DRIVERS AND EFFECTS OF GULLY EROSION ON COMMUNITIES IN SUSWA CATCHMENT, NAROK COUNTY, KENYA: A GEOSPATIAL APPROACH

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Declaration

I Charity N. Konana do declare that this thesis and its content is my original work and that to the best of my knowledge, it contains no materials previously accepted for any academic award of any other institution of higher learning. Where the works by other scholars have been used due acknowledgement has been made in the text. With approval of my supervisors, I submit this thesis to the Board of Postgraduate Studies for the award of degree of Doctor of Philosophy in Dryland Resources Management.

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Dedication

This work is dedicated to my family which have been a great source of support during my entire study. To my parents-Simon and Lois Konana and siblings- Olive, Victor and Cynthia. THANK YOU.

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ABBREVIATION AND ACRONYMS

ASALs: Arid and Semi Arid Areas

ERMIS: Environmental Resource Mapping and Information Systems

FAO: Food and Agriculture Organization

GEF: Global Environmental Facility

GPS: Global positioning systems

KALRO: Kenya Agricultural and Livestock Research Organization

LULCC: Land Use and Land Cover Change

NEMA: National Environment Management Authority

NGO: Non-governmental Organizations

NRM: Natural Resource Management

PGIS: Participatory Geographic Information Systems

RS: Remote Sensing

SLM: Sustainable Land Management

UNDP: United Nations Development Programme

UON: University of Nairobi

USAID: United States Agency for International Development

Abstract

Soil erosion is a serious issue in Arid and Semi-Arid lands and affects community livelihoods and soil conservation efforts. This study was undertaken in Suswa Catchment, Narok County. The objective of the study was to assess land use and land cover changes(1985-2011) using satellite images, to establish the drivers of gully formation and development using participatory geographic information systems (PGIS) and also to determine the effect of gully erosion on the livelihoods of the local community.

Land use and land cover change detection was established using ENVI Ex software. Changes in land use and land cover changes were determined using remote sensing and participatory geographic information systems (PGIS). Chi-square was used to determine if there were significant changes in land use and land cover changes. A questionnaire was used to investigate the effect of gully erosion on livelihoods (movement, infrastructure, livestock and farming practices). Chi-square goodness of fit was used to determine if there were significant effects on livelihoods.

Results using satellite images showed that there were no significant changes in built up areas, agricultural land, bareland, grassland and shrubland during the period. It was however observed that the overall change of built up area, shrubland, bareland, agricultural land increased over the 26 years (1985-2011) period, while grassland decreased during the same period. Grasslands were therefore converted to build up areas, shrubland, bareland and agricultural areas during this period. An increase in built up area, bareland and agricultural land and a decrease in grassland are therefore likely drivers of gully erosion which is affecting the area. It was observed through PGIS that there were significant changes in shrubland which decreased in Eluai village and no significant changes in built up areas, bareland, agricultural land, waterbodies, grassland and shrubland in the three villages (Enkiloriti, Olepolos and Olesharo). PGIS therefore agrees with satellite images that a decrease in grassland was a driver of gully erosion in the study area.

Results using the questionnaire showed that the effect of gully erosion on household activities differed significantly between the villages. This could be due to the fact that houses near the gully were the most affected by runoff. The effect of gully erosion on farming, livestock, level of income, water availability, firewood collection, building materials, health and mosquito breeding did not differ significantly between the four villages. This is because the effect on the mentioned livelihood activities was more or less the same in the 4 villages. There is urgent need to address gully erosion in order to safeguard community livelihoods and soil conservation in the catchment. A comprehensive land use plan needs to be developed in Suswa Catchment for effective rehabilitation of the gully and also reduce threats to livelihoods. Early warning signs of erosion particularly in highly prone areas should be emphasized. Community members also need capacity building particularly in the adoption of soil conservation measures in order to minimize the negative effects on their livelihoods.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Gully erosion is a process whereby runoff water accumulates over short periods, and removes the soil to considerable depths (Poesena *et al*., 2003). Globally, about 1.1 billion has erosion (Pathak *et al*., 2006). It is estimated that 80% of degradation on agricultural land has soil erosionr (Sharda *et al*., 2012). Erosion by water is a primary agent of soil degradation at the global scale, affecting about 1094 million hectares, or roughly 56% of the land experiencing human induced degradation (Nasri *et al*., 2009). The United Nations Environmental Program reported that crop productivity is reduced by about 20 million ha/year due to soil erosion and degradation (Lim *et al*., 2005). In Iran, soil erosion rates in agricultural lands vary between 7.6 and 32 ton/ha/yr and 4.3–22 ton/ha/yr in rangelands (Samani *et al.,* 2009). Research conducted in Imo, Abia and Anambra States, Nigeria shows that gully erosion generate between 4.2 and 10 m^3/ha/year of sediments, which constitute about 45–90% of sediment is from agriculture (Ogbonna *et al.,* 2011). Gully erosion contributes to 50% to 80% of overall sediment production in drylands (Ogbonna *et al.,* 2011). Global sediment yields constitute 12.1 in Ethiopia, 3.4 Kenya, 32 Niger, 16.1 Portugal, 64.9 Spain and 36.8 ton/ ha/yr in the USA (Frankl, 2012), hence affecting large areas that could have been put to productive use.

According to Van-Camp *et al*., (2004) soil erosion is 6.7 million ha in Romania, 4.8 million ha min Bulgaria, Poland and 4.7 million ha in Poland and 3.8 million ha in Hungary. Current rates of soil erosion documented in Ethiopia range from 16-300 tons/ha/year (Itanna *et al.,* 2011). Soil loss of more than 1 t/ha/yr is irreversible at 50-100 years (Van-Camp *et al.,* 2004). In Africa 29 million ha of land has gullies (Pathak *et al*., 2006). It is estimated that cultivated and degraded land generates 10–20 times more runoff than do forests; thus, expanding cultivation can accelerate soil degradation unless the land is well managed (Moges *et al.,* 2009). Gully development is believed to spread from upslope to downslope, and the rate of soil loss has been estimated to range from 11 to 30 t/ ha/yr in Ethiopia (Moges *et al.*, 2009) through gully erosion. According to Kodiwo *et al.,* (2013), 23 and 8 per cent of the total land area in Kenya is severely and very severely degraded respectively. Gully erosion is more often linked to the vulnerability of the landscape and the land use/cover changes (Frankl *et al*., 2011).

The driving forces of soil erosion are physical, ecological, social and economic (Van-Camp *et al.*, 2004). Soil erosion is driven by the forces of climate (energy of wind and rainfall), and also when vegetation and upper soil horizons have their storage and regulation functions impaired or diminished under the influence of human actions. Pollution, cultivation and land leveling lead to loss of the capacity of the soil and its ecosystem. According to Van-Camp *et al.,* (2004) the driving forces for erosion include land use changes such as change in scale and intensity, abandonment, and desertification, forest fires, land levelling and soil displacement by tillage, climate change (change in frequency and magnitude of events). Therefore the identification of driving forces in gully erosion is important for effective rehabilitation.

Socioeconomic variables are important determinants of soil erosion, since human actions are drivers of erosion processes. Most soil erosion studies do not take into account socioeconomic factors of soil erosion (Udayakumara, *et al*., 2010), and this aspect therefore needs to be investigated. This is because of the ongoing argument on whether natural resources are best managed by the people who use or by governments (Udayakumara, *et al*., 2010). However consideration of community member's perception is essential when making decisions on gully rehabilitation. If there was more awareness and concern by government and local communities on loss of capital and future opportunities (Van-Camp *et al.,* 2004), then every effort would be put in addressing the driving forces on fragile lands.

Some of the driving forces have been studied and reveal strong increases in gully erosion as a consequence of land use changes, in combination with extreme rainfall events and further induced by socio-economic changes. In Ethiopia erosion is estimated to range from 1,248 - 23,400 million ha per year from 78 million ha of pasture and range lands and cultivated fields (Itanna *et al.,* 2011). The organic matter loss is 15-1000 kg/ha/year which amounted to 1.17-78 million ha of organic matter lost per year from cultivated and grazing lands in Ethiopia (Itanna *et al.,* 2011). According to Titilola *et al.,* (2008), soil loss through erosion prompted by poor land use practices could be as much as 15 tons per hectare per year on a bare ploughed soil in Western Nigeria. About 850,000 hectares of land are badly affected annually or rendered useless for agricultural purposes and human settlement (Titilola *et al.,* 2008). Therefore the consequences of soil erosion are severe and every effort should be put to prevent it.

Gullies are in soils subjected to loess, (North America, European belt, Chinese Loess Plateau) and sandy soils such as the ones that are dominant in the study area in Suswa and Sahelian zone, north-east Thailand (Shahrivar *et al.,* 2012), hence further accelerating the driving forces and pressures of gully erosion. Therefore, the rate of gully erosion depends on the gradient of the gully channel, soil characteristics, size and shape of the gully and drainage Geyik, 1986). Gully erosion studies are concerned with off-site impacts. Exploitation of land resources in upper catchments results in sediment yield and nutrient loads in runoff, thus affecting downstream users (Poesena *et al.,* 2003), hence the need to study the effects of gully erosion on communities.

1.2 Problem Statement

According to Pathak *et al*., (2006) drivers of gully formation include overgrazing, cultivation in steep or marginal land and deforestation. These factors determine the potential hazard, intensity and rate of gully advance (Pathak *et al.,* 2006). Gully erosion is a threshold phenomenon when land use, topography and rainfall have been exceeded (Wu *et al.,* 2008), which is the case in the Suswa catchment. Gullies have been neglected because they are difficult to study and to predict (Nasri *et al*., 2009). Few studies assess the environmental impacts of gully erosion because of the extent, magnitude, rate, and complex processes (Lim *et al*., 2005), hence the need for land use and land cover change studies. Little scientific data are available to assess the extent of soil degradation and its relationship with land use (Basher *et al.,* 1996) and therefore this needs to be investigated further.

Gullies are destructive and cannot be eliminated by ploughing because of depth and soil type. Damages due to gully erosion include disconnection of roads and bridge breakage, recession of water table, immigration of people and movement of the location of villages (Shahrivar *et al.,* 2012). Livestock and community members are already being threatened by the existing gully to an extent of falling inside the gully. Some of the livestock have been killed because of falling into the gully. Flooding is affecting homes and the gully is cutting through homesteads making movement difficult in the Suswa catchment area, which is the main focus of this study.

Gully erosion can occur in different climatic regions and in various types of soil, although it mainly occurs in loess and sandy loam-textured soils in dry regions (Stavia et al., 2010). There is little information on how gullies respond to land use types and therefore requires further investigation. Soil loss through water erosion is usually associated with the loss of organic matter, nitrogen, phosphorus, potassium and other essential plant nutrients (Itanna *et al.,* 2011), indicating that land productivity is likely to be severely affected if erosion is not checked.

Remote sensing and participatory geographic information systems (PGIS) provided efficient methods for analysis of land use and land cover change detection. Hence, the need for application of these techniques for the current study. By understanding the driving forces of gully erosion in the past and present, and managing the current land use system with remote sensing and GIS tools, one will be able to know which areas are highly prone to soil erosion, and develop plans for multiple uses of natural resources while conserving the soil. Remote Sensing and PGIS helps improve communication between scientific and indigenous communities, bridging knowledge divides and contributing to sustainable development (Bhattacharyya, 2006*).*Therefore, it is necessary to bring local and scientific knowledge together to improve everyone's understanding of ecosystem services and processes, and to promote mutual respect between the holders of such knowledge (Chalmers *et al.*, 2007).

1.3 Justification of the study

Gully erosion is accelerated by land use change and climatic events, and often results from a long history (Valentin *et al.*, 2005). Therefore, knowing the age and rates of gully development during the last few decades will help explain the reasons for current land degradation (Nyssen, *et al*., 2009). Understanding historical and present-day gully erosion in Suswa Catchment is therefore essential when addressing the consequences of future land use scenarios (Frankl, 2012). Land use and land cover history in therefore helps to give information in disturbed catchments, enabling accurate assessment of reference conditions for restoration. The use of historical information and trends from satellite images and participatory geographic information systems (PGIS) help to understand the drivers of gully erosion in Suswa Catchment. Understanding the drivers of gully erosion is therefore important for reclamation and rehabilitation, hence the need for this study.

The driving forces for erosion include land use changes such as change in scale and intensity, abandonment, and desertification, forest fires, land levelling and soil displacement by tillage, climate change-change in frequency and magnitude of events (Van-Camp *et al.,* 2004). Communities in Suswa Catchment depend on livestock, cultivation and forests for their livelihood. However grazing, cultivation and deforestation over time can lead to loss of the capacity of the soil and its ecosystem on which the community depends on. Gullies develop rapidly to large dimensions making it difficult to rehabilitate, which is the case in the Suswa Catchment. Therefore assessing drivers and effects of gully erosion in Suswa Catchment will help the community to have a more sustainable livelihood.

1.4 General Objective

To assess drivers and effects of gully erosion on communities in the Suswa Catchment Narok County using a Geospatial Approach

1.5 Specific Objectives

1. To assess land use and land cover change for the last 26 years in the study area using Satellite images

2. To establish drivers of gully formation and development using participatory geographic information systems (PGIS) with the local communities.

3. To determine the effect of gully erosion on the livelihoods of the local community.

1.6 Research questions

1. How has the land use systems changed over the last 26 years in the study area?

2. What are drivers of gully formation and development from the communities' perspective?

3. What is the effect of gully development and formation on community livelihoods?

1.7 Scope of the study

This study analyses drivers and effects of gully erosion on communities in the Suswa Catchment. Satellite imageries were used to classify land use and land cover changes for 1985, 2000 and 2011. Land use and land cover change included grasslands, forests, settlements, agricultural land and water bodies. Participatory geographic information systems (PGIS) also analysed 1985, 2000 and 2011 for land use and land cover changes and focused on forests, the gully, grassland, water resources, settlements, agricultural land, schools, police posts, churches and roads. These are features that the community considers as important on which they depend on for their livelihood. Schools, police post, settlements, water resources, churches and the road are the built up areas/land uses. The effect of gully erosion on livelihoods was collected using a questionnaire on movement, infrastructure, livestock and farming practices and recommendations given.

