in the creation of resilient ecological systems (Crona, 2006).

2.4. Watering points and their management

Rangelands form one of the largest ecosystems globally (Luo *et al.*, 2010), and an understanding of the response of these fragile ecosystems to land-use changes is important if management is to formulate appropriate strategies for monitoring the range trend and condition (Bardgett and Wardle, 2003; Hopkins and Holz, 2006; Liang *et al.*, 2009). Grazing in the arid and semi-arid rangelands are focused around resources, with maximum impact witnessed around concentrators such as watering points, salt licks and grounds suitable for bedding (Washington-Allen *et al.*, 2004; Wesuls *et al.*, 2012). These concentrators create areas of gradual attenuation in regards to grazing intensity, which leads to areas of differential change in species composition, vegetation cover and soil physio-chemical characteristics away from the concentrators and this is known as watering points (Brooks *et al.*, 2006; Rajabov, 2013).

Watering points are important range monitoring locations. They provide a medium for differentiating short to long term effects of livestock activity in a rangeland from other ecological patterns (Todd, 2006). Water is one of the ecological services under threat of depletion, and water vulnerabilities induced by climate change present the greatest obstacle to sustainable livelihoods in the rangeland areas (Nampala *et al.*, 2015). Availability of water in the rangelands is essential as it determines survival and growth of livestock, as well as their spatio-temporal distribution across the landscape (Shahriary *et al.*, 2012; Egeru *et al.*, 2015). Watering points in these areas ignite a substantial ecological impact as they lead to localized range degradation causing piospheric effects (Mugerwa *et al.*, 2014). Even though watering points from water points are created to alleviate water scarcity and reduce the risks associated with drought, most developed water points are haphazard and fueled by other interests other than scientific evidence of need (Avery, 2014). Their construction is hasty and disregards other environmental services including forage and patterns of grazing (Egeru *et al.,* 2015).

In order to enhance rangeland resource management, both water resource development and their designs require evidence based research to inform interventions (Landman *et al.,* 2012; Sternberg, 2012). Rangeland assessment and monitoring therefore becomes useful in improving the effectiveness of management approaches, enables land users to detect symptoms of ecosystem degradation before severe degradation occurs and acts as a point of information to stakeholders on land changes (Riginos and Herrick, 2010).

2.5. Effect of watering points on vegetation

Worldwide, grazing is one of the most vital agents of degradation in arid and semi-arid areas (van der Westhuizen *et al.,* 2005; Liang *et al.,* 2009; Akhzari *et al.,* 2015). The influence of grazing on vegetation is therefore critical, since both livestock and wildlife contribute to range degradation (Wei *et al.,* 2011). The high proportion of Africa's rangelands that witness over-utilization stems out of the low intensity, low input and extensive nature of pastoralism, the sluggard response to changes in land management in dry climates and the socio-economic challenges that accompany reduced livestock populations in heavily grazed areas (Opiyo *et al.,* 2011; Mganga *et al.,* 2015). Overgrazing has adverse impacts, including upsurge of unpalatable plant species (Louhaichi *et al.,* 2009), reduction of biomass and decrease in vegetation cover (Zhao *et al.,* 2011; Louhaichi *et al.,* 2012), and reduced species diversity (Deng *et al.,* 2014). Compared to heavy grazing, light to moderate grazing improves biomass production and could therefore enhance rangeland health (Akhzari *et al.,* 2015). Vegetation biomass is however reduced where grazing intensity is high (Alphayo, 2015).

Defoliation of plants by livestock and transport of seeds affect plant characteristics. Grazing animals can lead to increase or decrease in plant diversity within range ecosystems (Zhao *et al.,* 2006). Further, defecation and urination by grazing animals could avail the required nutrients by plants, hence altering diversity and richness, a common phenomenon near watering points (Shahriary *et al.,* 2012). Whereas light to moderate grazing has been found to increase plant diversity and alter species composition (Wu *et al.,* 2009), research has shown that heavy grazing reduces the diversity of vegetation within rangeland ecosystems (Zhao *et al.,* 2006; Todd, 2006; Egeru *et al.,* 2015). While conducting a study in the Mojave Desert in the United States of America, Brooks *et al. (*2006) observed an increase in alien, unpalatable species near the watering points. The results were attributed to the depletion of native palatable species as a result of overgrazing that had been observed near the watering points. Similarly, in a related study conducted by Todd, (2006) in the Nama-Karoo rangelands of Southern Africa, it was observed that forbs and annuals had replaced the palatable plants near the watering points. This was because of increased grazing concentration around the watering points that led to excessive defoliation and trampling leading to decrease in composition and diversity of preferred perennial grasses. Further, Egeru *et al. (*2015) observed that increaser species such as *Eragrostis spp* and *Sporobolus spp* had replaced palatable grass species such as *Hyperrhenia hirta* and *Setaria sphacelata* near the watering points. This was mainly due to increased degradation near the watering points, which had led to depletion of decreaser grasses and paved way for the increaser species that were tolerant to grazing. When seeking to reverse range degradation, grazing prohibition and use of enclosures is the most widespread measure taken by most range managers (Golodets *et al.,* 2010; Wu *et al.,* 2010; Wairore, 2015).

2.6. Effect of watering points on soils

Studies have revealed higher soil bulk densities in grazed rangelands compared to un-grazed rangelands (Mckenzie *et al.*, 2004; Han *et al.*, 2008). Heavy grazing results in increased soil bulk density due to soil compaction (Alphayo, 2015). Similarly, soil moisture content undergoes alterations when grazing occurs (Weber and Gokhale, 2011). According to Wei *et al. (*2011) soil moisture content can be enhanced by light to moderate grazing. Related studies by LeCain *et al. (*2000) and Olofsson *et al. (*2008) revealed that soil moisture content was higher in enclosures than in highly grazed lands. In a study of the influence of livestock grazing on soil moisture characteristics and species composition in the rangelands found in Isfahan, Amiri *et al. (*2008) observed decreasing soil moisture content with increasing grazing intensity. These results were attributed to the fact that areas of mild to moderate grazing had higher rates of water infiltration as a result of high plant biomass and stable aggregates of the soil. The low moisture content in heavily grazed lands can be attributed to the fact that soil compaction inhibits water percolation through the soil through decreased pore volume and disintegrated soil aggregates (Bell, 2010; Alaoui *et al.,* 2011). Livestock grazing also leads to reduced soil porosity as a result of increased soil compaction. Findings by Azarnivand *et al. (*2010) also demonstrated that soil porosity was significantly lower in heavily grazed areas compared to light and moderately grazed zones. Effect of grazing on soil saturated hydraulic conductivity has also been documented (Egeru *et al.,* 2015). Heavy grazing results in low soil hydraulic conductivity (Bell *et al.,* 2010; Alaoui *et al.,* 2011). This was attributed to trampling which led to compaction of the soil surface, increasing the soil bulk density and reducing soil pore volume and impeding water movement into the soil. While conducting a study on the effect of grazing around the watering points of Karamoja, Uganda, Egeru *et al. (*2015) observed significantly lower soil hydraulic conductivity in areas of heavy grazing compared to areas of light to moderate grazing intensity. The results were attributed to increase in trampling near the watering points which led to soil compaction, hence reduction in soil pore volume.

Past studies have reported grazing to affect soil aggregate stability (Azarnivand *et al.,* 2010; Curran, 2010). While conducting a study on the effect of grazing on soil aggregate stability in Naibunga Conservancy in Laikipia County, Alphayo (2015) reported significantly lower soil aggregate stability in continuously grazed areas compared to areas that were under holistic grazing management. These findings were attributed to the fact that aggregate stability in continuously grazed lands had low organic matter content due to high grazing intensity that undermined soil microbial activity. Further, declined above ground biomass exposed the soils to direct effect of raindrops and wind which dispersed soil particles and thus decreased soil aggregate stability. Similarly, in a study conducted in the semi-arid rangelands of Otago, Curran, (2010) reported that areas placed under heavy grazing for long periods had lower soil aggregate stability compared to light and moderately grazed regions. Azarnivand *et al.* (2010) while undertaking a research in the Hosainabad rangelands, also observed that soil aggregate stability increased with decreased grazing pressure.

Studies have shown grazing alter soil pH. Shahriary *et al.* (2012) reported significantly higher soil pH in high grazing intensity areas around the watering points of Iran. Similarly, Egeru *et al.* (2015) observed that areas near the watering points that had highest concentrations of grazing livestock around the watering points of Karamoja, Uganda, had higher soil pH compared to farther distances from the watering points.

Research has produced contrasting results on the impact of grazing on soil organic carbon and total nitrogen (Wang *et al.,* 2008). Shahriary *et al.* (2012) observed higher soil organic carbon and total nitrogen concentrations in the first one hundred metres from the Iranian watering points. The results were attributed to increased defecation and urination by grazing livestock around this distance which led to deposition and consequent accumulation of nutrients over time. Increase in soil organic carbon and total nitrogen with increased grazing intensity was also reported by Reeder and Schuman, (2002). Ingram *et al.* (2008) however, reported that soil organic carbon and total nitrogen concentration decreased with increase in grazing intensity.

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CHAPTER THREE

General Materials and Methods

3.1. Study area

This study was conducted in Kiserian Sub-County, Kajiado County. Kajiado County borders Nairobi County to the North East, Narok County to the West, Nakuru and Kiambu Counties to the North, Taita Taveta County to the South East, Machakos and Makueni Counties to the North East and east respectively, and the Republic of Tanzania to the South. The county covers an area of 21,900.9 square kilometres (Km^2) and is situated between Longitudes 36° 5’ and 37° 5’ East and between Latitudes 1° 0’ and 3° 0’ South (GoK, 2005; GoK, 2013). Figure 3.1 shows the map of the study area.

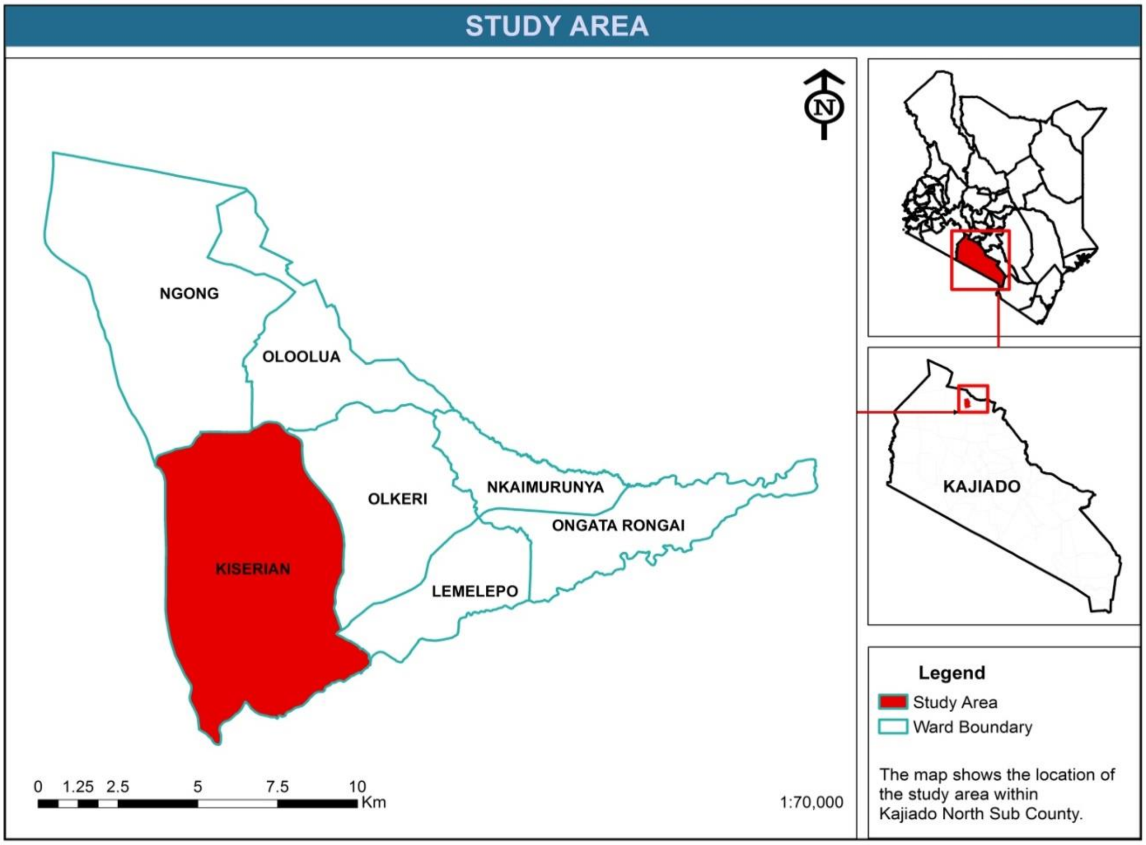

Figure 3. 1: Map of Kiserian area

3.2. Topography

Kiserian consists mainly of gently undulating slopes, which become rolling and hilly towards the Ngong hills. The altitude ranges from 1580 to 2460 metres above sea level. The hills are the catchment areas for Athi River, which is fed by Mbagathi and Kiserian tributaries (Kioko and Okello, 2010; GoK, 2013).

3.3. Climate

Rainfall in Kajiado County increases with altitude. The mean annual rainfall ranges from 300mm in the low lying regions of Amboseli to 1250mm in the Ngong Hills (Kareri, 2013). The County experiences a bi-modal pattern of rainfall (Ogutu *et al.,* 2013). The short rains fall between October and December while the long rains fall between March and May. The minimum and maximum mean diurnal temperatures are 10^{0}c and 24^{0}c respectively. The wettest month is April while the driest month is August (GoK, 2013).

3.4. Soils

The main soil type in Kiserian is Vertisols which are sticky when wet and form large cracks when dry (Leeuw *et al.,* 1991; Ombogo, 2013).

3.5. Vegetation and water resources

The most common species in the area are *Acacia mellifera*, *Acacia tortilis*, *Acacia nubica, Acacia ancistroclada, Acacia nilotica, Commiphora riparia*, *Commiphora africana* and *Balanites aegyptiaca.* Less drought-tolerant species (e.g. Combretum, Grewia and Premna) are confined to zone IV (Bekure, 1991). Kajiado County is dominated by the Acacia-Themeda associations (Kareri, 2013). Among the factors known to modify vegetation within the County are soil type, altitude and grazing activity by livestock and wildlife. Charcoal burning, fuel wood extraction and cultivation have led to vegetation reduction (GoK, 2013).

The main sources of surface water are the Mbagathi River and the Kiserian stream (Krhoda, 2002). Underground water is mainly obtained from private boreholes and wells which supply water to the residents at a cost (Simiyu and Dulo, 2015). Increase in agricultural activities coupled by an increase in human population has adversely affected water availability, quality, access and sustainable use (Okello and D'Amour, 2008). Water catchments and springs have been degraded through overgrazing and inappropriate anthropogenic effects such as farming which stimulates soil erosion especially during the rainy season, compromising the quality of water through siltation (Reid *et al.*, 2004).

3.6. Human population

Kiserian has a population of about 202, 651 people according to the Kenya National Census of 2009 (RoK, 2010). The population density is 1,369 persons per square kilometre and is projected to reach 2,087 persons per square kilometre by 2017 due to rapid urbanization influenced by proximity to Nairobi City. The human development index is 59.35%. The population growth rate is 4.5% per annum, and life expectancy is 45 years (GOK, 2005).

3.7. Community livelihoods and land use

Livelihoods are being diversified, especially by the Maasai community from subsistence pastoralism to formal employment, trade, cultivation and group ranching (Kioko and Okello, 2010). This is to capitalize on emerging social and economic opportunities and minimize environmental risks (Ogutu *et al.*, 2014). These are shown by land subdivision, sedentarization and land use intensification. Factors influencing livelihood diversification include frequent droughts, zoonotic disease outbreaks and declining livestock numbers, shrinking pasture land and reduced livestock productivity (Seno and Shaw, 2002; Ogutu, 2002; Campbell *et al.*, 2003; Okello, 2005). Meagre returns from wildlife, changing food preferences and lifestyles have also facilitated livelihood diversification (Norton-Griffiths, 2007; Homewood, 2009). The main land use is livestock rearing. Even though pastoralism has dominated land use over the years, commercial and industrial land use is gaining momentum especially in the urban areas (Okello *et al.*, 2009).

3.8. Economic activities

The main economic activity among the pre-dominant Maasai community in Kajiado County is pastoralism (Ogutu *et al.,* 2013; Okello *et al.*, 2014). However, other communities such as the Kamba and the Kikuyu have migrated into the area and are mainly cultivators, formally employed or business people (Ogutu *et al.,* 2014).

3.9. Water Resource Users' Associations in Kajiado

Water Resource Users' Associations are community based water resource conservation institutions that were created through Water Resource Management Authority (WRMA) following the enactment of the Water Act of Kenya, 2002 (Mathenge *et al.,* 2014). The aim of the Act was to devolve water resource conservation and supply to lower government institutions and enhance community participation in water access and use, and conflict resolution among competing users (K'akumu *et al.,* 2006). The main role of WRUAs is to promote a legal and controlled use of water, resolve water use conflicts and develop water resource conservation strategies that ensure adequate water reserves to meet the water demands for the environment, livestock, people and wildlife, and conservation of key water catchments (Rampa, 2011). Conservation of catchment areas is aimed at increasing water availability through improvement of the hydrological cycle.

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CHAPTER FOUR

Community Based Water Resource Conservation in the Southern Rangelands of Kenya

Accepted, Journal of Tropical and Sub-Tropical Agroecosystems,
http://www.revista.ccba.uady.mx/ojs/index.php/TSA/author

Abstract

Water insecurity is a threat to pastoral livelihoods and sustainability. The Water Act of Kenya, 2002, created the Water Resource Users' Associations (WRUAs) to enhance water resource conservation access at the local level. Nevertheless, environmental degradation has not been adequately mitigated, further exacerbating water crisis and threatening livelihoods. This study sought to assess the status of community based water resource conservation in Kiserian, Southern rangelands of Kiserian, Kajiado County, Kenya. Kiserian WRUA members were purposively sampled for this survey. Kiserian WRUA is based along Kiserian River. Data was mainly collected through administration of a semi-structured questionnaire. Focus group discussions and key informant interviews were also conducted to validate the data obtained from the questionnaire. Chi-square and descriptive statistics were used to analyze the data using SPSS version 20. Results indicated that access to information on water conservation and training were significantly associated, with membership to the WRUA (χ^2=0.56, $p \leq 0.05$) and (χ^2=0.71, $p \leq 0.05$), respectively. Majority (79.5%) of the Kiserian WRUA members had participated in tree planting within the catchment. Half (50%) of the WRUA members were mainly motivated to join the association because of perceived benefits like improved access to water at lower prices and participation in catchment protection. The main challenges facing the WRUA were inadequate funding from the government and other stakeholders (93.2%) and lack of support from county leadership (34.1%). It was concluded that WRUAs, especially in the rangelands of

Kajiado, Kenya, played a key role in catchment conservation and water access for resilient livelihoods among pastoralists. This study therefore recommends public awareness initiatives to increase WRUA membership and allocation of sufficient funding from the government and other related stakeholders to WRUA conservation activities, if catchment conservation for improved water access in the area is to be realized.

Key words: Kiserian, Community Based Water Resource Conservation, Water Resource Users' Association, Rangelands

4.0 Introduction

Water insecurity has been linked to poverty and disease in most parts of the world, as impeded access and affordability of water hampers human well-being and development (Shivoga *et al.*, 2007; Luwesi *et al*., 2012; Luwesi and Barder, 2013). In order to address the water crisis, there have been concerted efforts by several stakeholders especially in rangelands of Africa, where both statutory and customary set-ups play major roles in water management (van Koppen *et al*., 2014). These efforts have been triggered by the realization that natural resource dependent economies such as pastoralism are vulnerable to climate change and variability, and as such, possess low adaptive capacity (Opiyo *et al*., 2014; Reid *et al*., 2014).

Kenya instituted key reforms in the water sector, culminating in the enactment of the Water Act of 2002, and subsequent establishment of various Water Resource Users Associations (WRUAs) by the Water Resource Management Authority (Yerian *et al*., 2014; Baldwin *et al*., 2015). Some of the responsibilities on water management were decentralized to lower government institutions and non-governmental organizations and were mandated to provide water and manage water resources, provision of water resources was alienated from Water Resource Management Authority and policy making disintegrated from daily operations of institutions dealing in water

(K'akumu *et al*., 2016; McCord *et al*., 2016). The Act vested the power to manage water resources on the Water Resource Management Authority (WRMA), with the Ministry of Water and Irrigation playing the policy and oversight role. The WRUAs were formed and exempt from supplying water, yet mandated to conserve water resources at the local level (Mathenge *et al*., 2014).

Community based water resource management through the WRUAs has gained popularity in most parts of Kenya (Mathenge *et al*., 2014; K'akumu *et al*., 2016). WRUAs have been identified as key instruments in improving water access and availability especially in the rangelands where land degradation and low rainfall have limited the capacity of ecosystems to provide adequate water resources (Murtinho *et al*., 2013). This can be achieved by formulation of conservation strategies unique to particular regions' climatic conditions and livelihood options. Currently, there is a spill of population from urban centers into the rangelands of Kenya and as such, water demand in these areas has been further stretched beyond the supply (Nkedianye *et al*., 2011).

Insights on community water resource conservation and management are vital if the government and other stakeholders are to realize improved water access and reduced land degradation in the rangelands. Previous studies have shown that the rangelands of Kenya experience acute water shortages that adversely impact on livelihoods of the people (Kioko & Okello, 2010; Opiyo *et al*., 2011; Ogutu *et al*., 2014; Okello *et al*., 2014; Kiringe *et al*., 2016). However, there is insufficient information on community based water resource conservation in these areas. Water interventions have therefore been haphazard and without evidence on how local communities can improve availability of water from natural sources such as rivers and springs. This study therefore sought to establish the status of community based water resource management in the southern rangelands of Kenya to obtain information to provide guidelines for future interventions or policy makers.

4.1 Materials and methods

4.1.1 Study area

The study was done in Kiserian, Kajiado County (Longitudes 36° 5″ and 37° 5″ East and Latitudes 10 ° ″ and 30 ° ″). The altitude ranges from 1580 to 2460 metres above sea level. Kiserian is found in agro-ecological zone IV and is therefore a semi-arid region. Rainfall is bimodal in its distribution. The first rains, locally referred to as long rains are received from March to May while the short rains (second rains) fall between October and December (Ogutu et al., 2013). The seasonal rainfall received within the County is between 300-1250mm (Kareri, 2013). The minimum and maximum mean diurnal temperatures are 10 °C and 24 °C respectively (Krhoda, 2002). The r/ET_0 is < 0.65 (Middleton & Thomas, 1997). The main soil type in Kiserian is vertisols which are sticky when wet and form large cracks when dry (de Leeuw et al., 1991; Ombogo, 2013). *Acacia mellifera, Acacia tortilis, Acacia nubica, Acacia ancistroclada, Acacia nilotica, Commiphora riparia, Commiphora africana* and *Balanites aegyptiaca* are the most common plant species (Bekure, 1991).

The area has a population of about 202,651 people with a population growth rate of 4.5% and a life expectancy of 45 years (RoK, 2010). The main land use and livelihood source is livestock rearing, although livelihoods have been diversified in order to capitalize on emerging social and economic opportunities and minimize environmental risks (Ogutu et al., 2014). Formal employment, trade, cultivation and group ranching are replacing subsistence pastoralism in the area, especially among the traditionally nomadic Maasai community (Kioko & Okello, 2010).

4.1.2 Research design

A survey was used for this study. Descriptions were given for the various subjects including motivation, benefits and challenges of WRUA membership discussed under this research.

4.1.3 Population sampling

Primary data obtained by interviewing Kiserian water users was used for this study. Purposive sampling was used to select Kiserian WRUA members for interviews. According to Mugenda & Mugenda (2003), 10-50% of the population can be taken as a representative sample. Out of the 60 members of the Kiserian WRUA, 44 were selected using the formula;

$$n = \frac{z^2 pqN}{e^2(N-1) + z^2 pq} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (1)$$

Where n=sample size, N=entire population, z=level of significance (0.05), e=expected error (0.03), p=probability that an individual has desirable characteristics and q=probability that an individual does not have the desired characteristics

Random sampling was used to select 38 non-WRUA members for interviews using the recommendations of Nyariki (2009);

$$n = \frac{z^2 pq}{d^2} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (2)$$

Where n=sample size, z=level of significance (0.05), d^2=expected error (0.03), p=probability that an individual has desirable characteristics and q=probability that an individual does not have the desired characteristics.

4.1.4 Questionnaire administration

A pre-test was done on 10 participating water users to validate the questionnaire before presentation to the selected interviewees. The questionnaire collected information on socio-economic and demographic characteristics of the water users, water sources, motivation and benefits of WRUA membership, capacity building on water resource conservation, WRUA conservation projects and challenges facing the WRUA. Respondents were interviewed to fill the questionnaire under the guidance of trained enumerators for enhanced quality.

4.1.5 Focus group discussion and Key informant interviews

Five focus group discussions were also conducted to verify and reinforce the information obtained from the questionnaire and to gather information on proposals to guide policy review. Two local water distributing company officials, one WRMA extension officer, a local chief and the chairperson of the Kiserian WRUA were used as Key Informants for the study.

4.1.6 Data analysis

Data analysis was done using SPSS version 20. Qualitative data was presented as tables and discussed. Quantitative data was organized and descriptions given in frequencies, means and percentages. Chi-square tests were done to determine the association between categorical variables. Threshold for significance was set at $p \leq 0.05$.