CHAPTER 2

LITERATURE REVIEW

2.1 Gully Formation and Development

Water erosion encompasses sheet, splash, rill and gully erosion. Sheet erosion, is the removal of soil where the velocity of run-off is 0.3 to 0.6 meters per second (Geyik, 1986). Raindrops on soil cause downhill movement, resulting in splash erosion. Rill erosion is the removal of soil in shallow channels. Rill erosion has a greater capacity than sheet erosion. Gullies are formed where rills join and are more than 30 cm deep (Geyik, 1986). The rate of gully erosion is an important topic in erosion research. Gully- head retreat ranges from 1.25×10^{-4} - 6 m yr^{-1} (Wu et al., 2008). The development of gullies is rapid during the initial periods. Gully formation is sporadic because of variations in land use, topography and rainfall threshold factors (Wu et al., 2008). Land use changes that increase rainfall intensity and runoff properties, decrease the topographic threshold and accelerate erosion (Samani et al., 2009) and is therefore of concern. When the velocity of the runoff exceeds a critical threshold, gully erosion will occur (Ghosh et al., 2011). Therefore natural resource management decisions should be in response to changing seasonal or annual threshold conditions in rainfall and land use.

Gully development occurs due to gully-head incision. Gully-head retreat dissects cropland and results in gully expansion which is the case in the Suswa area. Therefore, protecting the surrounding land is important. Studies show that gully erosion represents an important sediment source in drylands, contributing on average 50–80% of sediment production by water erosion, while sidewall processes can account for >50% of the total sediment produced in gullies (Parkner et al., 2007). Few studies have addressed the contribution of sidewall erosion. Tension cracks decrease stability of the gully wall by reducing cohesion and, when filled with water, results in the collapse of sidewalls which is the case in the Suswa Catchment.

2.1.1 Classification of Gullies and Classes based on Shape

In many landscapes under different climatic conditions and with different land uses, one can observe the presence and dynamics of various gully types. Literature shows that permanent gullies are often defined for agricultural land in terms of channels too deep to easily ameliorate with ordinary farm tillage equipment, typically ranging from 0.5 to as much as 25–30 m depth (Poesen *et al.*, 2003). The gully in Suswa is difficult to rehabilitate with ordinary farm tillage equipment because of depth (Plate 2.1). Ephemeral gullies are eroded small channels that can be filled by tillage, and may occur again in the same location. This could be the case in the study area.

Plate 2. 1: The Gully in Suswa Catchment

Studies show that the shape of a gully (Fig 2.1) usually indicates the nature and intensity of erosion (Pathak *et al.,* 2006).

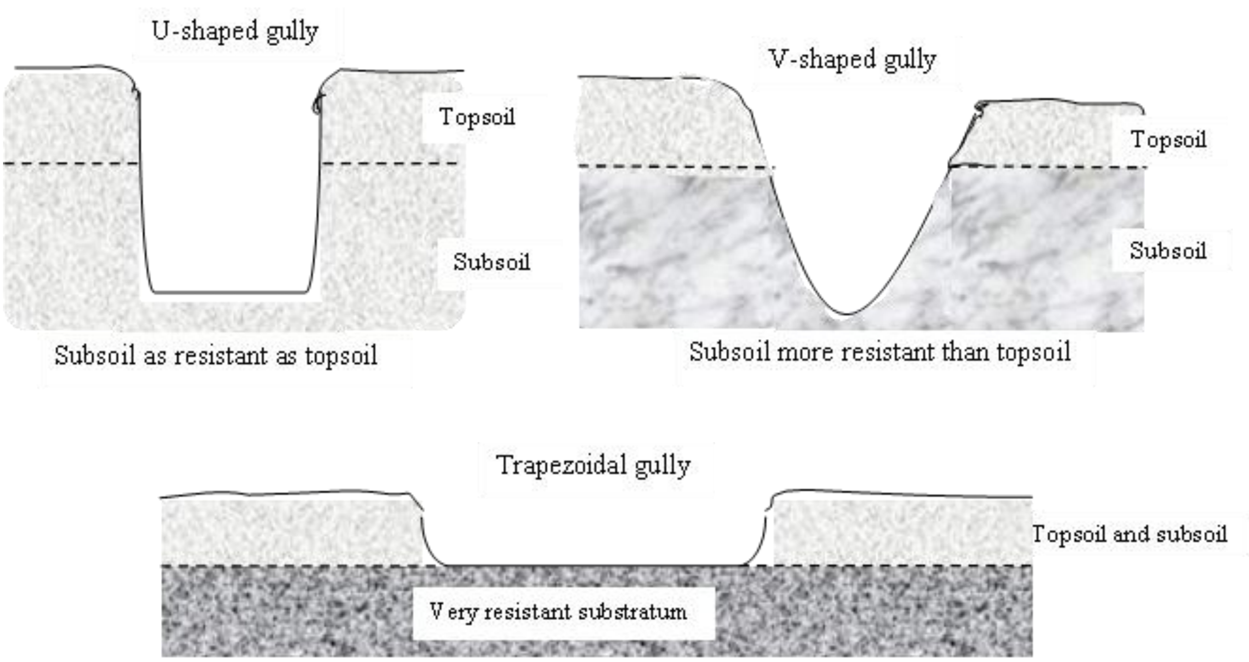

Figure 2. 1 Gully classes based on shape of gully cross-section (source: Geyik, 1986)

V (youth)-shaped gullies develop where the subsoil is more resistant than topsoil (Geyik, 1986). According to Eriksson *et al.,* (2010) V-shaped gullies have bare sides and are still deepening and widening (Frankl *et al.,* 2013). Trapezoidal gullies are formed where the gully bottom is made of more resistant material. U-Shaped gullies are formed where both the topsoil and subsoil have the same resistance (Geyik, 1986). U-shaped gullies indicate stabilizing gullies. According to Deng *et al.,* (2015) U-shaped gullies have high sand content (over 50%), followed by clay and silt contents, which promotes soil erodibility. However, the clay content in the bottom soil layer of U-shaped gullies is less than that of V-shaped gullies, meaning that the bottom layer of U-shaped gullies has higher erodibility. As a result, U-shaped gullies have more dominance. It should however be noted that some studies describe U shaped gullies as

Trapezoidal gullies. Rehabilitation of gully catchments requires reduction of run-off volume by the use of structural measures and revegetation. These methods may be sufficient to stabilize the gully in the Suswa catchment.

2.2 Factors affecting gully formation and development

2.2.1 Land Use and Land Cover Change

Changes in various types of land use in Kenya (forests, bushlands, grasslands, settlements, inland water bodies) from 2005-2008 are shown in Table 2.1. Eighty percent of Kenya's land area is arid or semi-arid (ASALs) supporting 50% of livestock and 80-90% of wildlife resources (NEMA). Twenty percent of the remaining arable land area has over 80% of the population living in these areas. Twelve percent of the land area was originally covered by forests and have been reduced to 1.7% of its original size, due to population pressure for settlements, infrastructure, demand for wood products and conversion to agriculture. Forest cover is therefore lower than the recommended threshold of 10% (National Environment Management Authority-NEMA (2011). This indicates a worrisome trend in land use and land cover change in Kenya.

Table 2. 1: Changes in various types of land use in Kenya from 2005-2008

Categories of land use type	**Areas ('000 ha) in Year-2005**	**Areas ('000 ha) in Year-2008**	**Remarks**
Indigenous closed canopy forests	1165	1165	
Mangroves	54	54	Located in Kilifi , Malindi, Lamu (coastal areas).
Industrial plantation Forests	134	107	This is in addition to 16000 ha of the unplanted designated areas
Private plantation Forests	83	90	Increasing trend due to accelerated commercial planting by private sector and farmers
Woodlands	2075	2 050	
Bush-lands	24570	24 510	In ASALs and medium rainfall areas
Grasslands	10350	10350	
Settlements	8152	8 202	
Tree on farmlands	10320	10 385	Mainly in high and medium rainfall areas
Inland water bodies	1123	1123	
Total area	58037	58037	

Source: National Environment Management Authority –NEMA (2011)

Changes in various types of land cover in Narok County are shown in Table 2.2

Table 2. 2: Land cover changes in Narok County

Category	**Total Area (ha) 1970**	**Total Area (ha) 2000**	**% change (1970-2000)**	**Projected % change 2030 (ha)**
Woodland	444 079	49231	-88.9	Substantial
Shrubland	374 202	785890	52.4	53.0
Bareland	59 242	804	-98.6	-
Cropland	42388	328 104	87.1	94.0
Open natural Forest	390 871	189050	-51.6	-60.2
Close natural Forest	-	103 174	100.0	100.0
Grassland	201 223	55752	-72.3	-74.3
Total (Ha)	1 512 005	1 512 005		

Source: NEMA (2011)

Land cover change in Narok County between 1970 and 2000 (Table 2.2) showed an increase in shrubland (52.4%), cropland (87.1%) and close natural forest -including Mau Forest (100%), and a decrease in woodland (-88.9%), bareland (-98.6%), open natural forest (-51.6%) and grassland (-72.3%). Therefore woodland, bareland, open natural forest and grassland were converted to shrubland, cropland and close natural forest. The projected scenario by 2030 showed an increase in the area under shrubland (53.0 %), cropland (94.0 %) and close natural forest (100 %) and a decrease in grasslands (-74.3 %) and open natural forest (-60.2 %) in Narok County. This indicates overgrazing and deforestation will reduce vegetative cover resulting in increased runoff in the County. Gully erosion is affected by land use and land cover changes. Land use and land cover changes include cultivation, forest clearing and livestock grazing and are discussed in sections 2.2.1.1 to 2.2.1.3.

2.2.1.1 Effect of cultivation on gully erosion

Agricultural practices encourage soil compaction, reduce water holding capacities and increase erosion. Agricultural intensity without adequate soil conservation measures such as in the Suswa area, are linked to erosion in high risk areas. Slopes are however prone to water erosion when cultivated and are steeper than 10 to 30% (Kodiwo et al., 2013). Cultivation in steep slopes is widely practiced in Kenya, hence higher likelihoods of soil erosion. Conventional cultivation techniques (compared to no-till or minimum-till), expose bare soil to rain, which is more serious in arid and semi-arid areas. Kimigo et al., (2008) while working in Sasumua catchment showed that land management practices such as intensive cultivation of horticultural crops, overgrazing of pastureland and farming on steep areas were contributing to soil degradation. Therefore land use management affected soil health in the catchment.

Waruru et al., (2005) working in river Nyando catchment observed that permanent settlements into the forest reserves, introduction of annual crops in the steep forest or tea areas, overstocking in the lowland areas contribute to the erosion hazard. Maeda et al., (2010) in Taita Hills reported that the expansion of agricultural activities and an increase in rainfall resulted in soil erosion. In Taita Taveta, Waswa et al., (2002) observed that inappropriate tillage practices, deforestation and heavy rains resulted in gully erosion. During dry years, farmers will generally have reduced cropping seasons (Frankl, 2012), therefore timing of cultivation is critical. Farming practices associated with some crops encourage runoff and erosion. Cultivation of potatoes in rows channel runoff (Boardman et al., 2003). According to Forsyth (2007) erosion from rain-fed rice are 60 tons per hectare per crop cycle. Maize and beans were least erosive with losses of 19 and 10 tons per hectare per crop cycle respectively. Erosion in cabbage fields lay in between these extremes. Therefore crops have varying impacts on runoff, thus affecting land use planning.

Cultivation on steep slopes as a result of using farm machinery encourages runoff. Larger machines have been developed for farming, however there has an increase in axle loads, without reductions in ground contact pressures (Van-camp *et al.,* 2004), which could be the case in the arid and semi-arid areas. After levelling land is vulnerable and a few storms can cause losses. Soil compaction occurs when soil is subjected to heavy machinery or grazing, especially in wet soil conditions, which could be the case in the arid and semi-arid areas. In a study by Klaus *et al*., (2014) in Souss Basin Morocco on land levelling, results showed that on levelled study sites, runoff was 1.4 times higher than in undisturbed areas. Sediment production was even 3.5 times higher under the influence of land levelling. Hence, the erosive impact was increasing along ploughing rills and gullies. Disturbances on the land therefore results in high amounts of water runoff and sediment erosion.

In mountainous regions, annual cropping intensifies rill and gully erosion. Studies show that irrigation water flowing over abandoned fields can result in erosion, as shown by (Valentin *et al.*, 2005) in the oasis of San Pedro de Atacama in northern Chile. Gully erosion has been observed in the sandy soils of West Africa during fallow periods (Valentin et al., 2005). Soil crusting has resulted in abandonment of cultivated fields in South Africa. Soil crusting is a problem in the loess belts of China, Europe, Spain, New South Wales, South Africa and North America (Valentin *et al*., 2005). Due to scarcity of vegetation, soils of the arid and semi-arid regions such as Suswa are subjected to crusting, runoffs and erosion.

Research by Turkelboom *et al.*(2008) in Northern Thailand showed that land use changes at Pakha led to the concentration of agriculture in certain areas of the catchment, increase of (semi)-permanent agriculture, change in crop types, increase of tillage operations, and the expansion of paths and irrigation infrastructure. The earlier natural hydrological equilibrium at the Dze Donglo catchment became severely disturbed during this transition, and led to landscape instability and the acceleration and emergence of different land degradation processes. Turkelboom *et al.*, (2008) therefore concluded that land use changes can therefore accelerate gully erosion processes. Mugagga *et al.*, (2010) in Mount Elgon, Eastern Uganda showed that slash and burn is a very common and continuously increasing practice in the non-irrigated marginal cultivated uplands of the Mt. Elgon catchment area. As a result various forms of erosion (including rills, gullies and sheet) were observed in the fields that have been prepared using this method. Slash and burn is common in ASALS of Kenya and is therefore of concern.

In a study by Farhan *et al*., (2014) in the Wadi Kufranja catchment northern Jordan, results showed that the average soil loss from "mixed rainfed" cultivation across the watershed is much higher when compared with forest area, and open rangeland, and bare soils. Hence, the expansion of cultivated areas, and intensified use resulting from reduction and almost complete abandonment of fallow system, led to intensified soil degradation and sediment loss. Therefore land use planning should be of high priority in order to effectively reduce soil loss. Young *et al*., (2014) in the Midwest, U.S.A results showed that one-half of the fertile topsoil in Iowa has been lost through erosion during the last 150 years of farming, and erosion continues today at a rate of about 30 t/ ha/ yr because of the topography and the type of agricultural practices. Therefore agricultural practices can result in long term soil loss in some cases. In a study by Zhang *et al*., (2010) in Yongding river basin, northwest of Beijing results showed that regions where erosion risk had increased by more than three levels were in the gentle slope, were easily cultivated. These sloping cultivated lands were created by destroying natural vegetation and hence exposed as bare areas without crop residue cover because of one cropping in a year. By identifying areas in most need of conservation measures to address soil erosion, this will facilitate the planning of future soil conservation actions based on priorities.