4.2 Results and discussion

4.2.1 Social and demographic characteristics of Kiserian water users

A majority of WRUA members (70.4%) and non-members (65.8%) interviewed were male, whereas 29.6% and 34.2% of WRUA members and non-members interviewed, respectively, were females. The mean age of the respondents was 41.85 years. These findings could be attributed to the fact that men are the main decision makers in most households in the Kenyan rangelands (Wasonga, 2009) and could therefore decide on their membership status without any consultation with other household members. The findings concur with Lugusa (2015) who observed that pastoral community based organizations in Baringo, Kenya were male dominated based on the fact that most households were male-headed. Agevi *et al. (*2014) also found out that men in Malava, Kenya were more likely to join community groups than women because of the benefits they expect. As reported by Coulibaly-Lingani *et al. (*2011), household chores and reproductive roles could/would deter women from joining community conservation groups.

Most of the respondents (37.8%) had attained primary education while 20.1% had no formal education at all. Secondary and tertiary education had been attained by 24.4% and 18.3% of the respondents, respectively, a status greater than the county's documented education levels where only 7.8% of the population had attained secondary education (GoK, 2013).

Pastoralism was found to be the main land use and was the predominant source of livelihood (30.4%). Cultivation of crops was the main livelihood source for 19.5% of the respondents while 23.2%, 10.9% and 15.8% of the respondents earned their livelihood mainly from business, formal employment and casual labour, respectively. Kajiado County Integrated Development Plan 2013-2017 (GoK, 2013) stated that a majority of the population within the County are livestock keepers, which concurs with our findings. Homewood (2009), Okello *et al. (*2014) and Omondi *et al. (*2014) also reported that livestock rearing was the main means to livelihood in Kajiado County, Kenya. Species reared included cattle, sheep, goats and donkeys although most respondents revealed from the focus group discussions that cattle had declined within their herds, concurring with the findings of Kagunyu and Wanjohi (2014) and Lugusa (2015) that preference for shoats had increased among Kenyan pastoralists.

Businesses, formal employment, crop cultivation and casual labour emerged as alternative livelihood sources. The diversification in livelihoods could have been triggered by changing climate, a shift in lifestyle and food preferences and a need to gain from emergent socio-economic opportunities. These results are consistent with those of Okello *et al. (*2005) that outbreak of zoonotic diseases, shrinking land and diminishing livestock numbers had led to livelihood diversification in Kajiado County. The observations of this study further corroborate with those of Lamprey & Reid (2004), Norton-Griffiths (2007) and Homewood (2009) that lifestyle and food preference change were key drivers of livelihood diversification among the Maasai community of Kenya.

4.2.2 Categories of water users in Kiserian

Table 4.1 shows water use in Kiserian, Kajiado County. Water was mainly used for livestock rearing (42.7%) and domestic purposes (40.1%). Other main water uses included crop cultivation (9.8%), business (3.7%) and forestry (3.7%). Increased urbanization of Kiserian could justify the high proportion of domestic water users where people working in Nairobi and its environs living in the study area have increased in the area in recent years (Mukunga, 2012). Reed *et al. (*2015) reported that livestock keeping was the main water use in the rangelands of Kenya. In addition, Opiyo *et al. (*2011) and Omondi *et al. (*2014) also showed that livestock production was the predominant water use in Mwingi and Amboseli, Kenya, respectively.

Table 4. 1: Categories of water users in Kiserian

Variable	Frequency (N=70)	Per Cent (%)
Crop cultivation	8	9.8
Livestock keeping	23	42.7
Domestic users	33	40.1
Business	3	3.7
Forestry	3	3.7

4.2.3 Type of water sources in Kajiado

Surface and underground water sources were used by residents in the study area (Figure 4.1). The most prevalent water resources used was borehole (54.8%). Other water sources included piped water (13.4%), wells (3.7%), rivers (9.8%), surface dams (4.9%) and springs (13.4%).

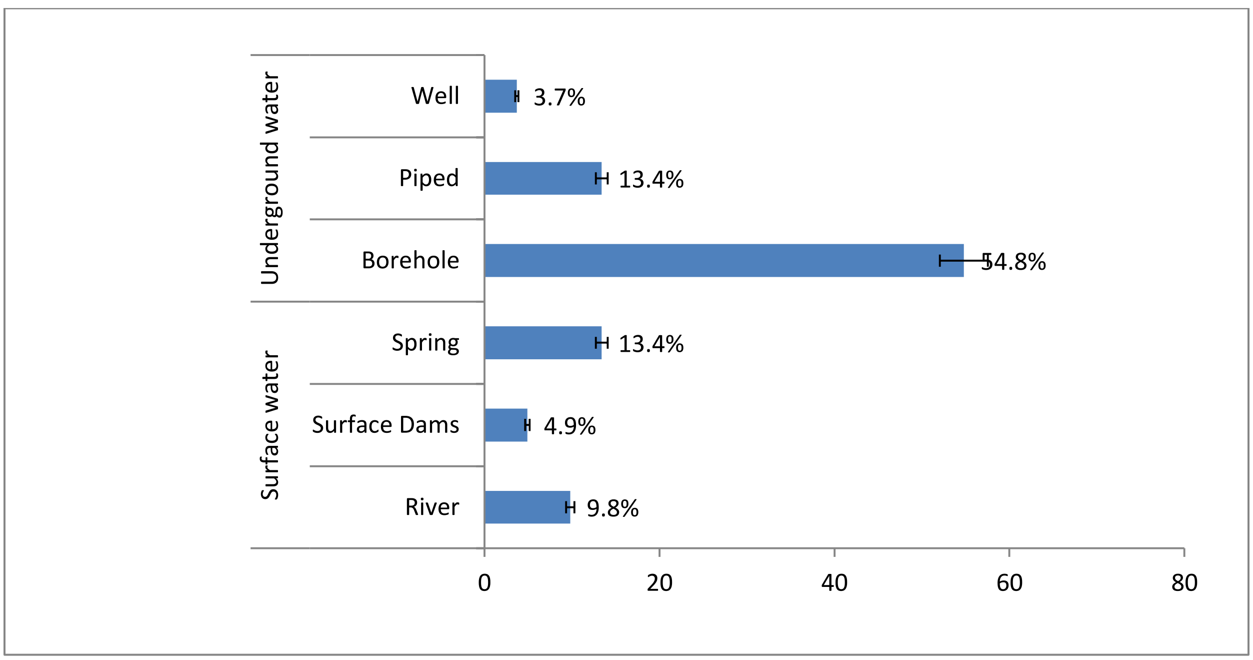

Figure 4. 1: Types of water sources in Kiserian

The widespread use of borehole water in Kajiado County emanates from the fact that the County suffers from water scarcity which necessitated water intervention measures (Kioko & Okello, 2010; Okello *et al*., 2014). These measures include drilling of boreholes and supply of tank water by the Ministry of water and the County government, respectively (GoK, 2013). Kiserian dam was also built in 2011 to boost water supply in the region (Mukunga, 2012). Wahome *et al. (*2014) and Kiringe *et al. (*2016) also observed that boreholes were the major source of water in Kajiado and Samburu. Underground water was also reported to be more accessed compared to surface water in Yemen (van Steenbergen *et al*., 2011) due to prolonged use and reliable supply during droughts.

4.2.4 Motivation and benefits of joining WRUA membership

The motivating factors and benefits of WRUA membership are presented in Table 4.2. A majority (68.2%) of the members were motivated by desire to protect the catchment while water shortage experience and desire to access training were motivating factors for 43.2% and 38.6% of the members, respectively. Peer pressure and passion for community service motivated 9.1% and 25% of the members to join the WRUA, respectively.

Experience of drought effects and perceived benefits have been observed to be the main factor motivating rangeland community members to join climate change adaptation and conservation groups (Wasonga, 2009; Lugusa, 2015). Acute water shortages especially during droughts might have created awareness among members on the need to conserve the catchment and consequently influenced them to join the WRUA. Similar observations were reported by Kyeyamwa *et al. (*2008) where farmers formed groups to boost their chances of accessing credit and fertilizers. While conducting a study on factors motivating household participation in fodder groups in Baringo, Lugusa (2015) observed that drought experience was the main motivating factor in joining the fodder groups.

Table 4. 2: Motivation and benefits of WRUA membership

	Variable	Frequency (N)	%
Motivation for joining WRUA	Water shortage experience	19	43.2
	Catchment protection	30	68.2
	Pressure from neighbours	4	9.1
	To access training	17	38.6
	Passion for community service	11	25
Benefits of WRUA membership	Improved water access	18	40.9
	Access to water management information	17	38.6
	Enhanced community awareness	12	27.2
	Participation in catchment protection	22	50
	Access to market for trees	1	2.3
	New farming methods	7	15.9

Half (50%) of the members had benefited by participation in catchment protection while 40.9% of the members had benefited through access to water resources. Other benefits of membership included access to water conservation information and training (38.6%), enhanced community awareness (27.2%), access to market for tree seedlings (2.3%) and acquisition of new farming methods (15.9%).

Most governments in Africa use community based organizations in up-scaling technologies that enhance rural economies as opposed to targeting individuals (Franzel *et al*., 2001; Noordin *et al*., 2001). Local community groups therefore provide structures for the government and other development agencies to carry out technology transfer and capacity building. Key Informant Interviews revealed that WRMA, Ministry of Livestock, non-governmental organizations, Kenya

Tea Development Authority and Water Trust Fund were the main sources of training and information on water resource conservation.

Access to information on water conservation and training were significantly associated, with membership to the WRUA (χ^2=0.56, p≤0.05) and (χ^2=0.71, p≤0.05), respectively, (Table 4.3). As a result, the WRUA members had a higher mean daily household water supply (0.17m^3) compared to non-members (0.15m^3) and obtained the same amount of water (20L gallon) at a lower mean price of Kshs. 11.25 and Kshs. 12.60, respectively (Table 4.4).

Table 4. 3: Capacity building on water resource conservation

	WRUA Members		Non-WRUA Members		Chi square value	p-value
	Frequency	Per Cent	Frequency	Per Cent	(χ^2)	
Access to training	35	79.54	5	13.16	0.71	<0.001
Access to information	41	93.18	12	31.58	0.56	<0.001

Table 4. 4: Daily water demand, supply and cost (per 20L gallon) in Kiserian

	WRUA members		Non-WRUA members	
Variable	Mean	Std. deviation	Mean	Std. deviation
Daily household water demand(m^3)	0.17	0.1	0.23	0.1
Daily household water supply(m^3)	0.15	0.1	0.2	0.1
Price per 20L gallon of water(Kshs)	11.3	4.6	12.6	5.4

Munyua and Stilwell (2013) reported that vulnerable communities had formed groups in order to benefit from extension services and capacity building programs offered by the government in Central Kenya. While conducting a study on milk farmers in Meru, Davies *et al. (*2004) observed that organized groups had better access to training as opposed to individual farmers.

4.2.5 Conservation projects carried out by Kiserian WRUA

Table 4.5 shows the conservation projects undertaken by the Kiserian WRUA members. Majority (79.5%) of the members had participated in river de-silting, 75% in tree planting and 45.4% in river pegging. Lowest participation was observed in riparian area fencing and community sensitization (15.9%).

Table 4. 5: Participation in conservation projects carried out by Kiserian WRUA

Variable	Frequency (N)	%
Tree planting	33	75.0
De-silting	35	79.5
River pegging	20	45.4
Riparian area Fencing	7	15.9
Community sensitization	7	15.9

WRUA activities were mainly conservation oriented, and thus in tandem with WRUA mandate outlined by Rampa (2011). Tree planting is a widely known conservation measure, and has been used to rehabilitate degraded areas (Mogaka, 2006). Luwesi and Barder (2013) Mathenge *et al. (*2014) witnessed tree planting in rehabilitation of Muooni sub-catchment in Machakos and Ngaciuma sub-catchment in central Kenya, respectively. Low literacy levels have hampered community sensitization programs by community based organizations (Alufah *et al*., 2012) and could justify the low participation in community sensitization activities by the Kiserian WRUA.

4.2.6 Challenges facing the Kiserian WRUA

The challenges faced by the Kiserian WRUA are shown in Figure 4.2. The main challenge facing the WRUA (93.2%) was lack of funding. Fundraising efforts through proposals and collaboration with NGOs, CDF and County government was not sufficient. Other challenges included community hostility towards conservation initiatives (29.5%), low literacy among members (40.9%), incompetent leadership (13.6%) and duplication of roles with water service providers (50%). Inadequate funds available to WRUA could be because of the limited funding sources. WRMA was the main financier of the Kiserian WRUA. Community hostility towards conservation initiatives might have been due to inadequate understanding from the general public on the need to conserve the catchment. Incompetent leadership could have been caused by the low literacy levels among the members. Most members stated during the focus group discussions that they lacked training in leadership and management.

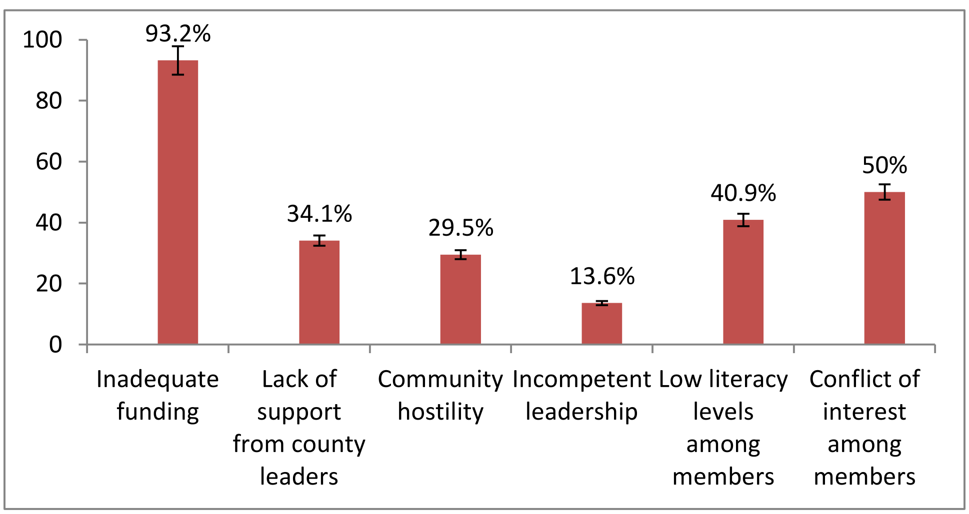

Figure 4. 2: Challenges facing the Kiserian WRUA

The findings of this study concur with past studies. Agevi *et al. (*2014) observed that inadequate funding was the main challenge facing community based organizations in Malava, Kenya. Murtinho *et al. (*2013) also reported that external financial support significantly enhanced the capacity of local communities to adapt to water scarcity in Columbia. Similarly, Mathenge *et al.*

(2014) observed that overlap of roles between Water Service Providers (WSPs) and WRUAs hindered conservation efforts in Ngaciuma sub-catchment, Kenya, respectively.

4.3 Conclusion and recommendations

Use of boreholes had gained popularity as a water intervention measure aimed at curbing water scarcity in Kajiado County. WRUA members had better access to capacity building and therefore accessed water at lower costs. The communities in the study area had diversified their livelihood options to better adapt to changing climate and socio-economic landscape Funding and duplication of roles were the main challenges facing the WRUAs in the southern rangelands of Kajiado. Perceived benefits were the main motivation for rangeland communities to join WRUAs. This study therefore recommends that community sensitization on roles and benefits of WRUAs be done by WRMA to enable a larger proportion of the general public to join the WRUA. Besides, there is need for stakeholders to empower the local communities in adopting sustainable livelihood diversification strategies by supporting WRUA activities through funding and technical guidance. Water resource governance and access policies should also be reviewed to avoid overlapping and conflicting functions of water service providers (WSPs) and WRUAs.

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CHAPTER FIVE

Plant Species Composition and Diversity Depending on Watering Points in the Southern Rangelands of Kenya

Published, Journal of Ecological Processes, Springer:
https://ecologicalprocesses.springeropen.com/articles/10.1186/s13717-017-0083-7

Abstract

Scarcity of water in the rangelands of Kenya has led to introduction of watering points as an intervention measure. Previous research has however not adequately addressed the effect of these watering points and seasonality on Shannon-Wiener's diversity index. In this study, the impact of these watering points on plant species composition, diversity and richness was assessed. Vegetation sampling was done during both the long rains (April) and the dry season (August). Three watering point types (dam, trough and a seasonal river) were studied using 0.25 m^2 quadrats to sample vegetation at intervals of 20 m along four 100 m transects per watering point in North, East, South and West directions. Shannon-Wiener's diversity index was used to determine species richness and composition. Two-way ANOVA was used to determine if piospheric distance had effect on species diversity, richness and evenness using GenStat 15th edition. A total of 22 grasses and 29 forbs were recorded in the study area. The most abundant grasses near the watering points were *Eragrostis tuneifolia* (12.9%) and *Cynodon dactylon* (10.6%). *Eragrostis tuneifolia* is an increaser species and was most abundant in areas of severe grazing while *Cynodon dactylon* is known to be tolerant to grazing. The most abundant forbs were *Crotolaria brevidens* (37.5%). Shannon-Wiener diversity index significantly increased (F=25.07, p=0.001) with distance from the three watering points owing to the high grazing intensity near the watering points and was significantly different between watering points, being higher ($F=10.05$, $p=0.001$) at 20m from the river (1.2 ± 0.1) compared to a similar distance from the dam (0.9 ± 0.1) and the trough (0.8 ± 0.2). This was probably because the trough was smaller in size compared to the other watering points thereby concentrating more grazing animals per unit area and causing a greater impact on plant species.

The study demonstrated that Shannon-Wiener's diversity index, Species richness and Pielou evenness were low near the watering points due to heavy grazing and was low near the trough compared to the dam and the river. Therefore, there is need for the management to ensure evenly distributed grazing pressure through planned and controlled herding. This is to improve range condition improvement if sustainable livestock production is to be realized. We further recommend reseeding of degraded areas near the watering points with perennial species.

Key words: Watering point, Species Composition, diversity, Richness, Rangelands

5.0. Introduction

A piosphere is defined as the radial pattern of differential grazing and the associated animal impact which develops around the water points (Lange, 1969; Todd, 2006). These patterns formed around watering points form a basis for studying the effects of livestock grazing and differentiating them from other environmental factors (Todd, 2006). Watering points have an effect on both soil and vegetation. Impacts on soil include alterations to soil nutrients (Shahriary *et al.,* 2012), soil compaction which results in high soil bulk density and reduced porosity and hydraulic conductivity (Smet and Ward, 2006). The effects on vegetation include increased shrub mortality, plant defoliation, alterations to species composition and demography (Riginos and Hoffmann, 2003), and changes in herbaceous vegetation composition (Egeru *et al.,* 2015). Plant defoliation by livestock and wildlife grazing around these watering points increases palatable species' mortality, thereby reducing their ability to favorably compete with less palatable alien and exotic species (Hunt, 2001; Shahriary *et al.*, 2012). Further, trampling reduces seed production and seedling establishment in the rangelands (Chaichi *et al.*, 2005; Amiri *et al.*, 2008). Grazers also change rangeland vegetation through deposition of urine and feces which accumulate nutrients (Shahriary *et al.*, 2012) and by dispersing plant seeds and propagules (Rosas *et al.*, 2008).

The attempt to create a generalized pattern of effect of watering points on vegetation across the world is based on the perception that plant species with similar morphological and physiological traits should respond similarly when exposed to grazing (Brooks *et al.*, 2006; Todd 2006). Piospheric studies on species composition, richness and diversity indices have been done in most parts of the world including Australia (Landman *et al.*, 2012), Asia (Shahriary *et al.*, 2012), Southern Africa (Todd, 2006), Northern Africa (Tarhouni *et al.*, 2010) and Uganda (Egeru *et al.*, 2014; Egeru *et al.*, 2015). Nevertheless, there have been no studies conducted in Kenya, especially in the Southern rangelands where water interventions have been widely undertaken to alleviate water shortage and enhance pastoral livelihoods (Opiyo *et al.*, 2014; Wahome *et al.*, 2014; Kiringe *et al.*, 2016). It is known that haphazard introduction of watering points without ecological considerations lead to rangeland degradation (Brooks *et al.*, 2006). This study therefore sought to establish the effect of watering points on plant species composition, diversity and richness in the Southern rangelands of Kajiado County, Kenya in order to provide insights for designing water intervention strategies that will enhance pastoral livelihoods without adversely affecting vegetation.

5.1. Materials and methods

5.1.1. Study area

The study was done in Kiserian, Kajiado County (Longitudes 36° 5″ and 37° 5″ East and Latitudes 10 ° ″ and 30 ° ″. The range of altitude in this County ranges between1580 and 2460 metres above sea level. The annual rainfall received ranges from 300mm to 1250 mm (Kareri, 2013). Rainfall is bimodally distributed. The long rains (first rains) fall between March and May whereas the short rains (second rains) are received from October to December (Ogutu et al. 2013). The minimum and maximum mean diurnal temperatures are 10^0c and 24^0c respectively (Krhoda 2002). The r/ET_0 is < 0.65 (Middleton and Thomas 1997). Kiserian is a semi-arid area found within agro-ecological zone IV. Soils are mainly vertisols, sticking when wet and forming large cracks during dry seasons (de Leeuw et al. 1991; Ombogo 2013). The most widespread plant species are *Acacia mellifera; Acacia tortilis, Acacia nubica, Acacia ancistroclada, Acacia nilotica, Commiphora riparia, Commiphora africana* and *Balanites aegyptiaca* are the most common species (Bekure 1991).

5.1.2. Research design

A randomized block design was used for this research with four watering points forming blocks while plots (5) were the distances from water points. Quadrats ($0.25m^2$) were the main sampling points, placed at intervals of 20m, 40m, 60m, 80m and 100m within a 100m transect from the watering point. Each treatment was replicated four times in the East, West, North and South directions from the watering points. A trough, a dam, and a seasonal river of similar durations of use and management type were assessed. The troughs were smaller in size compared to the dam and the river and could have an impact by increasing grazing pressure around it due to greater animal concentration. The river was a natural water system and was therefore used to provide a basis of comparison with the artificially created water sources (dam and trough).

5.1.3. Vegetation sampling

Plant species diversity, richness and evenness are affected by climatic variables such as rainfall. Vegetation sampling was therefore done in April during the long rains (wet season) and August during the dry season. Similarly, seasonal rivers are also affected by rainfall and as such, differences in plant species diversity, richness and evenness were expected between wet and dry spells. However, dams and troughs were in use during both seasons and therefore, no significant changes were expected in the vegetation attributes determined. Transects were done starting at 10 m away from the watering point, to minimize edge effects, and stretched a distance of 100 m. Four transects were used per watering point. Plant species were assessed after every 20 m within 0.5 m by 0.5 m quadrats, and available species counted and recorded.

Per cent species composition was determined using their relative densities as described by (Krebs 1989), using the formula shown in equation 1,

$$\left(\frac{n_i}{N}\right) \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \qquad \text{Equation (1)}$$

Where, n_i is the quantity of individual species per quadrat, while N is the total quantity of species within the same quadrat.

Species diversity was determined using Shannon Weiner's diversity index (1963) as described by Krebs (1989). Shannon-Weiner's Diversity index (H');

$$H' = -\sum\left[\left(\frac{n_i}{N}\right) \times \ln\left(\frac{n_i}{N}\right)\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \text{Equation (2)}$$

Where; n_i is the number of individuals of each species, N is the total number of individuals (or amount) for the site and Ln is the natural log of the number.

Species richness (S) was calculated as the total number of species per quadrat while Pielou evenness was calculated as described by Krebs (1989).

$$J = \frac{H©}{\ln(H©)_{max}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \text{Equation (3)}$$

Where H' is the Shannon-Weiner's Diversity index for the quadrat and H© $_{max}$ is the natural log of species richness (S).

5.1.4. Statistical analysis

Statistical analyses were performed using GenStat 15th edition. Two-way ANOVA was used to determine if there were significant differences between means of species diversity, richness and evenness at various piospheric distances, watering points and seasons. Comparison of means was done to determine if there were significant differences between treatment pairs. Tukey's HSD test was used to compare the means. Significance was obtained at $p \leq 0.05$.

5.2. Results

5.2.1. Species composition

The relative densities (%) of grasses at various piospheric distances are shown in Table 5.1. A total of 51 herbaceous species were recorded. Among the 22 grass species recorded, 15 grass species were recorded in the dry season while 21 grass species were recorded during the wet season. Of these, 18 were perennial grasses while 4 were annual grasses. The annual grasses with the highest relative densities were *Chloris pycnothrix* and *Eragrostis tuneifolia* whereas *Themeda triandra, Setaria holstii, Aristida adoensis, Bothriochloa insculpta, Cynodon dactylon* and *Hyperrhenia hirta,* were the perennial grasses with highest relative densities. *Cynodon* *dactylon, Eragrostis tuneifolia, Eriochloa fatmensis, Chloris pycnothrix*, and *Setaria verticillata* were more pronounced near the watering points.

There were 29 forbs recorded during both dry and wet seasons (Table 5.2). Of these, 27 were recorded during the dry season while 25 forbs were recorded during the wet season. The most dominant forbs were *Indigofera spicata*, *Indigofera volkensii*, *Launaea cornuta* and *Glycine wightii*. Among the 29 forbs recorded, 10 belonged to family Fabaceae, representing 36% of the total, while six were members of family Acanthaceae representing 18%. Lamiaceae and Labiatae families had two species each, forming 15% of the total number of forbs recorded. One species each was recorded for families Phyllanthaceae, Polygalaceae, Asteraceae, Malvaceae, Tiliaceae, Euphorbiaceae and Solanaceae families, each family being 4% of the total forb population observed. Forbs were more pronounced around the water points.