2.2.1.2 Effect of livestock grazing on gully erosion

Livestock are a driver of gully erosion in rangelands, such as Suswa Catchment. Grazing intensity, duration, and frequency, as well as timing of grazing relative to vegetation availability, has been identified as a factor affecting ecosystem and rangeland health (Veblen *et al*., 2014). Poor rangeland health may point to historic grazing intensity which could be the case in the current study area. Grazing intensity must be closely managed to maintain a ground cover of perennial grasses at 60% or higher. If the grass cover drops below this value, a key biophysical threshold is surpassed with potentially dire consequences such as reductions in grass cover, increase in bare soil, decrease in infiltration and increase in soil erosion (Sannwald *et al.,* 2006).

According to Valentin *et al.,* (2005) research showed that erosion exceeds 190 t/ ha/year due to sheep grazing on Easter Island (Rapa Nui, Chile), which over time may contribute to gully formation. Livestock grazing reduces pasture and shrubs and is therefore of concern. Among the Gabbra and Samburu pastoral community, Marsabit sub-county by Okoti *et al*, (2006) showed that there is increased gully erosion, especially near the mountain areas and near settlements due to animal trampling and cutting of vegetation and also in some places where people had settled. The eroded places hardly grew with any vegetation, which was of concern to the local community. Gicheru *et al.,* (2012) working in Sasumua Catchment observed that overgrazing, intensive cultivation, and erosion by water affected soil quality. Amman *et* al., (2004) in Narok observed that high livestock levels resulted in degradation, especially during critical periods of drought, which could be the case in Suswa. Kodiwo *et al.,* in Nyakach (2013) observed that overgrazing along the river banks in Nyamarumbe resulted in land degradation. Sirviö *et al.,* (2004) *w*orking in Taita Hills reported that overgrazing, deforestation and poor land management resulted in degradation.

Research in Zaka's Ward 5, Zimbabwe by Makwara and Gamira (2012) showed that crop residue is either removed for storage as dry season fodder or it gets cleared by freely moving livestock from May to mid-November. Therefore it comes as no surprise that over 25% of the area is seriously eroded. In a study by Hillerislambers, *et al*., (2001), their spatially explicit model showed that an increase in the level of herbivore lead to transitions from a state with a closed vegetation cover, to a state with spatial vegetation patterning, to a state with bare soil. Results also showed vegetation changes are reversible if herbivore decreases, which is important for soil conservation. In a study by Yannelli *et al*., (2013) in Argentina results showed that grazed fields and abandoned crop fields were much more susceptible to potential gully erosion. Therefore understanding how long it takes to recover these ecosystems is crucial in order to then define whether they will recover on their own or whether it is necessary to apply active restoration techniques.

Johansson and Svensson Jakob (2002) in the semi-arid catchment of Lake Baringo showed that the change from cattle to goats has resulted in the goats eating much more bushes and twigs and therefore survive in much harsher conditions. But on the other hand this leads to an even harder pressure on the remaining vegetation. The animals eat up the vegetation and break the lower vegetation and root system through trampling. The trampling is often the initiation of gully erosion, which is common in the arid areas.

2.2.1.3 Effect of forest clearing on gully erosion

Research shows that 40% vegetation cover is critical, below which erosion occurs on sloping land (Van-Camp *et al.*, 2004), which could be the case in arid and semi-arid areas. Studies conducted in the Chinese loess plateau studies showed that an increase in grassland and forestland by 42% and decrease in farmland by 46% reduced sediment production by 31% (Valentin *et al.,* 2005).In addition research also showed that sediment production declined by 49% for a terraced hill slope and by 80% for a vegetated hill slope (Valentin *et al.,* 2005). This therefore demonstrates the effectiveness of terracing and vegetation in controlling erosion which could be useful in land use planning.

Research by Johansson *et al.,* (2002) in the semi-arid catchment of Lake Baringo showed that the clearance of the forest has resulted in a larger proportion of the rainfall forming surface runoff. Findings by King, (2008) in Baringo showed that ground cover by (*Aloe secundiflora)* prevented erosion, reduced surface water flow velocities and wind speed. This study also showed that over four growing seasons of *Aloe secundiflora* generated successional response similar to that seen when grazing intensity was reduced (King, 2008). Therefore, shrubs can retain soil in their immediate vicinity hence they are effective for gully rehabilitation. Gicheru *et al.,*

(2012) in Narok observed that the loss of land cover (grass, bushes and trees) further reduced pasture availability for livestock, resulting in increased exposure of the soil to erosion. In the Luangwa valley on Zambia's eastern border results, showed that areas with plenty of grass and trees had rates of erosion around 5 t/ha/yr while areas with poor vegetation cover had erosion exceeding 100 t/ha/yr (Makwara *et al.* 2012), further highlighting the effectiveness of vegetation cover for soil conservation.

In a study by Tesfahunegn *et al*., (2014) in the Northern Ethiopia catchment, results showed that the highest rates of soil detachment occurred in marginal lands, and subsoil exposed soils having low soil resistance to detaching forces. The lowest was observed in forest land, protected plantation areas, and farm lands with high soil quality regardless of the slope steepness. This study showed that the rate of soil loss increased with an increase of detaching forces. Therefore increasing vegetation cover can be part of the solution for reducing the amount of soil loss. In a study by Omuto *et al*., (2011) in Somalia, results revealed that about one-third of the country was degraded because of the loss of vegetation cover, topsoil loss and decline of soil moisture. Overgrazing, excessive cutting of trees and poor agronomic practices in agricultural areas are the primary drivers of land degradation in Somalia. These drivers therefore encourage soil loss hence sustainable land use planning should be a priority. In a study by Phillips *et al*., (2013) in France and New Zealand, results showed that an increase in vegetation cover in the last 150 years is closely coupled with a decrease in the sediment yield at the outlets of revegetated catchments. Field measurements showed that the fine sediment yield is 220 times less in the Brusquet catchment, which has an 87% vegetation cover, compared with the Laval catchment which has only a 32% vegetation cover. This therefore demonstrates that vegetation can help reduce soil erosion and runoff.

Kabanza *et al.*, (2013) working in South-Eastern Tanzania on land-use/cover dynamics, showed that as annual crops increased, natural vegetation lost large proportions of land, mostly bush land, wooded grassland or woodland, and which had been converted to cashew orchards. Therefore land-use/cover change led to an overall reduction of natural vegetation, a driver of soil erosion. In a study by Fentahun *et al*., (2014) to examine the trend of land use and land cover changes in Bantinaka watershed Southern Ethiopia, results showed that the expansion of cultivated land was at the expense of forests. Furthermore cultivated lands were extended into fragile areas due to the shortage of land, resulting in soil erosion. Maloney *et al*., (2008) in Chattahoochee and Muscogee counties, Georgia, USA on historical land use and stream conditions, showed that after 55 years of recovery from landscape disturbance, many forest patches are in successional stage. This is also the time when soils have largely recovered from prior agricultural practices. Land use history therefore helps to give information in disturbed catchments, enabling accurate assessment of reference conditions for restoration.

In a study by Bangash *et al*., (2013) in the Mediterranean river basin, results showed that the amount of sediment retained is two orders of magnitude higher than that exported, and most of the sediment produced in the basin is retained by existing vegetation. Therefore vegetation helps to reduce runoff and should be adopted for soil conservation. In a study by Colmenero, *et al*., (2012) in the Henares River basin southeast of Madrid, Spain, results showed that the planting of vegetative cover crops between rows of vines in sloping vineyards resulted in greater infiltration, and consequently, a four- to six-fold reduction in erosion compared with conventional tillage. Therefore vegetative cover can reduce losses from erosion and improve the infiltration of water for farming. Xin *et al*., (2010) in China's Loess Plateau showed that 60% loess and 10% vegetation cover were important thresholds for the relationship between sediment yield and runoff. The spatial pattern and intensity of sediment yield are therefore related to the distribution and proportion of vegetation cover. The thresholds of vegetation cover may provide valuable indicators for gully rehabilitation in the Suswa area.

Zhou *et al*., (2009) in Shaanxi province China, showed that a 1.2% conversion to forest per year may lead to a 10% or more yearly reduction of the annual sediment volume delivered to the main rivers. In a study by Renison *et al*., (2010) in Central Argentina results showed that degradation of forests and their soils is triggered by domestic livestock rearing. Therefore land use should always be considered in soil conservation efforts, with an emphasis on the need to manage livestock adequately, especially in susceptible areas. Li *et al*., (2010) in China's Loess Plateau Region, showed that the total area of forestland and grassland increased from 27.4% to 34.2%. These cumulative changes resulted in a 3.6–35.3% reduction in overland flow. These results suggest that the land-use changes gave rise to a mean erosion reduction of 38.8%. Thus, ecological restoration efforts can effectively mitigate the soil loss and thus contributed to the improvement of the ecological conditions.

In a study by Duvert *et al*., (2010) in the Mexican Central Highlands, results showed that traditional cropping practices with cattle grazing could lead to severe soil degradation in the Cointzio basin. Thus the formation of gullies in Huertitas and Potrerillos was triggered by those practices. This therefore demonstrates that human-induced land use changes are major drivers of soil erosion. Favreau *et al*., (2009) in southwest Niger, showed that land clearing increased surface runoff volume by a factor close to 3 (runoff volume), with a 2.5-fold increase in gullies. This study therefore assessed land use and land cover change and their implications on gully erosion.

2.2.2 Effect of climate change and climate variability on gully erosion

Global warming associated with the extension of grazing and cropping areas puts more regions at high risk of gully erosion in the future, with a particular threat on the semi-arid areas (Valentin *et al.*, 2005). During drought periods, vegetation dies leaving areas unprotected from rainfall splash, resulting in runoff which tends to promote gully erosion. A drier climate in the semi-arid zone is thus expected to foster rill and gully development. Changes in rainfall patterns increase storms after dry periods in the arid and semi-arid areas. Studies show that gully erosion occurred in the indigenous forest catchments of Raparapaririki and Mangapoi Rivers in New Zealand after a severe cyclone in 1988 (Parkner *et al.*, 2007). Research also shows that soil losses of 20 to 40 t/ ha/yr in individual storms, may happen once every two or three years, and are measured regularly in Europe with losses of more than 100 t/ ha/yr in extreme events (Van-Camp *et al.*, 2004). Research shows that the Mediterranean region is prone to dry periods, followed by heavy bursts of rain on steep slopes. Land use change therefore has greater impact than climate change (Valentin *et al.*, 2005).

Climate data provide the context for interpreting vegetation and livestock grazing information. Grazing information, coupled with climatic data, can be used to examine appropriateness of stocking rates. Yearly rainfall amounts have a direct bearing on impacts of a given grazing intensity, timing of grazing and also determines how grazing affects plants. Long-term trends in vegetation cover would be affected by lengthy drought periods, both with and without grazing. Research shows that assessments of long-term relationships between grazing and climatic patterns could provide insights into how rangelands might respond to future climate scenarios and suggest whether grazing intensities may need to be adjusted to cope with altered climate patterns (Veblen *et al.,* 2014). This remains an active area of research due to the challenge of quantifying climatic factors across complex landscapes, with sometimes limited historical climate data. Literature shows that in the Masai-Mara Ecosystem (Nyariki *et al.*, 2009) rainfall affects the seasonality and quantities of water available. As human population rises, so does the need for more water, both for the people and their animals. Limited supplies of water lead to overgrazing and trampling by cattle with a serious negative environmental impact, which is the case in the Suswa catchment.

In a study by Kathumo *et al.,* (2012) on effects of land use and climate change in River Gucha, results showed that stream flow increased with agricultural and residential lands expansions and reduction of forest cover. Stream flow showed a high relationship with land use and land cover than with the temperature and rainfall. The correlation with land use and land cover was due to expansion of agriculture and reduction of forest cover. Therefore evapotranspiration was reduced which causes soils to be eroded due to poor land husbandry, resulting to soil exposure. This affects the lower parts of the catchment. Control measures should include proper farming practices and the planting of trees. Land use changes induce emissions of carbondioxide into the atmosphere which result in global warming. Land use and land management options which enhance carbondioxide emission include deforestation, tillage and excessive grazing (Lal 2004). Therefore land use changes in Catchment should be controlled and well managed.

2.3 The Role of Remote Sensing and Geographic Information Systems in Land Use Management

Remote sensing and geographic information systems (GIS) provided efficient methods for analysis of land use and land cover change detection. Hence, the need for application of these techniques for the current study. By understanding the driving forces of gully erosion in the past and present, and managing the current land use system with remote sensing and GIS tools, one will be able to know which areas are highly prone to soil erosion, and develop plans for multiple uses of natural resources while conserving the soil.

In a study by Sakthivel *et al.*, (2011) in India, erosion hazard zones are found in steep slopes where agricultural activities are practiced. Also, high soil erosion prone areas are found at the higher outer slopes of Tumbal extension reserved forest area of western side of the study area which is due to agricultural practices. Areas prone to soil erosion were Pattimedu, Jadayagaundan (Southern portion), Kanai and Puttai reserved forests (Eastern portion) and were attributed to deforestation and human activities. Areas with moderate erosion hazard zones included reserved forest and plateaus of Vellimalai, Kariyalur and Innadu. Areas with low soil erosion hazards are found to the foothills and plain regions of the study area.

In a study to assess, record and map geohazards and georesources in Zaragova, Spain by Lamelas, *et al.*, (2009), results showed that in terms of erosion susceptibility, degraded slopes with irrigated land had the highest susceptibility values, due mainly to their high scores in terms of soil, slope, and erosion factors. Flat valley bottoms covered by non-irrigated arable land also had a high degree of erosion susceptibility, reflecting the unfavourable characteristics of the soil and slopes. In this case, gully erosion is the main erosion process. The lowest susceptibility to erosion included flood plains, forests, terraced and irrigated land. Therefore remote sensing and geographic information systems help to facilitate decision-making of different land-use forms in a semi-arid environment.