Table 5. 1: Relative densities (%) of grass species at various piospheric distances

		Relative Density (%)									
		Dry season					Wet season				
Species (N=22)	Distance(m)	20	40	60	80	100	20	40	60	80	100
Aristida adoensis		1.3	5.8	0.5	1.9	0.9	NP	0.9	4	1	4.1
Bothriochloa insculpta		11.5	6.6	3.6	4.8	5.5	4.4	5	2	7.6	6.9
Brachiaria lacnatha		NP	NP	NP	NP	NP	1.3	NP	NP	NP	1.4
Chloris pycnothrix		7.1	3.9	2.1	0.9	2.3	4.4	NP	2.8	1	NP
Cymbopogon excavates		NP	NP	NP	NP	NP	3.9	0.9	3.2	1	3.4
Cymbopogon vallidus		1.7	0.9	2.6	1.9	2.7	NP	NP	NP	NP	NP
Cynodon dactylon		11.1	6.2	2.6	3.9	2.7	10.1	5.4	3.6	2.1	NP
Digitaria macroblephara		NP	NP	NP	NP	NP	NP	1.8	8	NP	NP
Digitaria milanjiana		NP	NP	NP	NP	NP	NP	NP	1.6	1.5	NP
Digitaria scalarum		2.6	1.3	19.3	21.3	0.9	7.9	10	NP	14.2	NP
Eragrostis tuneifolia		16.4	13.3	11.5	9.7	7.4	9.3	7.7	NP	3.6	2
Eriochloa fatmensis		0.8	NP	NP	NP	NP	7.7	6.3	11.2	NP	1.4
Hyperrhenia hirta		2.6	1.7	1.6	5.8	1.8	2.2	0.5	NP	1.1	2.7
Hyperrhenia lintonii		2.2	NP	2.1	3.8	0.5	1.3	3.6	29.7	3.6	9.6
Michrocloa kunthii		NP	0.8	1	NP	0.5	NP	0.5	NP	5.6	NP
Pennisetum mezianum		1.3	NP	NP	0.97	NP	NP	1.8	NP	NP	NP
Setaria holstii		25.7	24.3	26	21.3	37.7	13.6	17.2	NP	18.8	32.9
Setaria sphacelata		NP	NP	4.7	1.93	NP	1.3	3.6	29.7	3.6	9.6
Setaria verticillata		NP	NP	NP	NP	NP	8.4	NP	NP	NP	NP
Sporobolus discosporus		NP	NP	NP	NP	NP	1.3	0.5	NP	NP	NP
Sporobolus pyramidalis		NP	1.9	3.6	1.93	5.6	NP	NP	NP	0.5	NP
Themeda triandra		15.1	29.2	18.7	19.3	30.2	23.4	36.2	29.7	38.1	34.3

NP=Not Present

Table 5. 2: Relative densities (%) of forbs at various piospheric distances

		Relative Density (%)									
		Dry season					Wet season				
Species (N=29)	Family Distance (m)	20	40	60	80	100	20	40	60	80	100
Ajuga remota	Labiatae	NP	1.5	NP	NP	NP	9.4	NP	4.3	NP	NP
Alyscarpus rogusus	Fabaceae	8.3	7.7	NP	NP	3.1	0.9	3.3	6.4	1.2	3.2
Barleria acanthoides	Acanthaceae	NP	1.5	NP	2.9	NP	0.9	1.1	1.1	NP	1.1
Becium obovatum	Labiatae	NP	NP	NP	NP	1.5	1.9	2.2	2.1	1.1	13.8
Corchorus olitorius	Tiliaceae	NP	NP	2.2	NP	NP	NP	NP	NP	NP	NP
Crotolaria brevidens	Fabaceae	37.5	15.4	32.6	33.3	30.8	NP	NP	NP	1.2	NP
Crotolaria pycnostachya	Fabaceae	NP	1.5	NP	2.9	3.1	2.8	1.1	2.3	NP	NP
Dyschoriste radicans	Acanthaceae	1.4	12.3	10.9	7.3	6.2	NP	NP	3.2	NP	NP
Evolvulus alsinoides	Convulvulaceae	12.5	6.2	10.9	4.4	3.1	NP	1.1	NP	NP	NP
Euphorbia inequilatera	Euphorbiaceae	NP	1.5	NP	NP	NP	5.2	9.8	5.6	26.4	NP
Glycine wightii	Fabaceae	14.9	12.3	17.4	14.4	13.9	NP	1.1	1.1	NP	1.1
Hypoestes verticillaris	Acanthaceae	NP	1.5	NP	NP	NP	3.8	10.0	5.3	1.2	6.4
Indigofera brevicalyx	Fabaceae	5.6	1.5	2.2	15.9	4.6	1.4	NP	1.1	6.9	1.1
Indigofera spicata	Fabaceae	2.8	1.5	10	3.6	21.5	19.5	8.2	10.4	NP	22.3
Indigofera volkensii	Fabaceae	NP	26.7	NP	NP	1.5	19.5	14.4	23.4	NP	22.3
Ipomea mombassana	Convulvulaceae	NP	1.5	NP	NP	NP	NP	14.7	10.4	12.6	8.5
Launaea cornuta	Asteraceae	5.7	1.1	3.2	3.1	2.1	3.7	NP	4.2	19.5	10.6
Leucas martinicensis	Lamiaceae	1.4	NP	NP	NP	NP	2.8	2.2	4.2	9.2	4.2
Ocimum basilicum	Lamiaceae	NP	3.1	2.2	1.5	NP	5.6	1.1	1.1	3.4	2.1
Phyllanthus maderaspatensis	Phyllanthaceae	1.4	NP	NP	NP	NP	NP	3.3	NP	3.5	NP
Polygala sphenoptera	Polygalaceae	1.4	NP	NP	1.5	3.1	NP	NP	NP	NP	NP
Rhynchosia minima	Fabaceae	1.4	NP	NP	NP	NP	NP	3.3	NP	2.3	1.1
Ruellia patula	Acanthaceae	4.2	4.6	4.4	7.3	6.2	NP	3.3	NP	2.3	1.1
Senna mimosoides	Fabaceae	NP	NP	2.2	NP	NP	2.8	2.2	1.1	2.3	NP
Sida cuneifolia	Malvaceae	NP	3.1	NP	NP	NP	2.8	2.2	1.1	2.3	NP
Solanum incanum	Solanaceae	1.4	NP	NP	2.4	1.5	4.7	3.3	NP	NP	NP
Thunbergia alata	Acanthaceae	NP	1.5	2.2	NP	NP	12.3	12.1	11.7	4.4	NP
Thunbergia elliotii	Acanthaceae	NP	NP	NP	NP	NP	NP	NP	NP	NP	1.1
Vigna membranaceae	Fabaceae	NP	NP	2.2	1.5	NP	NP	NP	NP	NP	NP

NP= Not Present

5.2.2. Species diversity, richness and evenness

Plant species Shannon-Wiener diversity index, Species richness and Pielou evenness at various distances from the dam, the trough and the river are shown in Table 5.3. Interactions between various treatments and seasons are presented in Appendix 3. Shannon-Wiener's diversity index significantly increased (F=25.07, p=0.001) with piospheric distance, and was significantly different (F=10.05, p=0.001) between watering points, being (1.2±0.1) at 20m from river compared to a similar distance from the dam (0.9±0.1) and the trough (0.8±0.2). There was no significant difference (F=0.24, p=0.622) in Shannon-Wiener's diversity index between the wet and dry seasons. Moreover, the interactions between treatments (distance*season*watering point) were not significant (F=0.45, p=0.889).

Similarly, species richness (S) significantly increased (F=17.05, p=0.001) with distance from all the three watering points. Although higher species richness was observed at 20m from the river and the dam (4.5±0.5) compared to a similar distance from the trough (3.0±0.5), species richness was not significantly different between watering points (F=0.39, p=0.536), and seasons (F=3.25, p=0.780). Interactions between treatments (distance*season*watering point) were also not significant (F=0.34, p=0.950).

Pielou evenness significantly increased (F=7.47, p=0.001) with distance from the three watering points. However, Pielou evenness was not significantly different between watering points (F=3.05, p=0.052) but was higher at 20m near the dam (0.8±0.5) compared to a similar distance from trough (0.7±0.1) and the river (0.7±0.1). Species evenness was also not significantly different between the wet and dry seasons (F=0.24, p=0.629). Besides, there was no significant interactions between treatments (distance*season*watering point) (F=0.75, p=0.648).

Table 5. 3: Plant species Shannon-Wiener diversity index, richness and Pielou evenness (Mean ± SE) at various piospheric distances

		Dry season					Wet season				
Watering point	Distance (m)	20	40	60	80	100	20	40	60	80	100
Dam	Diversity	0.9±0.1a	1.2±0.1a	1.1±0.4a	1.5±0.1a	1.8±0.1a	0.7±0.1a	0.9±0.2ab	1.16±0.1bc	1.5±0.2cd	1.7±0.3d
	Richness	4.5±0.5a	5.5±1.1ab	6.5±0.3bc	7.3±0.5bc	8.0±0.0c	4.8±1.1a	5.6±0.8a	6.25±0.9a	7.0±0.7a	7.5±0.5a
	Evenness	0.8±0.5ab	0.8±0.1a	0.87±0.1ab	0.9±0.2ab	0.9±0.1b	0.8±0.1a	0.8±0.2a	0.84±0.2a	0.9±0.2a	0.9±0.1a
Trough	Diversity	0.8±0.2a	0.9±0.1a	1.3±0.2ab	1.3±0.1ab	1.6±0.3b	1.1±0.1a	1.4±0.2ab	1.5±0.1b	1.6±0.1b	1.7±0.1b
	Richness	3.0±0.5a	3.8±0.3ab	5.0±0.8ab	4.8±0.5ab	5.3±1.0b	4.3±0.5a	5.3±1.1a	5.8±0.8a	6.3±0.4a	6.5±0.7a
	Evenness	0.7±0.1a	0.7±0.1a	0.8±0.1ab	0.8±0.3ab	0.9±0.3b	0.7±0.1a	0.8±0.2b	0.9±0.1b	0.9±0.1b	0.9±0.1b
River	Diversity	1.2±0.1a	1.3±0.2ab	1.6±0.1bc	1.7±0.1c	1.9±0.8c	1.2±0.2a	1.3±0.1ab	1.6±0.1ab	1.6±0.1ab	1.7±0.9b
	Richness	4.5±0.5a	4.5±0.3a	4.3±1.1a	5.5±0.5ab	7.5±0.9b	3.0±0.4a	3.5±0.7ab	4.5±0.3bc	5.3±0.2bd	6.5±0.3d
	Evenness	0.7±0.1a	0.8±0.1a	0.7±0.2a	0.9±0.1a	0.9±0.1a	0.6±0.1a	0.8±0.04b	0.8±0.0b	0.9±0.1b	0.8±0.1b

Means with different letters in the same row are significantly different ($p \leq 0.05$)

5.3. Discussion

5.3.1. Species composition

More grass species were observed during the wet season compared to the dry season. This was because some of the ephemerals like *Setaria verticillata* were present only during the wet season. Ephemerals are grass species which regenerate immediately after the rains (Verdoodt *et al.*, 2010; Lugusa *et al.*, 2016), emerging where decreaser species have been depleted as a result of heavy grazing and are indicators of poor range condition (Oluwole *et al.*, 2012). *Eragrostis spp*, for instance, are increaser species, increasing in abundance where there is severe grazing that leads range degradation (Du Toit, 2009). These results corroborate with Egeru *et al. (*2015) who recorded thirty-four species during the wet season and twenty-six species during the dry season in Karamoja sub-region of Uganda. As reported by Sabiiti *et al. (*2004) and Machogu (2013), *Chloris, Hyperrhenia, Aristida and Sporobolus spp* are some of the most pronounced grasses in the East African rangelands due to their self-seeding ability, tolerance to drought and spreading capacity.

The results suggest that most grasses were more prevalent away from the watering points, while forbs were predominant near the watering points. This was probably because most grasses were decreaser species and therefore susceptible to grazing. *Aristida spp, Hyperrhenia spp, Bothriochloa spp, Themeda triandra* and *Setaria holstii* are decreaser species (Angassa, 2014). Grazing alters species composition within the rangeland ecosystems (Todd, 2006; Wu *et al.*, 2009). High grazing pressure reduces the density of palatable plants forcing the animals to forage on species of low nutrition value (Amiri *et al.,* 2008; Lalampaa *et al.*, 2016). As such, most preferred plant species cease to grow, giving way for the proliferation of forbs (Chaichi *et al.*, 2005 Loydi *et al.*, 2012). Similar observations were made by Hoshino *et al*. *(*2009) who reported that species composition changes along grazing gradients are characterized by changes in density and cover of life forms, and annual species and forbs replace perennial grasses near the watering points. The results are consistent with Mudongo *et al. (*2016) who observed that continuous grazing led to diminished perennial grass population and increase in forbs and woody species in the Kalahari rangelands of Botswana. Furthermore, the findings under this study corroborate with those of Mureithi *et al. (*2010) who reported a prevalence of forbs under heavy grazing in the Njemps Flats of Kenya. Similar observations were also made by Todd (2006) in Nama-Karoo rangelands of Southern Africa where forbs and annual grasses replaced perennial grasses due to heavy grazing near the watering points. *Cynodon dactylon* was however, more pronounced near the water points. This was because *Cynodon dactylon* can withstand heavy grazing, is extremely tolerant to fire and adapts to various climatic and edaphic conditions, in addition to being tolerant to both salinity and flooding (Rita *et al.*, 2012; Egeru *et al.*, 2015). In a related study in the Sonamarg area of the Kashmir Himalayas, Mir *et al. (*2015) also observed that the importance value index of *Cynodon dactylon* significantly increased during peak grazing seasons. *Cynodon dactylon, Chloris pycnothrix, Eragrostis tuneifolia, Sporobolus discosporus* and *Sporobolus discosporus* decreased with distance away from the watering points. These findings corroborate with the observations of Oluwole *et al. (*2008) and Mansour *et al. (*2012) who found out that *Cynodon dactylon, Sporobolus spp Eragrostis spp* increased near the watering points.

5.3.2. Species diversity, richness and evenness

Trampling and defoliation observed near the watering points could justify the significantly lower plant species diversity, richness and evenness. Due to higher animal concentration near the watering points, there was greater plant defoliation that hampered seed germination, plant growth and development. Besides, increased trampling slowed down plant regeneration upon grazing therefore reducing species richness and diversity. Further, hoof action could have led to soil compaction hindering infiltration of water and consequently low plant growth (Mapfumo *et al.*, 2000; Lalampaa *et al.*, 2016). As reported by Amiri *et al. (*2008), soil compaction also triggers depletion of soil organic matter, which hampers growth of plant species. Defoliation, excretion and seed dispersal by grazing animals influence plant diversity (Akhzari *et al.*, 2015). Animal excreta improve nutrient and water cycling which favors growth of palatable species and augment soil organic matter. This leads to fertile range soils that provide optimum condition for plant growth and improved rangeland health and productivity (Todd-Brown *et al.*, 2014). Light or moderate herbivory increases plant diversity (Akhzari *et al.*, 2015). Continuous grazing leads to overuse of forage. This reduces their quality and quantity particularly during the reproductive stage (Lalampaa *et al.*, 2016). Heavy herbivory has been known to result in death of species and repetitive reproductive failure (Landsberg *et al.*, 2003; Brooks *et al.*, 2006; Todd, 2006). Besides, overgrazing hampers seed germination and consequently inhibit plant growth and development (Maitima *et al.*, 2009). Further, high intensity grazing reduces vegetation cover, soil hydraulic conductivity and nutrients available to plants (Amiri *et al.*, 2008). These findings corroborate with those of Angassa (2014) who observed that 80% of herbaceous species exhibited a high vulnerability to grazing in the Borana region of Southern Ethiopia. Shahriary *et al. (*2012) also reported a decrease in species richness with increased grazing intensity around the watering points of Iran. Similarly, Socher *et al. (*2013), Meyers *et al. (*2014) and Haynes *et al. (*2016) also observed that heavy grazing reduces plant species diversity richness and evenness. Mureithi *et al. (*2014) also reported that diversity of herbaceous species abundance and richness was higher in areas mildly to moderately grazed areas compared to heavily grazed areas in North Western Kenya. Besides, Todd (2006), while conducting a similar study in the Nama-Karoo rangelands of

South Africa, observed that there were twice as many species further from the watering points as nearer the watering points.

No significant difference in plant diversity, richness and evenness was observed between seasons. This could be due to the fact that 18 out of the 22 grass species observed were perennials (Table5.1), and had lifespans of more than a season. The four annuals observed (*Chloris pycnothrix, Eragrostis tuneifolia, Eriochloa fatmensis* and *Setaria verticillata*) were not sufficient to produce a significant difference. Similarly, at least 25 out of the 29 forbs were observed during both dry and wet seasons (Table 5.2), with the exception of *Thunbergia elliotii* and *Polyghala sphenoptera* which were not recorded in the wet season and *Corchorus olitorius* and *Becium obovatum* which were not recorded in the dry season. The findings could be attributed to the fact the study area was mainly dominated by *Setaria holstii* and *Themeda triandra* (Table 1) which are perennial grasses. Most forbs observed were also perennial and survived for more than a season. Pre-dominance of perennial grasses during dry and wet seasons was also observed by Egeru *et al. (*2015) in Karamoja sub-region of Uganda. As noted by Kasale (2013) and Wesuls *et al. (*2013) perennial grasses possess a self-seeding characteristic, are tolerant to drought and have a spreading capacity that enable them develop good cover and hence survive both seasons.

Differences in landscape use led to significantly higher plant diversity being observed around the seasonal river compared to the dam and trough. It was observed that livestock grazed as they walked along the river thereby evenly distributing grazing pressure as opposed to around the dam and trough where animals concentrated around the same point. The river was long and therefore provided the grazing animals with a large surface area for foraging. This evenly distributed grazing pressure along the river reducing animal impact on vegetation, hence the higher species diversity. Similar results were observed by Egeru *et al.* (2015) in the Karamoja sub-region of Uganda who attributed the observations to varying use of landscape, watering point location and herder characteristics. The results further corroborate with those Hu *et al.* (2015) that herd movements impacted on species composition, diversity and richness.

5.4. Implications for management

The results from this study point to consistent and severe alterations in plant composition and diversity that are possibly attributable to the cumulative long-term consequences of watering point-concentrated grazing. The impact could potentially be greater, owing to the proliferation of watering points in the Kenyan rangelands as a water intervention measure. Range managers should therefore seek conservation measures that can sustainably protect forage species that are sensitive to grazing. Grazing exclusions have been known to preserve plant species composition in most rangelands of the world (Todd, 2006; Zarekia *et al.*, 2012). This is because these rest periods allow for plant regeneration and seed bank restoration after seasons of intense trampling and defoliation. Managers can therefore use watering points alternately to ensure that livestock use the selected ones while the others regenerate.

5.5. Conclusions and recommendations

The study demonstrated that areas near the watering points have been heavily grazed by animals thereby reducing plant species Shannon-Wiener diversity and richness. It is recommended that grazing animals be placed under strict monitoring to reduce the amount of time spent around the watering points. Range reseeding should also be done to rehabilitate the areas that are already degraded with the observed grazing tolerant species such as *Cynodon dactylon*.

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CHAPTER SIX

Effect of Watering points on Physio-Chemical Soil Properties in the Southern Rangelands of Kenya

Published, Journal of Ecological Processes, Springer:
https://ecologicalprocesses.springeropen.com/articles/10.1186/s13717-017-0082-8

Abstract

Water based interventions haphazardly introduced in the drylands of Kenya have led to the introduction of watering points as use concentration mounts. Not much is known about the effect of these watering points on soil physio-chemical properties, especially in the Kenyan rangelands. The government and other development agencies have created watering points aimed at curbing water shortages and sustaining livestock production. This study assessed the effect of watering points on soil physio-chemical characteristics in the southern rangelands of Kajiado, Kenya, in order to provide evidence based insights that will be useful in guiding future water interventions. Soil samples were collected within 0.25m^2 plots at 20 metre intervals along 100 metre transects from three watering points (a dam, a trough and a seasonal river). Two-way ANOVA was used to determine if there were significant differences in soil parameters between piospheric distances. Soil bulk density was significantly different between piospheric distances ($F=22.25$, $P=0.001$) and watering points ($F=13.10$, $P=0.002$), being highest at 20 metres from the trough (1.1-1.21gcm^{-3}) relative to a similar distance from the dam (1.01-1.20gcm^{-3}) and the river (1.1-1.17gcm^{-3}). On the other hand, mean soil aggregate stability significantly increased ($F=66.89$, $p=0.001$) with piospheric distance, being lowest at 20 metres from the trough (43.9-46.2%), the dam (43.1-48.9%) and the river (46.6-47.5%). High soil bulk density and consequent low soil porosity, hydraulic conductivity and moisture content demonstrated that compaction was high

near the watering points. It is recommended that livestock should be herded away from the watering points after drinking water to ensure that grazing livestock spend less time near the watering points if reduced soil compaction is to be realized. Watering points should also be better planned and placed at landscape level to exploit landscape heterogeneity.

Key words: Watering points, Grazing pressure, Bulk density, Hydraulic conductivity, Rangelands

6.0. Introduction

Watering points create an attenuating pattern of grazing as a result of concentrated activity around them thereby developing a unique source of analysis of range trend and condition distinct from other environmental factors (Brooks *et al.*, 2006; Todd, 2006). Several studies have revealed that watering points, created to curb water scarcity in most rangelands across the world have adverse effects on both soil and vegetation (Brooks *et al.*, 2006: Landman *et al.,* 2012; Shahriary *et al.,* 2012). Concentrated grazing around the watering points leads to excessive trampling leading to soil compaction, increased soil bulk density and reduced soil porosity (Gomez *et al.,* 2006; Stankovicova *et al.,* 2008). Reduced soil pore volume impedes percolation of water through the soil hence low soil moisture levels (Chaichi *et al.*, 2005). Compacted soils hamper air and water circulation, hinder root penetration into the soil and limit seed germination and seedling establishment in the rangelands (Amiri *et al.*, 2008; Azarnivand *et al.,* 2010). Grazing animals also alter soil nutrient and chemical composition through deposition resulting from urination and defecation (Shahriary *et al.,* 2012). Dung deposition influences soil organic carbon and total nitrogen concentrations (Han *et al.,* 2008; Ingram *et al.,* 2008) in addition to altering soil pH and soil microbial activity (Bell, 2010; Alaoui *et al.,* 2011).

Research has not conclusively established the effect of watering points on physical and chemical properties of the soil. Therefore, there is need for conclusive insights on the piospheric effect on soil physio-chemical characteristics because such information is useful in developing sustainable water interventions for improved water availability and increased productivity in the rangelands. The findings of this study will be very relevant in Kenyan rangelands where there is widespread introduction of watering points to alleviate water scarcity (Wahome *et al.*, 2014). Research on piospheric effect on soils has been done in parts of East Africa and Asia (Shahriary *et al.*, 2012; Egeru *et al.*, 2015). A study conducted by Egeru *et al. (*2015) in the Karamoja sub-region of Uganda showed low levels of nitrogen near the watering points. On the contrary, Shahriary *et al. (*2012) reported a high concentration of nitrogen near the watering points of Iran. The disparity observed in these findings could be because of the varying residence time spent by grazing animal around the watering points as a result of, among other factors, different grazing regimes (Sternberg, 2012; Egeru *et al.*, 2015), differences in watering point types and location which determine the patterns of landscape use by grazing animals (Egeru *et al.*, 2015) and differential response of various soil types upon exposure to grazing (Sun *et al.*, 2011; Schrama *et al.*, 2013). This study therefore sought to assess the effect of watering points on soil physical and chemical characteristics in the Southern rangelands of Kenya and their predisposing factors.

6.1. Materials and methods

6.1.1. Study area

The study was done in Kiserian, Kajiado County (Longitudes 36° 5″ and 37° 5″ East and Latitudes 10 ° ″ and 30 ° ″. The range of altitude in this County ranges between1580 and 2460 metres above sea level. The annual rainfall received ranges from 300mm to 1250 mm (Kareri, 2013). Rainfall is bimodally distributed. The long rains (first rains) fall between March and May whereas the short rains (second rains) are received from October to December (Ogutu et al. 2013). The minimum and maximum mean diurnal temperatures are 10^0c and 24^0c respectively (Krhoda 2002). The r/ET_0 is < 0.65 (Middleton and Thomas 1997). Kiserian is a semi-arid area found within agro-ecological zone IV. Soils are mainly vertisols, sticking when wet and forming large cracks during dry seasons (de Leeuw et al. 1991; Ombogo 2013). The most widespread plant species are *Acacia mellifera; Acacia tortilis, Acacia nubica, Acacia ancistroclada, Acacia nilotica, Commiphora riparia, Commiphora africana* and *Balanites aegyptiaca* are the most common species (Bekure 1991).

6.1.2. Research design

A randomized block design was used for soil sampling. The four watering points formed the blocks while sampling plots were the distances (20m, 40m, 60m, 80m and 100m) from water points. Soil samples were obtained within 0.5 m x 0.5 m quadrats placed at the sampling plots, each with with four replications in the North, East, West and South directions. (See a detailed research design in Chapter Five)

6.1.3. Soil sampling and laboratory analysis

Both disturbed and undisturbed soil samples were collected for analysis. Disturbed soil samples were collected using a 600cm^3 soil auger at a depth of 20cm. Four samples were taken from the corners and centre of each quadrat and then mixed in a bucket to form a composite sample for each replication. These composites were divided into four segments where one segment was picked to form a representative sub-sample of 125g. This procedure was repeated for all replications until a representative sample of 500g was obtained. These four representative samples were air-dried at room temperature for 72 hours, ground and sieved through 2mm mesh to remove plant roots, stones and organic residues. These samples were used for texture and pH determination. For texture and pH determination a 2mm sieve was used because soil samples >2g were required for analysis. Further sieving was done using a 0.5mm sieve. This was to enhance soil sample homogeneity since <2g of the soil sample was required for analysis (Bremner and Mulvaney, 1982; Buresh *et al.*, 1982). The samples obtained were used for organic carbon and total nitrogen determination. Undisturbed soil samples were obtained at the same depth using steel core rings for bulk density, porosity and saturated hydraulic conductivity determination.