In a land use and land cover analysis study by Sulieman *et al.,* (2013) in Eastern Sudan, the clearance of natural vegetation due to expansion of rain-fed agriculture had exposed the soil surface to accelerated water erosion in areas along the Atbara River. The decrease or disappearance of certain plant species reduces vegetation cover and increases the exposure of soil surfaces to wind and water erosion, leading to more land degradation, a case which is likely to happen in the area of study. In a similar study to assess gully sensitivity in Kendu escarpment, Nyanza provine by Katsurada (2007) results showed that areas with scarce vegetation and steep slope and sedimentation can cause rapid runoff and severe gully erosion. Therefore improving precision of detection of gully erosion is important in arid environments.

A study by Ochola *et al.,* (2003) in Kusa, Nyando District involved the use of spatial water resources hazard assessment decision support system (DSS) for floods, surface water erosion, water hyacinth weed and ground water fluctuation and contamination. In-depth spatial analysis from maps was possible. Results from the maps shows that it is possible to identify the potential hot spots and spatial distribution of both primary and secondary water resources hazards using remote sensing. The areas most affected by surface water erosion are farm units recently abandoned as a result of the construction of the new hydro-electric power plant along River Sondu-Mirui while the least affected areas are the flat lands. Therefore remote sensing and geographic information systems enabled soil and water conservation in the area and investigation of spatial and temporal trends in water hazard status.

The results of a land use land cover change simulation/scenario study by Maeda *et al.*,(2010) in Taita Hills indicate that agricultural expansion is driving into areas with less pronounced slopes, lower precipitation and, consequently, lower soil erosion potential. If current trends persist, it is projected that agricultural areas will occupy 60% of the study area by 2030. These changes will result in accelerated soil erosion. In addition, agricultural expansion will inevitably result in increased soil erosion due to changes in vegetation cover. Remote sensing and geographic information systems are therefore effective in indicating the areas with a higher probability of land use and land cover change.

Bewket *et al*., (2009) assessed soil erosion hazard in the Chemoga watershed Ethiopia, their results showed that soil erosion hazard maps helped in the implementation of different types of soil conservation measures for sustainable land use. Prioritization of micro-watersheds involved ranking of the different micro watersheds according to the order in which they ought to be taken up for treatment with conservation technologies by considering the amount of soil loss occurring. Remote sensing and geographic information systems therefore helped in conservation planning for sustainable land use. Wang *et al*., (2013) in Danjiangkou Reservoir Area, China, showed that conservation priority maps helped to assess the water erosion (rill and sheet erosion) risk and dynamic change trend of spatial distribution in erosion status and intensity. Therefore remote sensing and geographic information systems can help to make comparisons of soil erosion risk over the years in order to identify soil conservation priorities.

Silva *et al*., (2013) in Tapacurá watershed, Pernambuco, northeastern Brazil identified sub catchments for soil conservation, and showed that soil loss maps helped in the identification of areas susceptible erosion. Therefore remote sensing and geographic information systems can be predictive tools for identification of critical areas of soil erosion in watersheds. Pratibha *et al*., (2014) working in the Block of Meghalaya, India showed that soils maps helped to group land into capability classes and included areas for afforestation, intensive cultivation in the existing cropped areas with soil conservation measures like mulching, zero tillage etc. and plantation in open scrub lands which are cultivable wastelands. Therefore remote sensing and geographic information systems in this study helped in better management of land resources for sustained productivity. Uribe *et al*., (2012) on dynamics of land use change in Mexico, showed that CHI (chinampas agriculture) had 50% probability to change to CHT (chinampas agriculture in transition), CHT had 69% to change to GH (Greenhouse) and GH had 65% probability to change to URB (urban). Remote sensing and geographic information systems therefore help us to see relationships in land use/land cover change dynamics for effective management.

2.4 Participatory Geographic Information Systems (PGIS)

The merging of community development with geo-spatial technologies for the empowerment of less privileged communities has come to be known as participatory geographic information systems or PGIS (Rambaldi *et al.*, 2006). PGIS combines a range of geo-spatial information management tools and methods such as sketch maps, satellite imagery, and global positioning systems (GPS) to represent people's spatial knowledge for discussion, information exchange, analysis, decision making and advocacy.

Consideration of peoples' perception is an essential factor when making decisions on soil and water conservation (Udayakumara *et al*., 2010). The adoption of participatory action by involving community members, for assessing the resource base conditions has become an attractive methodology for many conservation and development studies (Pathak *et al.*, 2006). For the assessment of catchments, liaise with residents (they would know own farm sizes and size of their neighbors' land and estimate flow patterns and can therefore assist in giving reasonable figures on catchment size. They can also contribute own perception of level of runoff from an area- high, medium or low (Eriksson and Kidanu, 2010)

A study by Bhattacharyya (2006) among the native community of the Onge in the island of Andaman, India, contributed to the identification and understanding of places of historic, cultural and religious significance, providing insight into the community's metaphysical vision and their hazard perception (related to the tsunami). The generated data can be used for better planning, monitoring and evaluation of the existing resources. It can also help policy makers develop a more participatory development policy and improve communication between the scientific and indigenous communities for sustainable development.

A PGIS study by Kathumo *et al.*, (2012) to trace the trends in the decline of forest quantity and quality since 1970 of Lower Tana River forest found that, land resource use changes from forestry to agricultural use, an increase in settlements, roads, schools and dispensaries in the area over time, resulted in reduction in river flow volumes, erratic rains, high temperatures, disappearing of tree materials for making mats and boats. PGIS therefore enabled an awareness of the magnitude of the problem and a way forward to conserve the forest. Participatory management should be emphasized since it will help mobilize communities to become active in soil conservation.

In a study by Syombua (2013) in Taveta District, Participatory GIS (PGIS) and Remote Sensing were used to identify land use and land cover changes. The generated imagery was used to create awareness, promote sustainable management of land resources and reduce human-wildlife conflicts. Results showed that agricultural expansion (both rainfed and irrigated), charcoal burning, overgrazing, were found to lead to decimation of wildlife and livestock habitats of woodlands, forests, scrublands' and wetlands. There was also degradation of important niche habitats for elephants especially in Olo-bosoit area of Njukini location that has historically been used as a calving zone. Local communities were able to link decimation of wild habitats to the intensification of human-wildlife conflicts. This therefore means that indigenous knowledge provides an opportunity to engage in human-wildlife conflict management especially through land use planning. Indigenous knowledge in land use planning will therefore help to reduce gully erosion in Suswa catchment.

In a study to improve mapping of forest use in Mexico by Boccoa (2005), the community was able to plan forest land for the following 10 years. In addition, the volcanic soils were considered as a risky if unsustainable forest management took over. In assessing the relationship between land suitability and land utilisation requirements, rain-fed maize, grasslands, and orchards (peach and avocado) were considered suitable land uses based on soil qualities. Participatory geographic information systems therefore allowed the community members identify alternative land uses for possible diversification including ecotourism. Participatory geographic information systems therefore helped to strengthen natural resource management.

According to Ifenkwe *et al.,* (2013) in Chitravas, India, erosion control involved protecting the forest, planting of *Jatropha curacus,* construction of check dams and planting of grass species. Decision making in the three villages in Hoa, Bihn province and Northern Vietnam, were defined by farmers, extension workers and researchers during a PGIS exercise. The activities were meant to promote new technologies, reduce erosion and build local capacities. Results showed that the trees and the fodder crops reduced soil loss. Therefore the participatory approach to soil erosion enabled involvement of community members for success and to highlight gaps.

In a study by Giménez (2002) in Nicaragua, results showed that the development of sustainable land management practices have been effective at building and conserving soil, water and vegetation over time. For years, farmers had initiated sustainable practices with rock bunds, contour ditches and live barriers. Farmers working with shovels and tape measures not only detected extensive erosion, they also documented significant damage to vegetation. Sustainable land management practices however showed that farmers need to renovate, modify (e.g. bench terraces), and maintain conservation structures, to deal with excess runoff from extreme rainfall events. Therefore the participatory approach can contribute significantly to the monitoring and development of sustainable land management systems especially following natural disasters.

In a study to analyse the relationship between land use and soil erosion with local communities in China by Long *et al.,* (2006) results showed farmland with a slope over 25 degrees should be converted to forests or grassland, instead of terraces. This is in contrast to Kenya where cultivation is practiced in steep slopes. Therefore, planting shrubs and grasses provided benefits for animal husbandry and improved household energy. Tree planting and shrubs helped reduce soil erosion. Results also showed that integrating socio-economic assessments in farmland is important. Farmland should therefore be converted to forests or grassland reduce the decline of grain. If socio-economic ability is not strong, then attention should be given to irrigation and cultivation. These forms the basis for establishing erosion control measures for various conditions. Therefore socio-economic and physical conditions should be used to improve soil erosion.

In a study by Brown (2012) in South Australia on Regional and Environmental Planning, results showed that development preferences appear relatively easy for Public Participatory Geographic Information Systems (PPGIS) participants to identify. PGIS is often used to promote the goals of non- governmental organizations, grassroots groups and community based organizations, in relation to indigenous. In contrast, PPGIS can be recommended by government agencies for public participation. Brown (2012) in South Australia showed that development priorities can help in zoning and in the writing of development proposals. Therefore PPGIS like PGIS can assist in land use zoning and planning.

A study on Social and Infrastructural Mapping for Compensation in Sri Lanka by Alagan *et al.*, (2012), showed that participatory multimedia GIS database helped in compensation packages for property damage. Databases provided information for infrastructure, natural resources and administrative boundaries. Participatory geographic information systems therefore helped in resettlement site selection after natural disasters.

A study on participatory asset-mapping in Nyando Valley by Martin *et al.,* (2012) identified natural resources, physical infrastructure, associations, and institutions as assets. Participatory geographic information systems therefore help to identify assets. Results showed that community sessions provided an opportunity for specialization. Community sessions are therefore beneficial for natural resource planning.

In a study by Hunink *et al*., (2013) in the Tana catchment on impacts of land-use and management scenarios on soil and water resources, results showed that if Water Resources User Associations (WRUAs) could be successfully involved in the implementation and maintenance of the erosion control measures, the sediment yield to reservoirs could be reduced significantly by up to around 25%. Therefore the involvement of stakeholders in PGIS can reduce the amount of soil loss in the catchments. In a study by Cotle *et al*., (2013) in central Mexico results showed the value of understanding soil conservation attitudes and behavior and of recognizing cultural and biophysical variability. Therefore effective soil conservation is determined by the interrelationship of social environments and biophysical setting. Hence, PGIS can help to transform land use planning in order to reduce soil loss.

In a public participation GIS (PPGIS) study by Brown (2012) to delineate places of significant conservation value (natural heritage, recreation, history and tourism values) in New Zealand, results showed that PPGIS helped in coming up with proposals for implementing effective conservation management. Therefore PGIS helps in getting public perceptions about the relative abundance of conservation resources and associated values for effective management. In a study by König *et al*., (2012), results showed that the framework for participatory impact assessment (FoPIA) method proved suitable in diagnosing relationships behind the regional land use problems and in improving communication among stakeholders in five case studies. PGIS is therefore useful in land use planning.

Environmental Resource Mapping and Information Systems Africa (ERMIS) conducted marginalized community mapping with the Yiaku Peoples (also known as Mukogodo Peoples) living in the Mukogodo Forest of Laikipia, Northern Kenya, the Bwindi Impenetrable National Park in Uganda , the Sengwer People, Cherangany Forest Kenya and Ogiek peoples in the Mau Forest Complex to map their territories. Data was collected from 120 Ogieks. Elders designed their maps with memories dating back to 1925 and reconstructed the landscape as it was at that time. United States

Agency for International Development (USAID) in 2012 conducted a participatory mapping process in the Boni-Lungi-Dodori forest areas in Lamu County and inventoried natural resources for the purpose of identifying community land boundaries, protecting/conserving area resources and creating a framework for establishing shared use and access rights. Therefore participatory geographic information systems help in mapping natural resources for conservation.

2.5 Research Gap

Gullies are destructive and cannot be eliminated by ploughing because of depth. Gully erosion is a threshold phenomenon and occurs rainfall, topography, land use has been exceeded (Wu *et al.*, 2008), which is the case in the study area. Little scientific data are available to assess the extent of soil degradation and its relationship with land use and therefore this need to be investigated further. Understanding historical and present-day gully erosion is therefore essential when addressing the consequences of future land use scenarios (Frankl, 2012). Therefore historical information and trends from satellite imageries and participatory geographic information systems (PGIS) will help to better understand the drivers of gully erosion in Suswa Catchment. Understanding the drivers of gully erosion is therefore important for reclamation and rehabilitation, hence the need for this study. In addition, communication between scientific and indigenous communities, will help bridge knowledge divides and contribute to sustainable development (Bhattacharyya, 2006) in Suswa.

CHAPTER 3

MATERIALS AND METHODS

3.1 Study Site

The study was conducted in Suswa location in Narok County (Fig 3.1) which lies between latitudes 0^0 50' and 2^0 05' South; and longitudes 35^0 58' and 36^0 0' East and covers an area of 15,087.8 km^2 (NEMA, 2009).