Soil Organic Carbon concentration was determined using Walkley-Black wet oxidation method as described by Nelson and Sommers (1982), while total nitrogen was determined using Kjeldahl digestion method (Bremner and Mulvaney, 1982). Bulk density was estimated using the core method after oven drying the soil at 105^0c for 48 hours (Blake, 1965; McKenzie *et al.*, 2004), and was calculated by dividing the mass of dry weight of soil (g) by the soil volume (cm^3). From the bulk density values obtained, porosity was calculated in accordance with Flint and Flint (2002) using the formula $1 - \frac{\rho_b}{\rho_S}$ where, ρ_b is bulk density and ρ_s the particle density taken as 2.65 g $cm-^3$. Particle size distribution was analyzed using the hydrometer method after dispersing the soil and eliminating organic matter (Day, 1965), and pH-H_2O (ratio 1:2.5) by a pH meter (Mclean, 1982). Aggregate stability was determined by the wet sieving method while soil moisture content was determined by gravimetric method. Saturated soil hydraulic conductivity was determined by the constant head permeameter described by Reynolds and Elrick (2002) based on application of Darcy equation. A hydraulic head difference was imposed on the soil column and the resulting flux of water measured.

$$Conductivity = \frac{V.L}{A.T.H}, \text{ where}$$

V= Volume of water (Q) that flows through the sample of cross sectional area (A) in time T and H is the hydraulic head difference imposed across a sample length (L).

6.1.4. Statistical analysis

Statistical analyses for soil parameters were performed using GenStat 15th edition. Two- way ANOVA was used to determine if there were significant differences between means of various treatments and seasons. Tukey's HSD test was used to separate the means. Significance was obtained at $p \leq 0.05$.

6.2. Results and discussion

6.2.1. Soil bulk density

Table 6.1 shows soil bulk density, per cent porosity, saturated hydraulic conductivity, per cent aggregate stability, and per cent soil moisture content at various distances from the dam, the trough and the seasonal river. Interactions between various treatments and seasons are presented in appendix 4. Soil bulk density significantly decreased (F=25.07, p=0.001) with piospheric distance and was significantly different (F=13.10, p=0.002) between watering points. Troughs were smaller in size compared to the dam and therefore, the surface area available for grazing animals was reduced leading to greater compaction. Due to the fact that the main soil type was vertisols, bulk density was significantly different between seasons (F=5.92, p=0.035), being higher during the wet season as a result of greater compaction. During the dry season vertisols become hard and crack, making it difficult to compact even under heavy grazing. The interactions between treatments (distance*season*watering point) were, however, not significant (F=0.52, p=0.818).

The results demonstrate greater compaction around zones of high intensity grazing. Arnhold *et al. (*2015) observed increased soil bulk densities in areas where high intensity grazing was applied in the Lambwe Valley of Kenya. Similarly, Shahriary *et al. (*2012) and Egeru *et al. (*2014) reported increased trampling and soil compaction around the watering points of Iran and Uganda, respectively. The findings of this study also corroborate with those of Smet and Ward (2006) who reported high soil compaction levels around South African watering points

6.2.2. Saturated hydraulic conductivity and soil moisture content

Saturated hydraulic conductivity significantly increased (F=1084.51, p<0.001) with piospheric distance, being higher away from the watering points. This could be attributed to high compaction levels that reduced soil porosity inhibiting percolation of water into the soil, further exacerbated by high animal trampling which reduced plant cover and exposed the soil to solar radiation triggering moisture loss through evaporation. No significant difference was observed in saturated hydraulic conductivity between the watering points (F=2.53, p=0.294) and seasons (F=1.07, p=0.326). The interactions between treatments (distance*season*watering point) were also not significant (F=0.60, p=0.762). Due to the low infiltration near the watering points, soil moisture content was significantly lower (F=16.94, p<0.01) near the watering points. No significant difference (F=0.26, p=0.618) was observed in soil moisture content between watering points. Higher rainfall during the wet season increased moisture input into the soil as compared to the dry season. Consequently, soil moisture content was significantly higher (F=256.76, p<0.001) during the wet season. The interactions between treatments were not significant (F=1.57, P=0.247).

These findings corroborate with those of Zhang *et al. (*2006) and Azarnivand *et al. (*2010) that high soil compaction reduced water infiltration in the loess soils of China and the rangelands of Hosainabad, respectively. Amiri *et al. (*2008) also observed higher soil moisture content in light and moderately grazed lands compared to areas under heavy grazing intensity in the rangelands of Isfahan.

6.2.3. Soil aggregate stability

Soil aggregate stability significantly increased ($F=66.89$, $p<0.001$) with piospheric distance, though there was no significant difference ($F=3.43$, $p=0.073$) between watering points. Because the soil class type was mainly sandy clay loam, soils were highly disintegrated during the wet season when sticky compared to dry season when they were hard and cracking. The aggregate stability of the soils was thus therefore significantly lower during the wet season ($F=698.41$, $p<0.001$). The interactions between treatments (distance*season*watering point) were not significant ($F=1.55$, $p=0.254$).

Heavy grazing reduces soil aggregate stability due to high compaction. Animal trampling reduces plant cover thereby exposing the soil to direct raindrops which disintegrate soil particles (Wasonga 2009; Mugerwa and Zziwa 2014). This could be the probable reason for the low aggregate stability observed near the watering points. Alphayo (2015) also observed low soil aggregate stability under high intensity grazing in Laikipia County, Kenya. Similarly, Azarnivand *et al. (*2010) and Curran (2010) reported low soil aggregate stability under heavy grazing compared Hosainabad and Otago rangelands respectively.

Table 6. 1: Soil bulk density, porosity, hydraulic conductivity, aggregate stability and moisture content at various piospheric distances

		Wet season					Dry season				
Watering point	Distance(m)	BD(gcm^3)	%Porosity	K-Sat	% SA	%MC	BD(gcm^3)	Porosity	K-sat	~~%~~SA	%MC
Dam	20	1.20b	55.84a	0.04a	43.05a	20.90a	1.09c	58.86a	0.05a	48.86a	18.90a
	40	1.07ab	59.24ab	0.07a	46.52ab	25.40ab	1.06bc	60.00ab	0.07a	50.00a	21.10a
	60	1.05ab	60.00b	0.13b	50.30bc	25.80b	1.06ab	60.00ab	0.11ab	46.17a	19.60a
	80	1.02a	60.37bc	0.13b	50.81c	26.20bc	1.05ab	60.37b	0.12b	50.37a	20.40a
	100	1.01a	61.13c	0.33c	51.80d	30.70c	1.03a	61.13c	0.29c	51.13a	20.60a
Trough	20	1.23c	53.66a	0.11a	43.92a	18.40a	1.19c	56.23a	0.11a	46.23a	11.60a
	40	1.19bc	55.09ab	0.13a	44.53a	21.90ab	1.16bc	56.43ab	0.12a	46.42a	11.90a
	60	1.16ab	56.41b	0.19b	50.31b	24.20b	1.14bc	57.17b	0.20a	47.17ab	12.60ab
	80	1.09ab	58.87bc	0.94c	50.31b	26.10bc	1.11b	58.11bc	0.89b	48.11ab	12.80ab
	100	1.07a	59.81c	5.15d	56.98c	31.80c	0.96a	63.96c	4.68c	53.96b	16.50b
River	20	1.17c	54.72a	0.03a	47.54a	20.10a	1.2d	56.61a	0.02a	46.61a	11.50a
	40	1.08ab	59.62ab	0.11ab	48.89ab	21.20a	1.07c	59.64b	0.11a	49.64b	11.60a
	60	1.06b	60.37b	0.39b	49.25bc	22.60ab	1.02b	61.52bc	0.37a	51.52bc	11.90a
	80	1.05b	61.51bc	4.64c	50.87c	23.10b	1.01b	61.89bc	4.68b	51.89bc	12.60ab
	100	1.00a	61.89c	5.81d	55.85d	25.10c	0.89a	66.41c	5.92c	56.41c	13.70b
	LSD	0.05	2.04	3.17	3.74	5.54	0.82	2.93	2.17	3.87	6.95

Means with the same letters within a column are not significantly different ($p \leq 0.05$)

Key: BD= Soil bulk density; K-sat= saturated hydraulic conductivity; %SA= Soil aggregate stability; %MC= Soil moisture content

6.2.4. Soil textural characteristics

Table 6.2 shows soil textural characteristics, soil organic carbon, total nitrogen and pH at various distances from the dam, the trough and the river. The soil textural class was sandy clay loam across all the watering points. Sand content was higher near the watering points although the difference between piospheric distances was not significant (F=2.73, p=0.090). Besides, the difference in sand content was not significantly different between watering points (F=1.79. p=0.217) and seasons (F=0.86, p=0.574). The interactions between treatments (distance*season*watering point) were also not significant (F=0.01, p=1.000).

Clay content significantly increased (F=14.43, p<0.001) with distance from the watering points. The difference observed in clay content was however neither significant between watering points (F=0.38, p=0.557) nor seasons (F=0.01, p=1.000). The interactions between the various treatments (distance*season*watering point) were also not significant (F=0.01, p=1.000).

The high sand content near the watering points could be attributed to increased degradation around the watering points that exposed the soil to erosion. Fine particles of clay and silt were thus carried off by either wind or water erosion, justifying the significantly higher clay content observed away from these watering points. Similar observations were made by Al-Seekh *et al. (*2009) who reported higher percentage of sand in grazed areas compared to un-grazed and mildly grazed sites in the rangelands of Hebron in Palestine. Pei *et al. (*2008) also observed higher sand content in degraded rangelands relative to enclosures in Palestine. In addition, Mohammed (2000) reported that overgrazing in the southern West Bank resulted in severe soil erosion that caused the soil to lose its silt and clay and increase sand content.

6.2.5. Soil organic carbon and total nitrogen

A significantly higher ($F=17.24$, $p<0.001$) soil organic carbon was recorded near the watering points, being highest at a piospheric distance of 20 m. There was however, no significant difference in soil organic carbon between watering points ($F=0.77$, $p=0.489$) and seasons ($F=0.95$, $p=0.520$). Moreover, the interactions between treatments (distance*season*watering point) were not significant ($F=1.38$, $p=0.309$).

Similarly, total nitrogen significantly decreased ($F=3.90$, $p=0.037$) with piospheric distance. No significant difference was however observed in total nitrogen between watering points ($F=0.74$, $p=0.503$), seasons ($F=3.55$, $p=0.089$), and the interactions between the treatments of distance*season*watering point ($F=0.73$, $p=0.663$).

It was observed that grazing livestock spent more time near the watering points. As such, defecation and urination by these animals could have enhanced nutrient deposition and accumulation leading to soil organic carbon and nitrogen augmentation. Stump (2005) witnessed high dung deposits around the Mongolian watering points. Smet and Ward (2006) and Shahriary *et al. (*2012) also reported high soil organic carbon and total nitrogen around the watering points of South Africa and Iran, respectively. Egeru *et al. (*2015) also observed high total nitrogen near the watering points of Karamoja, Uganda.

6.2.6. Soil pH

Soil pH significantly decreased ($F=12.69$, $p=0.001$) with piospheric distance. No significant difference was however observed in soil pH between watering points ($F=0.46$, $p=0.874$), seasons ($F=0.01$, $p=1.000$), and the interactions between the treatments of distance*season*watering point ($F=0.01$, $p=1.000$).

High compaction near the watering points reduced infiltration which might have hampered nutrient leaching to the lower horizons of the soil profile. According to Beukes and Ellis (2003), sodium and calcium ions accumulate at the soil surface when leaching is hindered, leading to increased soil pH. This could have been the possible reason for the significantly higher soil pH observed near the watering points. Al-Seekh *et al. (*2009) also observed high soil pH in high intensity grazing areas in the West Bank rangelands of Pakistan. Similarly, Smet and Ward (2006) and Egeru *et al. (*2015) reported high soil pH near the watering points of South Africa and Karamoja, Uganda, respectively. Further, Shahriary *et al. (*2012) witnessed a decreasing trend in soil pH from Iranian watering points.

Table 6. 2: Soil textural properties, organic carbon, nitrogen and pH at various piospheric distances

		Wet Season						Dry season					
Watering point	Distance(m)	% Sand	% Clay	% Silt	% OC	% N	pH	%Sand	% Clay	% Silt	% OC	% N	pH
Dam	20	65.40c	28.50a	6.10a	2.92d	0.35b	6.46b	64.60c	28.62a	6.78a	3.01d	0.36b	6.42b
	40	62.80b	32.50ab	4.70a	2.74cd	0.33ab	6.03b	62.84bc	32.57ab	4.59a	2.69cd	0.31ab	6.04b
	60	62.60b	34.50bc	2.90a	2.58bc	0.24ab	5.85ab	62.71bc	34.29bc	3.01a	2.54cd	0.21a	5.88ab
	80	62.60b	34.50bc	2.90a	2.56ab	0.14ab	5.85ab	61.90b	34.51bc	3.59a	2.59bc	0.21a	5.72a
	100	55.80a	36.50c	7.70a	2.43a	0.09a	5.75a	55.80a	36.50c	7.71a	2.33ab	0.21a	5.66a
Trough	20	61.50b	29.50a	9.01a	3.21d	0.43c	6.32b	61.50b	32.50a	6.01a	3.14d	0.37b	6.43b
	40	60.40b	31.60ab	8.02a	3.21d	0.26b	6.07ab	61.21b	34.60ab	4.19a	3.07cd	0.33ab	6.08b
	60	58.70ab	34.30bc	7.01a	3.15cd	0.23ab	5.92ab	58.75ab	35.32bc	5.93a	2.96bc	0.25ab	5.94ab
	80	57.64ab	35.20bc	7.16a	2.98ab	0.22ab	5.88ab	57.37ab	38.50bc	4.13a	2.89ab	0.20a	5.89a
	100	55.82a	36.90c	7.28a	2.92a	0.19a	5.71a	55.72a	40.50c	3.67a	2.85a	0.18a	5.76a
River	20	64.92c	28.60a	9.80a	3.42c	0.23ab	6.37b	64.92c	26.50a	8.58a	3.24d	0.25b	6.26c
	40	63.21c	29.50a	7.19a	3.02bc	0.23ab	6.05b	61.21bc	29.50ab	9.28a	2.91cd	0.24b	6.03b
	60	60.30bc	32.10b	9.29a	2.92ab	0.22ab	5.87ab	59.89bc	32.10bc	9.01a	2.88bc	0.21a	5.93ab
	80	58.5b	32.50bc	9.10a	2.53ab	0.21a	5.81a	57.90b	32.50bc	9.60a	2.61ab	0.23a	5.85a
	100	54.70a	35.50c	9.80a	2.28a	0.21a	5.69a	54.81a	35.46c	10.69a	2.41a	0.19a	5.82a
	LSD	7.15	6.02	5.33	0.66	0.16	0.33	5.51	4.2	4.79	0.28	0.04	0.27

Means with the same letters within the same column are not significantly different (p≤0.05; Soil Textural Class= Sandy Clay Loam

Key: OC=Soil organic carbon; N= Total Nitrogen

6.3. Conclusion and recommendations

The high soil compaction around the watering points resulted in high soil bulk density and reduced soil porosity. Consequently, soil hydraulic conductivity was hampered, reducing soil moisture content. Bare grounds near the watering points further exposed the soil to impact of raindrops, decreasing soil aggregate stability and making the soils vulnerable to erosion. This could have been the reason sand content was higher near the watering points, because the fine clay and silt particles had been carried off by either water or wind. It is recommended that that grazing animals be placed under strict monitoring to reduce the amount of time spent around the watering points and minimize soil compaction. Alternatively, watering points should be strategically planned in consideration of range condition and need in order to avert further degradation of the environment.

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CHAPTER SEVEN

GENERAL DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

7.1. General discussions

This study revealed that WRUAs promoted better access to water for residents at more affordable costs. This was attributed to the fact that the WRUA members had a higher chance of access to water conservation information compared to non-members. Vital conservation practices, among them tree planting and river pegging had also been started by the Kiserian WRUA in order to restore the catchment. Despite the efforts, WRUAs face shortage of funding for its activities and are unable to meet their conservation objectives. Further, duplication of roles, community hostility and low literacy levels of its members and the general public have thwarted the conservation efforts. Water provision and affordability are vital if sustainable livestock and wildlife production in the southern rangelands of Kenya is to be realized. Empowering Water Resource Users' Associations in the rangelands will facilitate development of locally suited environmental conservation strategies that will reduce land degradation and enhance access to water.

Watering points introduced to curb water scarcity adversely affects the range ecosystems. This study demonstrates that grazing around watering points resulted in animal trampling which reduced species diversity and richness. Degradation around watering points led to increase in forbs and increaser species like *Glycine wightii* and *Eragrostis tuneifolia*, and reduced the perennial grasses. The high soil compaction around the watering points resulted in high soil bulk density and reduced soil porosity such as *Setaria holstii* and Themeda triandra. Consequently, soil hydraulic conductivity was reduced hence reduced soil moisture content. The bare grounds near the watering points further exposed the soil to impact of raindrops, decreasing soil aggregate stability and making the soils vulnerable to erosion. This could have been the reason sand content was higher near the watering points where fine clay and silt particles had been carried off by either water or wind.

7.2. Conclusions

This study generated various conclusions that are useful in enhancing community based water resource conservation and improving water interventions through introduction of watering points;

- Funding is the main challenge facing the Kiserian WRUA. Inadequate funding has made it difficult for the WRUA to carry out projects aimed at conserving the Kiserian catchment.
- Species diversity, richness and evenness were lowest near watering points. Perennial grasses have also been replaced by annual grasses and forbs, signifying great degradation around the watering points.
- Soil compaction was highest near watering points. Consequently, soil bulk density was high, while soil moisture content, aggregate stability and hydraulic conductivity were low.

7.3. Recommendations

This study recommends the following;

- Both national and county governments should increase funding to Kiserian WRUA to enhance catchment protection activities. The WRUA should also develop funding proposals and present to development partners in order to broaden its financial base.

- Rest periods should be implemented by range managers. Alternate use of grazing areas will allow the depleted pastures to regenerate while animals graze the other areas. Besides, degraded areas should also be reseeded by the management of these rangelands to facilitate rehabilitation and improvement of range condition.
- Grazing animals should be properly herded by the pastoralists to minimize concentration around watering points and reduce soil compaction. This will ensure that the range is utilized optimally and degradation minimized.

7.4. Implications for management

The findings of this study showed a consistent degradation and changes in plant composition, plant diversity and soil characteristics that could be attributable to cumulative effects of concentrated grazing around the watering points. With increased use of watering points as a water intervention strategy, this degradation and adverse ecological effects could proliferate. Rangeland managers in these areas should therefore institute measures including, rest periods, herding and stocking rate control, range reseeding and adoption of fewer but larger watering points, among other methods. These interventions will aid in reducing animal impact around these watering points while allowing regeneration of vegetation and soils in already degraded areas.

APPENDICES

Appendix 1: Questionnaire

INTRODUCTION

My name is Stanley Jawuoro, a student from the University of Nairobi. As a requirement for my Master's degree in Range Management, I am conducting a study on water user groups found in this area. The survey is voluntary and you can choose not to take part. The information that you give will be confidential and will be used for academic purposes only; it will not include any specific names. Could you please spare 15-20 minutes for the interview and kindly answer the following questions.

WATER USERS QUESTIONNAIRE

1. General information QUESTIONNAIRE NO:-------------

1.1 Date of interview……..../…..…/…….... Name of enumerator………………………………...
1.2 Name of respondent……………………….…..Sex: 1) Male….…… 2) Female…………..
1.3 County……………………. Sub-County………………….. Division…………..…………. Location………………..… Sub-location……………..………….
1.4 Phone number of respondent…………….…………………………………………………
1.5 Age……………………………………………
1.6 Education: 1) None…..…2)Primary……… 3) Secondary…...…4) Post-Secondary……….
1.7 MAIN source of livelihood: 1) Pastoralism… 2). Ranching…..3) Crop cultivation…. 4) Business…..5) Charcoals burning…. 6) Formal employment… 7) Bee keeping……… 8) Remittances from relatives…….
1.8 What is the average monthly income amount from all your income generating activities? Please fill in the table below:

Source of income	Amount (Kshs.)

1.9. How long have you stayed in this area? .... Years

2.0. Water Access and cost

2.1. Have you ever experienced water shortages? 1) Yes………… 0) No…………..
2.2. What type of water sources exist in this area? 1) Borehole…… 2) Tap/piped………………. 3). Rain water……………..4) Surface dam…….. 5) Others (specify)………..
2.3. How long does it take you to reach the water point from your household?

Code	Range of time (Tick as appropriate)
1	0-15 minutes
2	16-30 minutes
4	31-45 minutes
4	46-60 minutes
5	>1 hour

2.4. What is the current price paid per a 20L gallon of water? ………………..Kshs.
2.5. How much water (In litres) are you able to access daily? ....
2.6. What is the estimated total household water consumption in a day? …………….Litres
2.7. How do you rate the quality of water that you use? 1) Very poor……2) poor…..

3) Good……… 4) Very good…….. 5) Excellent………..
2.8. What is the mode of access to water resources 1) Open………………..2) restricted………
2.8.1. If restricted, what is the basis for restriction 1) Clan…..2) Number of livestock owned……..3) Membership to the association…………4) Season (wet or dry)……….. 5) Payment …………6). Quota……6) Others (Specify)..

3.0. Water Users' Association Information

3.1. What is your main use of water? 1) Crop farming………2) Ranching……..3) Pastoralism………4) Domestic use……5) Business ……….. 6) Car wash…….7) Construction…………

3.1. Are you a member of the Kiserian Water Resource Users' Association? 1). Yes…… 0) No…….. (If NO, proceed to 3.3)

3.2. How long have you been a member of this association? 1) < 1 year 2) Between 2-5 years 3) > 5-10 years 4) >10 years

3.2.1. What is the total number of members in the association? .... 1) Adult males……… 2) Adult females………. 3) Male youth…… 4) .Female youth…..5). Civic/ religious leaders ……………….. 5).WRMA officials…….

3. 2.2.Does your association have a constitution? 1). Yes…………0) No…….

3.2.3. Do you hold annual general meetings? 1) Yes………..0) No……………

3.2.4. If yes, when was the last A.G.M you attended held? ....

3.2.5. How often are meetings on water conservation/management held? 1). Weekly…….2) fortnightly………. 3).Monthly………… 4) Annually………….. 5.) Others…………

3.2.6. How are your leaders determined? 1) Appointed………2) elected……..3) consensus…….4).

Others (specify)……………………………………..
3.2.7. What is the term for the office bearers (in years)? ....

3.2.8. Do you have access to official documents of the association? 1) Yes………. 0) No…….

3.2.9. What is the reason(s) that motivated you to join the association? ……………………………...

3.2.10. What are the benefits of belonging to the group? Please list and rank them in the table below:

Benefits	Rank (1=Most important, 2, 3………)

3.2.11. What are some of the challenges that you face as members of this association? ....

3.2.12. Please rate the overall performance of your association 1) Very poor………2) Poor……3) Good……4) Very good……….

3.2.13. How do you think the performance of this association can be improved? ....

3.3. Are there specified roles for each household/ group towards the maintenance/management of the catchment? 1) Yes…….0) No……….

3.3.1. If yes, kindly tick in the boxes below the type of management/ conservation activity that this association has participated in

Activity	Tick as appropriate
Building of terraces	
Regulating livestock numbers	
Planting of trees	
De-siting	
River pegging	
Paying maintenance fee	
Others (specify)	

4.0. Capacity building:

4.1. Do you ever get any information on water and resource management? 1) Yes…………… 0) No……………………….

4.1.1. If YES, what kind of information and from which sources? Please fill in the table below:

Type of information	Main source *[1=NGOs, 2=Other farmers, 3=Ministry of water, 4=other……………..]*	Information delivery channel *[1=Radio, 2=Extension workers, 3=Newspaper, 4= TV, 5=Other farmer, 6=Other(Local leaders))------------]*
Number of livestock to be owned		
Livestock wildlife interactions		
Climate change		
Rain water harvesting		
Other (Specify)--------		

4.2 Do you get any support to improve your management of water resources? 1) Yes…….……. 0) No……………..

4.2.1. If YES, please provide the following information:

Type of support	Source of support	Frequency	Service delivery

Codes for service delivery: 1) very poor 2) poor 3) good 4) very good.

4.1. Did you get any kind of training to sharpen your management skills? 1) Yes…….. 0) No……..

4.2. IF YES, please provide the following information:

Type of training	When (year)?	Provider of training	Amount paid

_THANK YOU FOR YOUR TIME

Appendix 2: Daily water demand, supply and cost

	WRUA members		Non-WRUA members	
Variable	Mean	Std. deviation	Mean	Std. deviation
Daily household water demand(m^3)	0.17	0.1	0.23	0.1
Daily household water supply(m^3)	0.15	0.1	0.2	0.1
Price per 20L gallon of water(Kshs)	11.3	4.6	12.6	5.4

Appendix 3: ANOVA of vegetation attributes under different treatments and seasons

	Diversity	Richness	Evenness
Distance	<0.001	<0.001	<0.001
Season	0.622	0.780	0.629
Watering point	<0.001	0.536	0.052
Distance* Season	0.985	0.363	0.978
Distance* Watering point	0.784	0.432	0.574
Season*Watering point	0.081	0.057	0.392
Distance*Season* Watering point	0.889	0.949	0.065

Significance obtained at ($p \leq 0.05$)

Appendix 4: ANOVA of soil physio-chemical properties under different treatments and seasons

	Distance	Season	Distance*Season	Watering point
Bulk density(g/cm3)	<0.001	0.08	0.544	0.002
Hydraulic Conductivity(cm/hr)	<0.001	0.92	1	0.294
% Moisture content	<0.001	<0.001	0.472	0.618
% Aggregate stability	<0.001	0.001	0.561	0.073
%Sand	0.90	0.574	1	0.217
%Clay	<0.001	1	1	0.557
%OC	<0.001	0.520	0.97	0.489
%N	0.04	0.089	0.246	0.503
pH	0.001	1	1	0.874

Significance obtained at ($p \leq 0.05$)