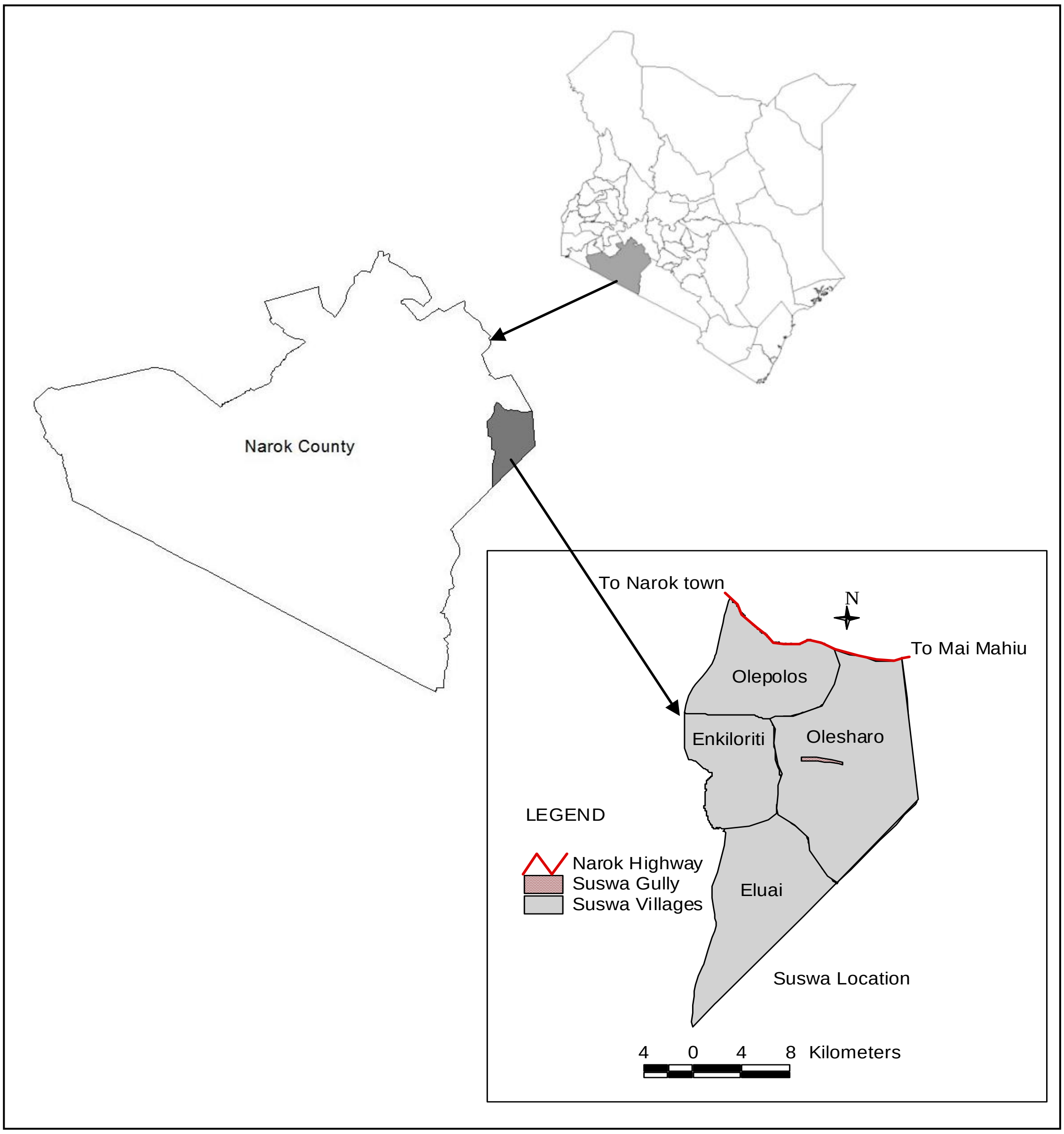

Figure 3. 1: Map showing location of Suswa in Narok County, Kenya

Narok County is straddled by five agro-climatic zones namely humid, sub-humid, semi-humid to arid and semi-arid (Sombroek *et al.,* 1982). Two-thirds of the county is classified as semi-arid. The agro-ecological zones found in the county include: Tropical Alpine (TA), Upper Highland zones (UH) Lower Highland zones (LH) and upper-midland zones-UM (Jaetzold *et al.*, 2005). Narok County has a population of 850,920 (GOK, 2009). The county has diversified topography which ranges from a plateau with altitudes ranging from 1000 m-2350 m.a.s.l at the southern parts to mountainous landscape which is about 3098 m.a.s.l at the highest peak of Mau escarpment in the North. The county experiences bi-modal pattern of rainfall with long rains (mid March-June) and short rains (September- November). Rainfall distribution is uneven with high potential areas receiving the highest amount of rainfall ranging from 1200 mm-1800 mm p.a while the lower drier areas classified as semi-arid receiving 500 mm or less per annum.

The county serves an important ecological and economic role and supports wildlife, tourism, livestock, farming activities and human settlements. The main soil types in the county include Andosols, Luvisols, Phaeozems, Vertisols and Acrisols. Areas with deep and well-drained soils include hilly and mountainous areas of Mau escarpment, Ngorengore, Shatuka, Suswa and Loita hills (Sombroek *et al.,* 1982; NEMA, 2009). The Suswa Catchment (400 km^2) was chosen as the study site due to the impact of gully erosion on livelihoods. In addition, there is an ongoing collaborative project being carried out by KARI, Sustainable Land Management, GEF/UNDP, KEFRI, UON and JKUAT to rehabilitate the gully. The community requested that gully rehabilitation be a priority because it is threatening their livelihood. Furthermore, the road leading to Narok town is being affected by soil deposition from the gully.

3.2 Methodology

3.2.1 Land use and land cover changes for the last 26 years

Satellite imageries were used to classify land use and land cover changes for 1985, 2000 and 2011. Landsat images for 1985, 2000 and 2011 were classified using ENVI 4.7 software. Images were classified into land use and land cover change using supervised classification and ground- truthing of the major land uses was done within the study area. Land use and land cover change were analysed on grasslands, forests, settlements, agricultural land and water bodies/water pan. Image selection was based on their availability and clarity with no cloud cover. Images were within the same season of the year, January for 1985, 2000 and 2011. The interval for the selected images was 15 years where possible. Thematic change detection was established using ENVI Ex software. This was done by comparing 3 images of different times (1985-2000, 2000-2011 and 1985-2011) to capture effects of land use and land cover change on gully development.

ENVI Ex software identified differences between images of different times (1985-2000, 2000-2011 and 1985-2011) with a resultant classification image and statistics. The area of land under different land uses and cover were used to calculate percentage changes in land use and land cover change using Excel software. The results were then analyzed using Chi-square goodness of fit to determine if there were significant changes in land use and land cover changes (water bodies/water pan, grassland, forest, agricultural land and settlement). Future projections of land use and cover change were established through linear regression analysis. Projections for land use and land cover trends were based on the assumption that there were no interventions and the status quo remained the same. The analysis was conducted using Microsoft excel. The three data points were plotted on a xy scatter plot. A trend line was then fitted displaying both the equation and R^2. Using this equation, estimates for 2021, 2031 and 2041 were conducted. These periods are ten year projections of land use and land cover change in Suswa Catchment from 2011 (the year of focus of this current study). These points were then plotted on the final graph. This resulted in a new equation and R^2. The projections of land use and land cover change in Suswa Catchment were in 10 year intervals similar to (Mortlock *et al.*, 1999; Vicente *et al.*, 2013; Haregeweyn *et al.*, 2017).

3.2.2 Past and current drivers of gully formation and development

Participatory geographic information systems are tools to convince communities on the importance of conserving land resources. Community members from four villages near the gully were identified. Consideration of peoples' perception is thus an essential factor when making decisions on soil and water conservation including land use decisions (Udayakumara et al., 2010). In each village, purposive sampling was used to identify 20 participants who included 10 individuals between 18-35 years, and 10 individuals above 50 years. The 36 to 49 age group was omitted because the youth and elderly were the target groups, inorder to better understand the historical land use and land cover changes. Gender balance was observed. Participants drew maps on manila paper for 1985, 2000 and 2011 on land use and land cover change to detect when the gully started.

The land resources targeted during the PGIS session included forests, the gully, grassland, water resources, settlements, agricultural land, schools, police posts, churches and roads. These are features that the community considers as important resources which they depend on for their livelihood. Ground – truthing of 5 key features (forests, the gully, grassland, water resources, settlements, agricultural land, schools, police posts, churches and roads) was done using a GPS in order to geo-reference each village.

The geo-referenced PGIS maps were printed for discussions by each village. Thirty participants of the mixed gender and age per village were selected. Direct and indirect benefits and undesirable effects of the changes of the major land resources were discussed. The participants recommended the way forward in minimizing the undesirable effects of the land resource changes.

The geo-referenced PGIS maps were exported to Arcview-GIS software to calculate areas under different land cover and land uses (namely, forest, agricultural land, grassland, water bodies and settlement). Percentage changes were determined for the period between 1985-2000, 2000-2011 and 1985-2011 using tables. Chi-square goodness of fit was used to determine if there were significant changes in land use and land cover change. PGIS maps were compared with the conventional GIS analysis to evaluate the extent to which local communities can effectively analyze resource changes.

3.2.3 The effect of gully erosion on the livelihoods of the local community

Purposive sampling was used to select the four villages affected by gully erosion. Data was collected using a questionnaire on family size, level of education, income, livestock keeping practices, farming practices, land management practices, causes of the gully and the effect of the gully on livelihoods (mainly movement, infrastructure, livestock and farming practices) and recommendations given. A minimum of 30 households (Ruxton, 2006) were selected randomly from each of the 4 villages. According to NEMA (2009) the county has a population of about 460,793, with only about 11% residing in the urban areas. Pilot testing of the questionnaire was done randomly on 10 respondents and the questionnaire rewritten before final administration. Enumerators were selected based on previous experience in fieldwork and level of education (secondary education and above). Key informant interviews were conducted on the Chief, Village Elders, Ministry of Agriculture, and Non-governmental organizations.

Land use practices (types of crops grown and livestock kept), level of income, level of education, size of farms, soil conservation measures and impacts of the gully on livelihoods (movement, infrastructure, livestock and farming practices) from the questionnaire were tested using SPSS. Chi-square goodness of fit was used to determine if there were significant effects on livelihoods.

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CHAPTER 4

Land Use and Land Cover Changes and their Implications on Gully Erosion in Suswa Catchment, Narok County

4.1 Introduction

Land use and land cover change are important components in managing natural resources and monitoring environmental changes. Land use and land cover is dynamic and provides an understanding of the relationship of human actions with the environment, which is important in the Suswa Catchment. Socio-economic processes for example agricultural, urban land, forestry, shape land cover and land use, and therefore need to be understood in order to mitigate human impacts on the environment (Nagendra *et al*., 2004).

According to Teferi *et al.,* (2013) transitions in land use and land cover can be caused by negative socio-ecological feedbacks that arise from a severe degradation in ecosystem services or from socio-economic changes and innovations. Transitions can be random or systematic, with random transitions being characterized by abrupt changes, whereas systematic transitions evolve steadily or gradually. Information on land use/cover change and possibilities of their optimal use is essential for the selection, planning and implementation of land use strategies to meet increasing human needs and welfare.

Land use and land cover change involves the modification, either direct or indirect, of natural habitats and their impact on the ecology of the area (Garede *et al.,* 2014). Land use and land cover change are often used to assess the impact on climate variability, land degradation, ecosystem stability and diversity. Land use and land cover analysis addresses where changes are likely to take place and at what rate are changes likely to progress (Veldkamp *et al*., 2001). Change detection using remote sensing and geographic information systems helps to assess landscape changes caused by human activities.

According to Lambin *et al.,* (2003) cropland as derived from remote sensing, has increased globally from 300–400 million ha in 1700 to 1500–1800 million ha in 1990, a 4.5 to 5 times increase and a 50% net increase just in the twentieth century. The area under pasture increased from around 500 million ha in 1700 to around 3100 million ha in 1990. These increases led to the clearing of forests and the transformation of natural grasslands. Forest area decreased from 5000–6200 million ha in 1700 to 4300–5300 million ha in 1990. Grasslands also declined from 3200 million ha in 1700 to 1800–2700 million ha in 1990. Pasture land has decreased in Eastern Africa and is attributed to an increase of cattle over this period, with an additional 872,000 head of cattle per year between 1992 and 1999,

Results by Brink *et al.,* (2009) in sub-Saharan Africa reveaedl that in between 1975 and 2000 agricultural land has increased by 57% from just over 200 million hectares to nearly 340 million hectares. This increase has taken place at the expense of forests and natural non-forests which have diminished respectively by 16 and 5%. These losses equate to 71 million hectares and nearly 60 million hectares respectively. Barren areas have increased by 15% to 6.5 million hectares. Sub-Saharan Africa has been gaining almost 5 million hectares agricultural land every year, which means an average annual change rate of 2.3%. The yearly deforestation rate has been 0.7%, which means that region has been losing nearly 3 million hectares of forests every year. The yearly deficit in non-forest natural vegetation has been 0.2%, which equates to more than 2 million hectares lost every year. Barren areas are estimated to have increased by 0.6%, which means over 0.26 million hectares every year.

Land use and land cover change (LULCC) are important factors that affect gully formation and development. Causes of gully formation are overgrazing, expansion of cultivation in marginal lands and deforestation (Pathak *et al*., 2006). Gullies are destructive and cannot be eliminated by ploughing because of depth. Damages due to gully erosion include disconnection of roads and bridge breakage, recession of water table, immigration of people and movement of the location of villages (Shahrivar et al., 2012). Livestock and community members are falling inside the gully, flooding is affecting homes and the gully is cutting through homesteads making movement difficult in the Suswa catchment.

Studies has shown the impact of gradual or sudden changes in land use and exploitation systems on the initiation and development of gullies. According to Murillo *et al.,* (2011) changes in land use can modify gully development leading to an increase in soil erosion or the reduction of the presence of gullies due to either their suppression by machinery or their colonization by vegetation. In a study by Wan *et al.,* (2007) in China, results showed that the ascending order of the runoff of five land use and land cover types was woodland, shrub, grassland, arable land and built-up land. The influence of land use and land cover change on runoff was therefore transforming other land use types into built-up areas. Hence, there is a correlation between different land covers and runoff. A study by Farhan *et al.,* (2014) in Jordan also showed that the average soil loss from mixed rainfed cultivation across the watershed is much higher when compared with forest area, and open rangeland, and bare soils. This study investigated land use and land cover change for the last 26 years in Suswa Catchment, Narok County using satellite images and their implications on gully erosion.

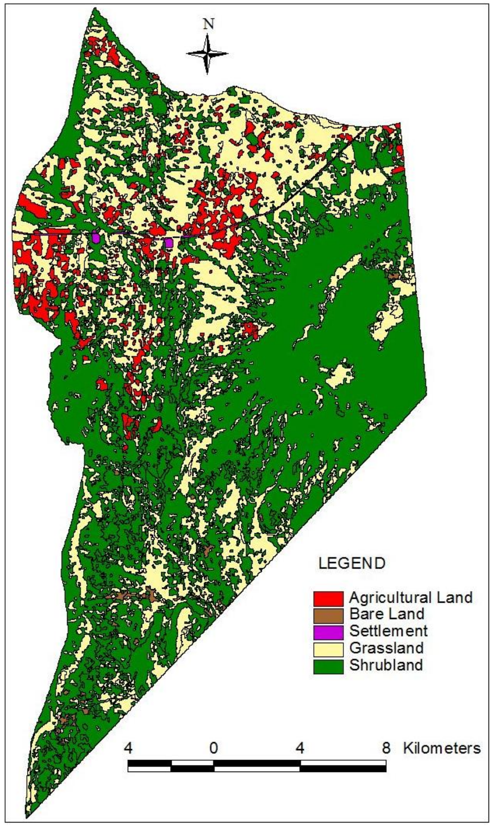
4.2 Materials and Methods

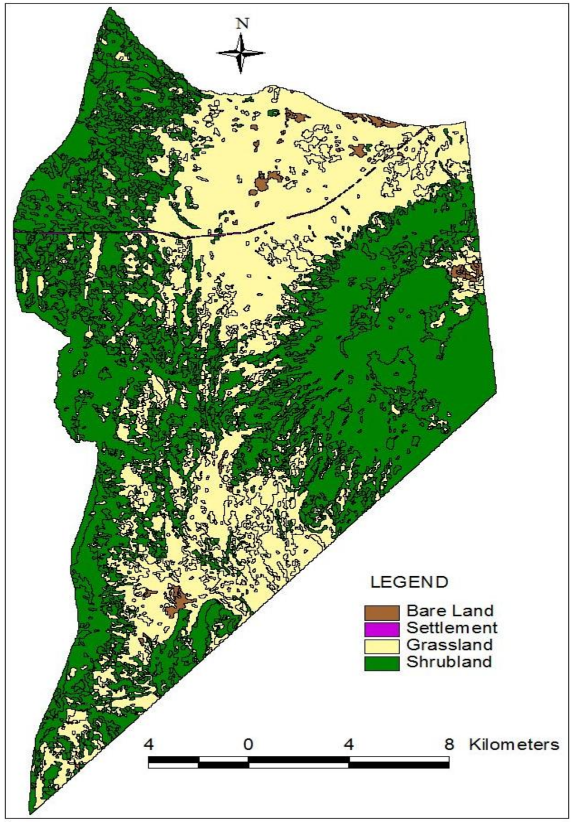
The description of the study area and methodology is given in Chapter 3.

4.3 Results

4.3.1 Land use and land cover changes between 1985 and 2011

Land use and land cover changes on grasslands, shrubland, settlements, agricultural land and bareland were shown in the classified land use and land cover maps (Figures 4.1- 4.3). Land use and land cover change for 1985, 2000 and 2011 for Suswa Catchment were analyzed as shown in Table 4.1. Major changes in land use were observed in shrubland, settlements, bareland, grassland and agricultural land. Built up area (settlements) increased by 18.18% by 2000, and further increased by 42.86% by 2011. Built up area change (1985-2011) however increased by 68.83%. Shrubland decreased by 26.18% in 2000 and increased by 39.39% in 2011. Shrubland change (1985-2011) increased by 2.90%. Bareland increased by 928.10% in 2000 and increased by 405.69% in 2011. Bareland change (1985-2011) increased by 103.31%. Grassland increased by 13.32% by 2000 and decreased by 27.12% by 2011. Grassland change (1985-2011) decreased by 17.41%. Agricultural land increased by 1433% by the year 2000 and further increased by 51.08 % by the year 2011. Agricultural change (1985-2011) increased by 2216%.





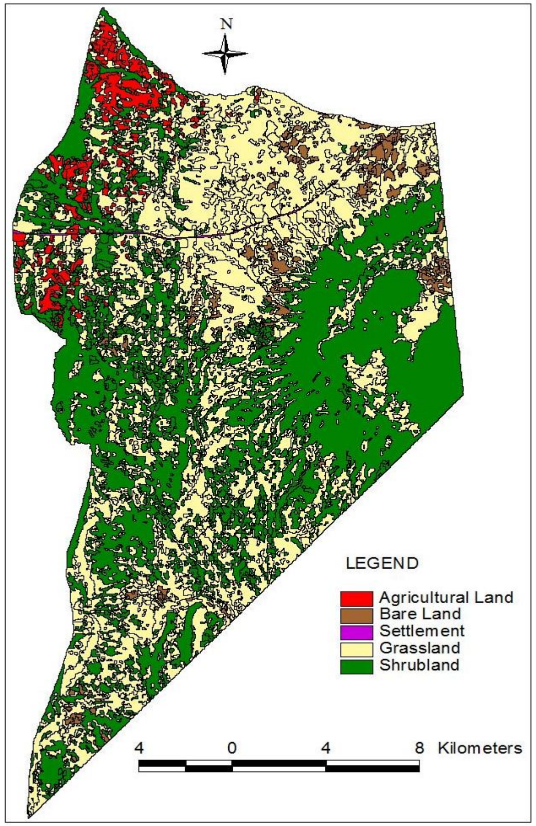


Figure 4. 1: Land use and land cover change (1985)

Figure 4. 2: Land use and land cover change (2000)

Figure 4. 3: Land use and land cover change (2011)

To determine whether the observed land use/land cover changes were significant, results of chi square goodness of fit test are shown in Table 4.4 There were no significant ($p < 0.05$) changes in built up areas, agricultural land, grassland, bareland and shrubland.

Table 4. 1: Land use/cover change in Suswa Catchment (1985-2011)

Landuse/ cover	**1985 Area (km^2)**	**% cover**	**2000 Area (km^2)**	**% cover**	**2011 Area (km^2)**	**% cover**	**Change % 1985-2000**	**Change % 2000-2011**	**Change % 1985-2011**
Built up area	0.77	0.19	0.91	0.24	1.30	0.32	+18.1	+42.8	+68.8
Agricultural land	1.00	0.24	15.33	3.81	23.16	5.67	+1433	+51.0	+2216
Shrubland	231.11	57.43	170.61	42.42	237.8	59.12	-26.18	+39.3	+2.90
Bareland	1.21	0.30	12.44	3.11	2.46	0.61	+928	+405	+103
Grassland	166.71	41.45	188.92	46.97	137.6	34.23	+13.3	-27.12	-17.41

Table 4. 2: Chi-Square goodness of fit test for land use/cover changes in Suswa Catchment between 1985 and 2011

Landuse/cover	1985 % cover	2000 % cover	2011 % cover	x^2	df	p
Built up area	0.19	0.24	0.32	0.0	2	1.0
Agricultural land	0.24	3.81	5.76	3.455	2	0.178
Shrubland	57.43	42.42	59.12	3.278	2	0.194
Bareland	0.30	3.11	0.61	3.0	2	0.223
Grassland	41.45	46.97	34.23	2.082	2	0.353

Future projections to year 2020 of land use and land cover change in Suswa Catchment are shown in Figures 4.4 to 4.8. Projections for land use and land cover trends were based on the assumption that there were no interventions and the status quo remained the same.

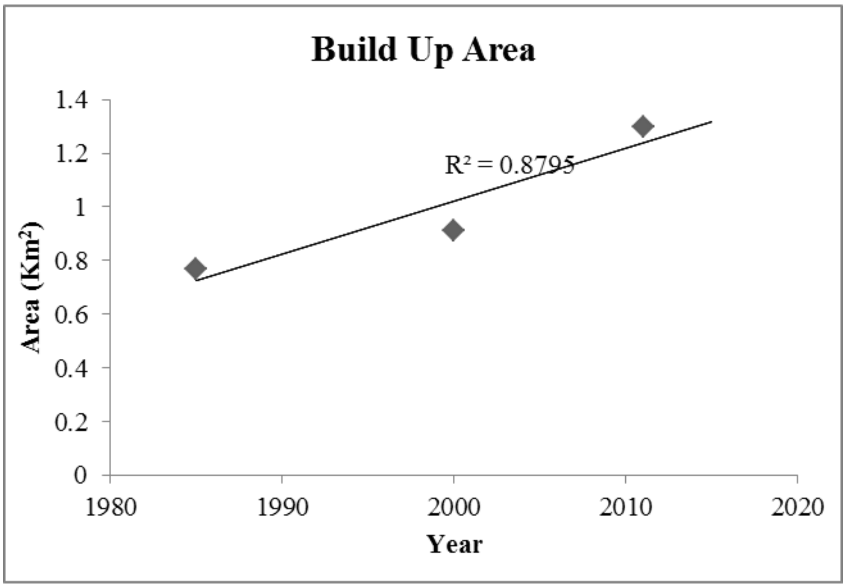


Figure 4. 4: Ten year projections (2020) of built up area change in Suswa Catchment

From the projections (Figure 4.4), a significant increase in built up area (R^2= 0.8795) will characterize the land use in the coming ten year period in the Suswa Catchment possibly due to increased settlement. Therefore there is a high association (87.95%) between built up areas and gully formation and development in the coming ten year period.

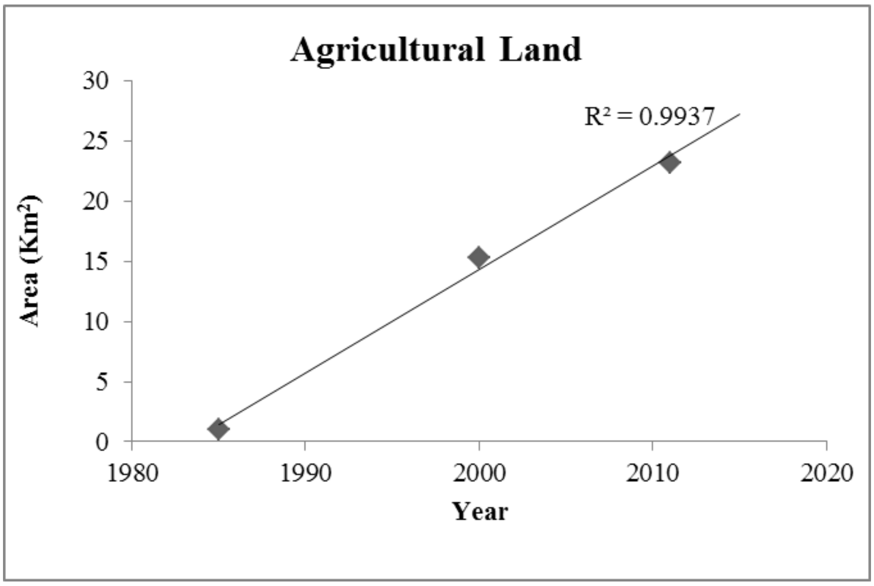


Figure 4. 5: Ten year projections (2020) of agricultural land in Suswa Catchment

Future projections (Figure 4.5), indicates an increase in the area under agricultural land (R^2 = 0.9937) will occur in ten years in the Suswa Catchment probably due to increased cultivation. Therefore there is a high relationship (99.37%) between agriculture and gully formation in the next ten year period.

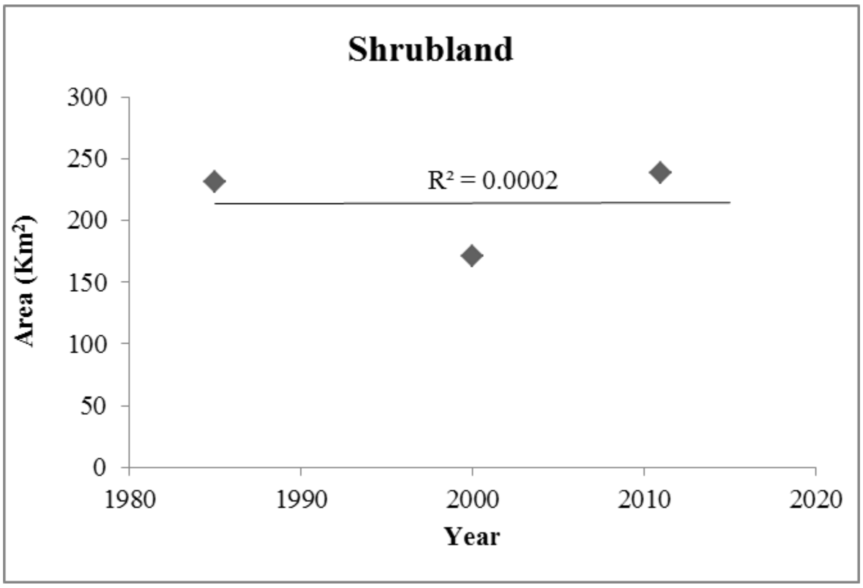


Figure 4. 6: Ten year projections (2020) of shrubland change in Suswa Catchment

From the projections (Figure 4.6), indicates no significant changes in shrubland (R^2 = 0.0002) in the coming ten year period in the Suswa Catchment, which probably indicates that exploitation may be minimal. Therefore there is a minimal association (0.02%) between shrubland and gully erosion risk in the coming ten year period.

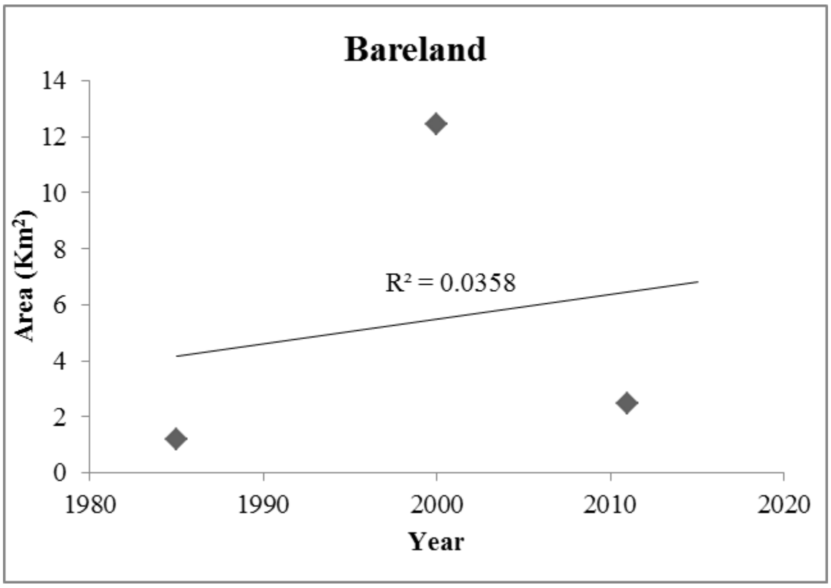


Figure 4. 7: Ten year projections (2020) of bareland change in Suswa Catchment

Future projections (Figure 4.7), indicate a significant increase in bareland (R^2 = 0.0358) which will be characterized in the coming ten year period in the study area probably due to increased soil erosion due to lack of vegetation cover. Therefore there is a minimal association (3.58%) between bareland and gully development in the next ten year period. Therefore bareland will not be a major driver of gully formation and development in the next 10 years.

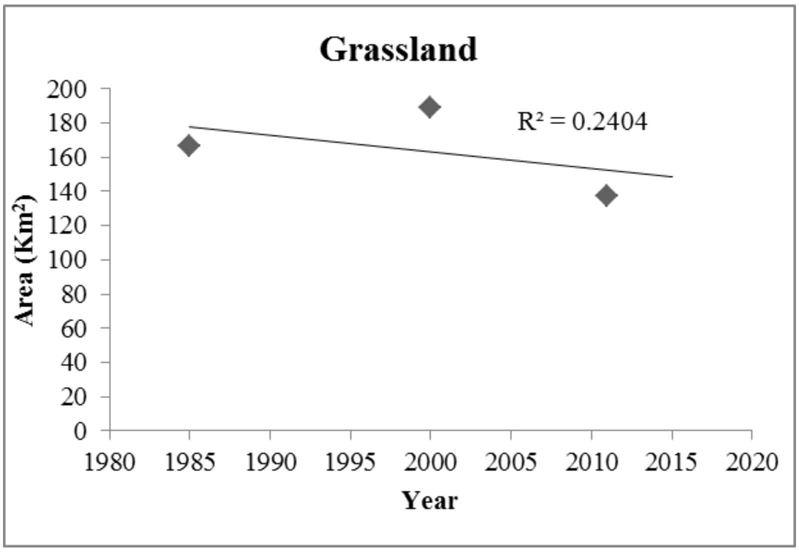


Figure 4. 8: Ten year projections (2020) of grassland change in Suswa Catchment

From the projections (Figure 4.8) a significant decrease of grassland (R^2 = 0.2404) will characterize the land use in the coming ten year period in the Suswa Catchment possibly due to overgrazing. Therefore there is a minimal relationship (24.04%) between grassland and gully formation in the coming ten year period.

4.4 Discussion

Satellite image analysis showed that land use and land cover changes have occurred in the area between 1985 and 2011. Between 1985 and 2000, built up area, bareland, grassland and agricultural land continued to expand, while shrubland decreased. Shrubland was therefore converted to built up area, bareland, grassland and agricultural land. Between 2000 and 2011, built up area, shrubland, bareland continued to expand, while grassland decreased. Grassland was therefore converted to built up area, bareland and agricultural land. Although built up areas, agricultural land, bareland, grassland and shrubland did not change significantly for the period under investigation, it was observed that the overall change of built up area, shrubland, bareland, agricultural land expanded between 1985 and 2011, while grassland decreased during this period. Grassland was therefore converted to built up area, shrubland, bareland and agricultural land during this period. An increase in built up area, bareland and agricultural land and a decrease in grassland are probable drivers of gully erosion. An increase in built up area results in a decrease in grassland.

In a Participatory Geographic Information Systems (PGIS) study in the area (by this author) it was observed that between 1985 and 2011 (26 years), there was an overall increase in built up area and bareland and decrease in shrubland and grassland in the 4 villages (Olepolos, Enkiloriti, Eluai and Olesharo). Therefore remote sensing and PGIS analysis both showed that a decrease in grassland was a driver of gully erosion in the study area. Although there was an overall increase in shrubland (an increase by 39.39% in 2011), this was due to invasive species observed in the study area. Invasive species were observed in areas of soil deposition which had very little grass and shrubs. Cheche *et al.,* (2015) in Narok observed similar results to this study in that, about 30% of the encountered species were exotic species that might have been introduced in the rangelands by human activities. Exotic species (*Datura suaveolens*, *Dovyalis caffra* and *Hibiscus rosa-sinesis*) were common in degraded areas with less than 40% vegetation cover. Invasive alien plant species (*D. suaveolens*, *Lantana camara*, *L. trifolia* and *Opuntia ficus-indica*) therefore affected grasslands by lowering yield and quality of forage, further leading to soil degradation.

Agricultural practices accelerate erosion through compaction, reduce water holding capacities and increasing erosion (Van-Camp *et al*., 2004). Agricultural practices without adequate conservation measures such as in the case of Suswa area is linked to erosion. Cultivation exposes bare soil to rain, which could be the case in the study area. Overgrazing is a driver of gully erosion in rangelands, such as the Suswa

Catchment. According to Veblen *et al.,* (2014) livestock grazing reduces pasture and shrubs hence, affecting rangeland health. Poor rangeland health could be due to historic grazing intensity which is the case in the Suswa area. In the study area grassland decreased by 17.41% between 1985 and 2011 indicating poor rangeland health. Land-use and land cover change is associated with transitions, which reinforce each other. According to Lambin et *al.,* (2003) transitions in land use/cover must be viewed as reversible dynamics. Transitions are development paths where the direction, size, and speed can be influenced. Historical land use and land cover changes therefore may have significant impact on erosion, which could be the case in the study area.

Similar results to this study were observed by Duvert *et al*., (2010) in the Mexican Central Highlands, indicating that traditional cropping practices with cattle grazing leads to severe soil degradation in the Cointzio basin. Therefore the formation of gullies in Huertitas and Potrerillos was triggered by these practices, which is also the case in Suswa Catchment. Okoti *et al*, (2006) observed a similar relationship in Marsabit where there was an increase in gully erosion, especially near settlement areas due to animal trampling and cutting of vegetation. As a result eroded places hardly support any vegetation. Observations by Yannelli *et al*., (2013) in Argentina showed that grazed fields and abandoned crop fields were much more susceptible to potential gully erosion. Results by Wessels *et a*l., (2007) in South Africa showed that long-term heavy grazing was the cause of range degradation. Vagen *et al*., (2013) in Ethiopia observed that soil erosion was due to overgrazing further exposing the soils. Leh *et al.,* (2011) in Arkansas showed that increased erosion risk in barren areas was not surprising because larger barren coverage meant larger areas without protective soil cover and therefore increased the risk of soil erosion. Results by Tesfahunegn *et al*.,

(2014) observed similar relationships in the Northern Ethiopia catchment, indicating that the highest rates of soil detachment occurred in marginal lands, and subsoil exposed soils having low soil resistance to detaching forces.

Sakthivel *et al.,* (2011) in India observed erosion hazard zones in areas with human settlements where agricultural activities are practiced. Also, high soil erosion prone areas were found at Pattimedu, Jadayagaundan (Southern portion), Kanai and Puttai reserved forests (Eastern portion) and this was attributed to deforestation and human interferences. In the study area built up area 1985-2011) increased by 68.83% between1985-2011 indicating human interferences. Observations by Sulieman *et al.,* (2013) in Eastern Sudan, showed that natural vegetation has been reduced from 26.1% in 1979 to 12.6% in 1999 and further to 9.4% in 2007. The majority of this reduction went into agricultural land. This reduction has exposed the soil surface to accelerated water erosion. The decrease or disappearance of certain plant species and reduced vegetation cover has increased the exposure of soil surfaces to wind and water erosion, which is the case in the study area.

Klaus *et al.,* (2014) in Morocco reported that agricultural practice influenced runoff within the catchment. Casasnovas *et al.,* (2009) in Spain showed that agriculture caused an increase in soil loss. A similar observation was seen in Suswa in that agricultural land increased by 2216% between 1985 and 2011. Casasnovas et *al.,* (2000) in Spain also showed that the main cause of soil erosion is the uncontrolled transformation of old vineyard plantations through mechanisation. The resulting soils from land transformation are therefore highly susceptible to erosion, which reduces the possibilities of water intake and most of the rain is lost as runoff. Land transformations through the use of farm machines in Suswa catchment could therefore be a probable cause of gully erosion. Xiubin *et al.,* (2004) in the Chinese Loess Plateau also observed that deforestation and cultivation exposed the fragile soil to water erosion. Xin *et al., (*2010) in the Chinese Loess Plateau indicated that there was a critical threshold in the relationship among sediment yield and vegetation cover. Therefore vegetation cover may provide the thresholds required for runoff and soil erosion, which is the case in the Suswa Catchment. Katsurada (2007) in Kendu escarpment, Nyanza province observed a similar relationship with areas with scarce vegetation and steep slope and sedimentation causing rapid runoff and severe gully erosion.

Results Omuto *et al*., (2011) in Somalia, showed that about one-third of the country was degraded because of the loss of vegetation cover, topsoil loss and decline of soil moisture. Overgrazing, excessive cutting of trees, and poor agronomic practices in agricultural areas were the primary drivers of land degradation. Maeda *et al., (*2010) in Taita Hills indicated that if current trends persist, it is expected that agricultural areas will occupy 60% of the study area by 2030, similar to Suswa. These changes will result in accelerated soil erosion. In addition, agricultural expansion will inevitably result in increased soil erosion due to changes in vegetation cover which is the case in the study area. From the projections a significant increase in built up area, agriculture and bareland and a decrease of grassland will characterize the coming ten year period (2020) in the Suswa Catchment.

Liavoga *et al.,* (2014) Yatta sub county observed that there was a decline in the area under traditional crops and an increase in introduced crops mainly maize and beans. Results also showed an increase in bare land and a decrease in shrubland. In the study area, bareland increased by 103.31% between 1985 and 2011 also. According to Liavoga et al (2014), the observed trends have implications for food security and dwindling land resources, which could be the case in the study area. Campbell *et al*., (2005) in Loitokitok, Kajiado District, observed that rain fed agriculture and livestock herding were the main causes of land use and land cover change in the area. As a result the ability of the Maasai herders to maintain their long-established livestock system has been curtailed and many now combine livestock and cropping.

Ayuyo *et al*., (2014) showed that changes in land use and land cover had occurred in the Mau forest complex, resulting in the reduction of forest cover. This is because the local community depend on forest products for farming, building materials, wood fuel, and charcoal burning which could be the case in the study area. Njoka *et al*., (2003) in Lambwe Valley, southwestern Kenya observed that human settlement caused land-use and cover changes, resulting in a scramble for the remaining high potential land, which could be the case in the study area. Mundia *et al*., (2009) in the Masai Mara Ecosystem, showed that agricultural expansion and an increase in cattle and sheep lead to diminishing pastures.

Similar observations to this study were made by Nyariki *et al*., (2009) in the Masai-Mara Ecosystem, in which patterns of land-use have changed from nomadic pastoralism to sedentary pastoralism, agropastoralism, and in some cases pure cultivation. These trends have adversely affected livestock production and diminished grazing areas. According to Maitima *et al*., (2009) land use changes in East Africa have transformed land cover to farmlands, grazing lands, human settlements and urban centres at the expense of natural vegetation. These changes are associated with deforestation and land degradation. Similar results to this study were observed by Gachene, *et al.*, (2015) in Lower Tana River Forest Complex in which forest cover decreased from about 7185.52 km^2 in 1995 to 1852.6 km^2 in 2004, a 74.2 per cent loss.

The area under agriculture increased considerably by almost ten times, from 243.87 km^2 in 1995 to 2346.65 km^2 ha in 2004, a 862.25% gain. This means that most of the area previously under forest was lost to cultivation. Opening the forest for cultivation and degradation is still continuing at an alarming rate, which is also the case in the study area. In Suswa, shrubland decreased by 26.18% between 19885 and 2000 indicating a change to other land uses.

From the projections a significant increase in built up area, agriculture and bareland and a decrease of grassland will characterize the coming ten year period in the Suswa Catchment. This scenario is likely to lead to further gully erosion activity as more areas will be opened up for agriculture and settlement. With no interventions, gully erosion activity will continue resulting in a threat to livelihoods in terms of agriculture and livestock grazing. Scenarios of land-use and land cover change therefore help to explore possible futures and can generate indicators of ecological sustainability or of vulnerability of ecosystems and people. Projections can be used as an early warning system for the effects of future land use changes and pin-point hot-spots that are priority areas for in depth analysis (Verburg, 2006).

Haregeweyn *et al.,* (2017) working in Ethiopia observed that projections can help improve assessments and management of erosion risk in river basins, evaluate the effectiveness of soil conservation practices while minimizing on-site and off-site erosion risks. Dymond *et al.,* (2010) in New Zealand reported that projected scenarios can estimate sediment for different land-use scenarios, which is also useful for the current study area. Vicente *et al.,* (2013) in Spain found that future projections can assess the effect of agricultural terraces and land abandonment on the rates of soil erosion. Similar observations were made by Alatorre *et al.,* (2012) in Spain in that projected scenarios can assess sediments on abandonment land. Chiverrell (2006) working in England reported that future scenarios can help identify causes of landscape instability. Paroissien *et al.,* (2015) in France observed that scenarios can assess soil sustainability to erosion under changes in land use and climate. Ruiz *et al.,* (2013) reported that projections can provide guidance for agricultural policy, improve identification of runoff and sediment contributing areas and soil conservation. Debolini *et al.,* (2013) in Italy observed that projections create alternative land use and land cover scenarios for the near future. Leh *et al.,* (2011) in the United States of America (USA) observed that scenarios can identify trends of land use and land cover change and predict their impacts on soil erosion. Feng *et al.,* (2010) in China reported that projected scenarios can predict the catchment sediment output.

4.5 Conclusions and Recommendations

From this study it was observed that the overall change of built up area, shrubland, bareland, agriculture expanded in 26 years (1985-2011), while grassland decreased during this period. Grassland was converted to built up area, shrubland, bareland and agriculture during this time period. An increase in built up area, bareland and agriculture and a decrease in grassland are therefore likely to be drivers of gully erosion which is affecting the area. From the projections, a significant increase in built up area, agriculture and bareland and a decrease of grassland will characterize the coming ten year period (2020) in the Suswa Catchment. If the present scenario continues, then gully erosion activity will continue. Therefore there is a need for land use planning in Suswa Catchment for effective rehabilitation of the gully and also reduce threats to livelihoods. Monitoring of actual soil erosion should be done under different land use systems in the study area in order to determine hot spots for effective land use planning. An assessment of invasive alien plant species and their impacts on soil degradation needs to be done.

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CHAPTER 5

Assessing the drivers of gully formation and development using participatory geographic information systems (PGIS) in Suswa Catchment, Narok County

5.1 Introduction

The merging of community development with geo-spatial technologies for the empowerment of less privileged communities is known as participatory geographic information systems or PGIS (Rambaldi *et al.*, 2006). PGIS combines a range of geo-spatial information management tools and methods such as sketch maps, satellite imagery, and global positioning systems (GPS) to represent people's spatial knowledge for discussion, information exchange, analysis, decision making and advocacy. The adoption of participatory action by involving community members, for assessing the resource base conditions has become an attractive methodology for many conservation and development studies (Pathak *et al.*, 2006). PGIS therefore helps to achieve development efforts that are socially desirable and ecologically suitable (Pokhrel, 2011).

PGIS helps community members identify, locate and classify past and present resource occurrence, distribution, use, tenure and access, and to reveal the significance the participants attach to them (IIRR, 1998). PGIS maps reflect the perception and vision of the community members about the resources and features they are portraying and also provide insight on relationships. The documentation and mapping of indigenous knowledge and traditional knowledge preserves and honours knowledge held by local indigenous people, whose ancestors have inhabited a region, or people who are new to a region bring their own traditions to a new community. The transfer of PGIS information into a computerized format provides a valuable contribution to resource management planning. PGIS for natural resource management (NRM) helps improve communication between scientific and indigenous communities, bridging knowledge divides and contributing to sustainable development (Bhattacharyya, 2006*)*.Therefore, it is necessary to bring local and scientific knowledge together to improve everyone's understanding of ecosystem services and processes, and to promote mutual respect between the holders of such knowledge (Chalmers *et al.*, 2007).

Land use change scenario maps such as PGIS maps illustrate changes in the landscape and also translate visions provided by the local community (Bohnet *et al.,* 2007). Landscape scenarios therefore show the effect of land use on land conditions. Landscape visualisations are ideal because they are easily accessible, attract attention and enhance participation in planning and management. Participatory natural resource management therefore includes community visioning for effective resource planning and monitoring (Sanginga *et al.,* 2004). Spatial maps are decision support frameworks for hazard assessment and management i.e. gullies (Ochola *et al.,* 2003). By defining the conditions of use of present resources, then better land use decision-making can be incorporated for sustainability. Participatory mapping therefore help in the analysis of problems such as land degradation and natural resource monitoring for informed decision-making and management at the local level (FAO, 2003). Participatory ecological monitoring is an effective approach for detecting trends, raising awareness and stimulating collaboration for sustainable management of resources (Andrianandrasana *et al.,* 2005). Participatory processes therefore make extensive use of stakeholder knowledge thus ensuring protection of natural resources (Puri *et al.,* 2003).

According to Pathak *et al*., (2006) causes of gully formation are overgrazing, expansion of cultivation in marginal land and deforestation. These factors determine the potential hazard, intensity and rate of gully advance (Pathak *et al.,* 2006). Gullies are destructive and cannot be eliminated by ploughing because of depth. Damages due to gully erosion include disconnection of roads and bridge damages, recession of water table, immigration of people and movement of the location of villages (Shahrivar *et al.,* 2012). The current study was carried out in an area where gully erosion is already affecting the community and livestock. The gully is cutting through homesteads making movement difficult while some of the livestock is reported to fall into the gully and homes are being flooded. The objective of this study was to establish drivers of gully formation and development using participatory geographic information systems (PGIS) with the local communities in Suswa Catchment, Narok County.

5.2 Materials and Methods

The description of the study area and methodology is given in Chapter 3.

5.3 Land use and land cover change analysis using PGIS

Community members from four villages near the gully were identified. In each of the 4 villages (Eluai, Olepolos, Olesharo and Enkiloriti), purposive sampling was used to identify 20 participants who included 10 individuals between 18-35 years, and 10 individuals above 50 years. The 36 to 49 age group was omitted because the youth and elderly were the target groups, inorder to better understand the historical land use and land cover changes. Gender balance was 1: 1 per age group. Participants drew land use and land cover change maps in Manila papers for the period 1985, 2000 and 2011 to detect how land use and land cover has changed over time.

The land features targeted during the PGIS session included forests, the gully, grassland, water resources, settlements, agricultural land, schools, shops, churches and roads. These were features that the community considers as important resources which they depend on for their livelihood. Ground – truthing of any of the following 5 key features (namely water resources, schools, shops, churches, gully and roads) was done using a GPS for each village. The 5 key features were selected based on whether they were accessible. The PGIS maps were then exported to Arcview-GIS software to calculate areas under different land cover and land uses (namely, forest, agricultural land, grassland, water bodies and settlement). Percentage changes were determined for the period between 1985-2000, 2000-2011 and 1985-2011. Chi-square test was used to determine if there were significant changes in land use and land cover change. Direct and indirect benefits and undesirable effects of the changes of the major land resources were discussed.

5.4 Results

5.4.1 Land use and land cover changes between 1985 and 2011 using PGIS

Land use and land cover changes were observed on grasslands, forests, settlements, agricultural land and water bodies as shown in the PGIS maps in four villages, namely Olepolos, Enkiloriti, Eluai and Olesharo (Figures 5.1). Land use and land cover changes for 1985, 2000 and 2011 for Suswa Catchment were analyzed as shown in Table 5.1.

The five land use and land cover types (namely built up area, shrubland, grassland, agricultural and bareland) were described in Eluai for 1985 (Figure 5.1). The area in this period were built up area (0.1 km^2), shrubland (29.71 km^2), grassland (10.44 km^2), agricultural (0.01 km^2) and bareland (0.70 km^2). The major land use types at this time were shrubland and grassland. Gullies were not present in Figure 5.1, since there was vegetation cover.

In Eluai for the year 2000 (Figure 5.1), a water pan (0.15 km^2) was established in this time period unlike in 1985 when it was not present. The area under grassland (14.37 km^2), bareland (2.05 km^2) agricultural (0.1 km^2), built up area (0.13 km^2) and water bodies (0.15 km^2) increased from 1985 while shrubland (28 km^2) decreased. Gullies were not seen in Figure 5.1 as vegetation cover was intact.

In Eluai village 2011 (Figure 5.1) the area under built up area (1.70 km^2), water bodies (1.05 km^2), agricultural (5.07 km^2) and grassland, bareland (5.78 km^2) increased from 2000 while shrubland (8.06 km^2) decreased. Gullies had developed as shown in Figure 3 largely due to a decrease in vegetation cover.

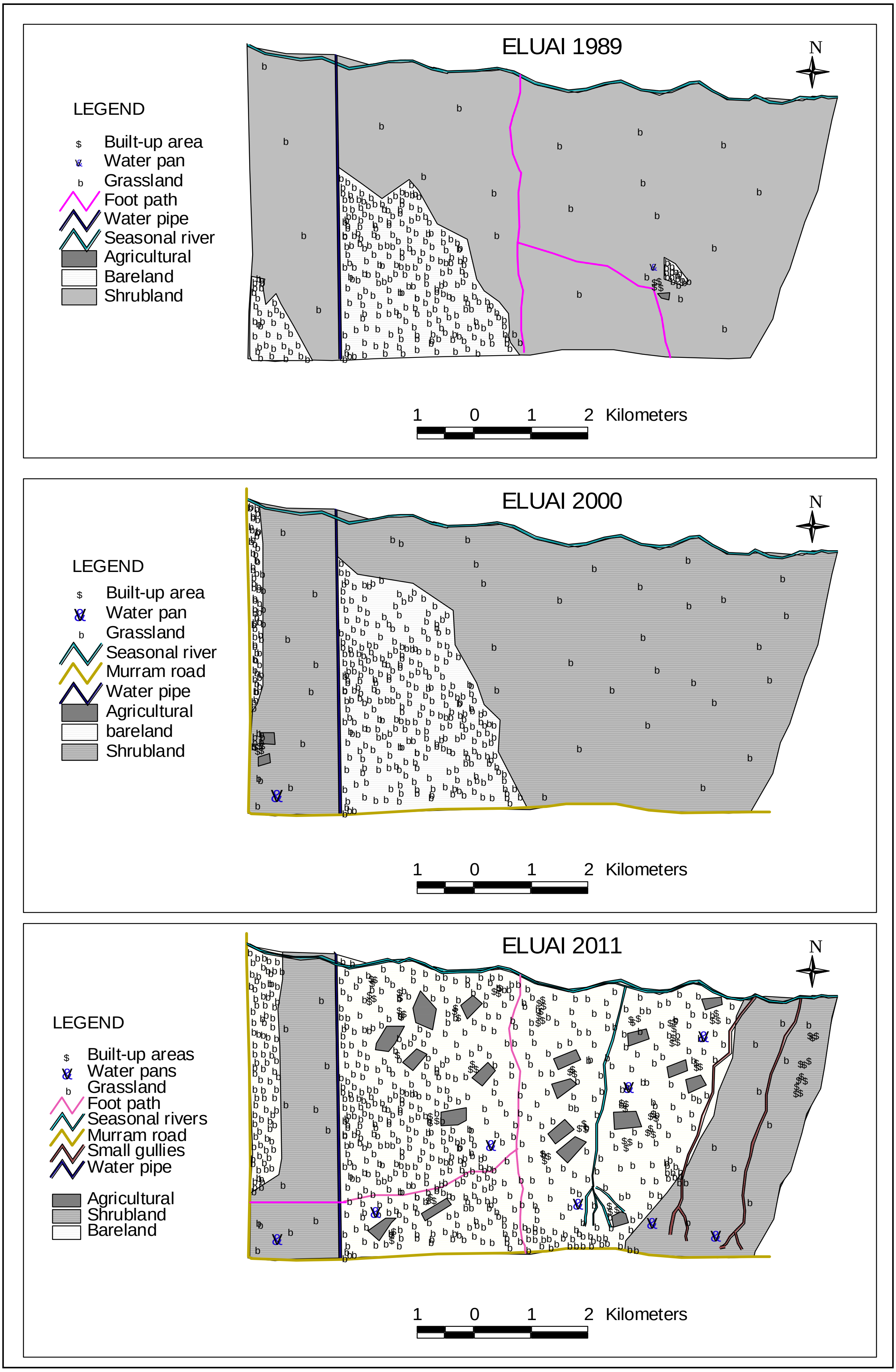

Figure 5. 1: Eluai village

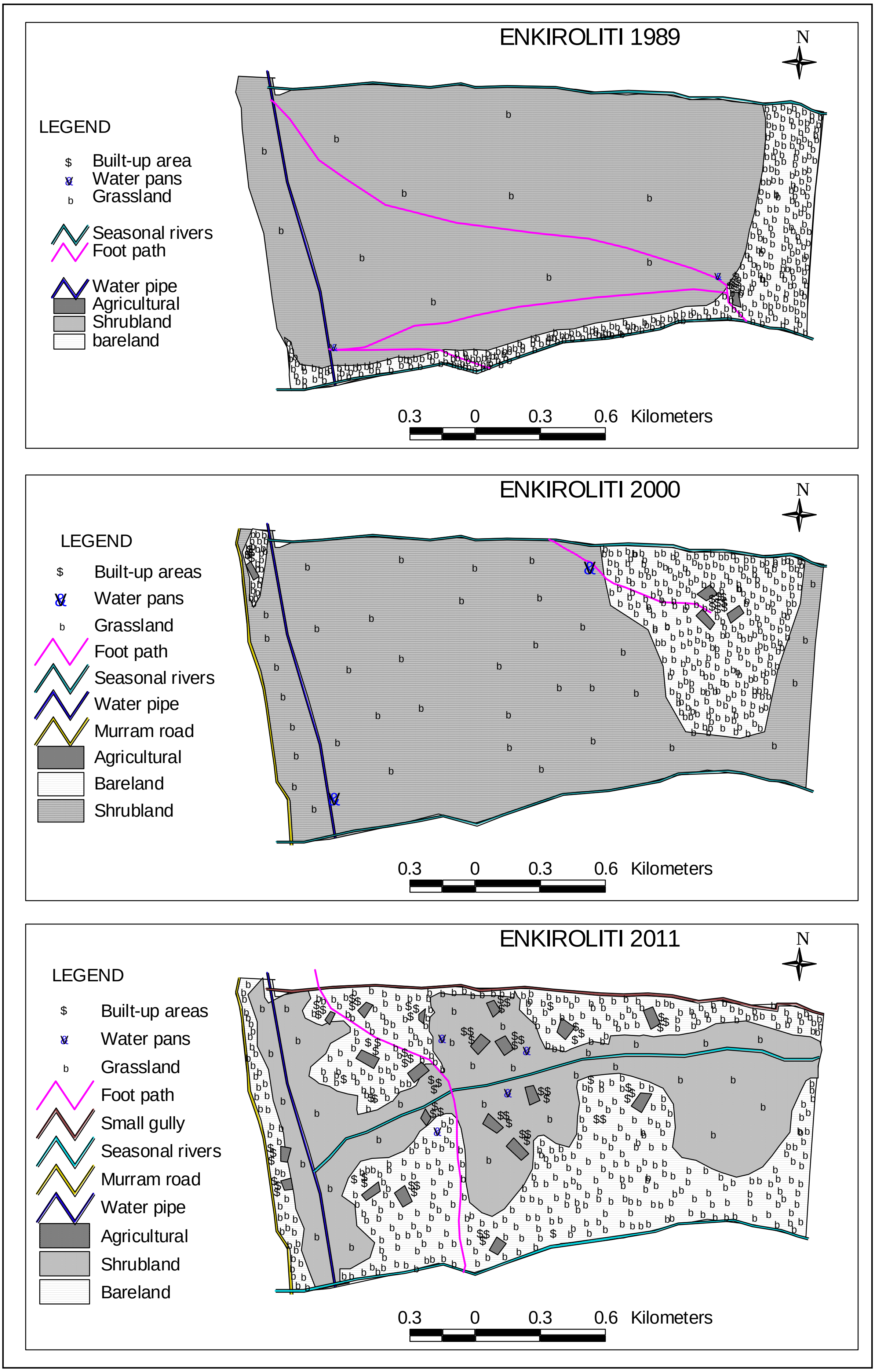

Figure 5. 2: Enkiloriti Village

Land use and land cover types were described in Enkiloriti for 1985 (Figure 5.2). The areas were: built up area (0.01 km^2), bareland (0.07 km^2), water bodies (0.001 km^2), agricultural land (0.001 km^2), shrubland (2.0 km^2) and grassland (1.05 km^2). The major land use types at this time were shrubland and grassland. Gullies had not formed as shown in Figure 5.2.

In Enkiloriti in the year 2000 (Figure 5.2), the area under built up area (0.02 km^2), bareland (0.16 km^2), water bodies (0.01 km^2), agricultural land (0.01 km^2), and grassland (1.14 km^2) increased while shrubland (1.81 km^2) decreased. Gullies were not present by this time (Figure 5.2).

In 2011 in Enkiloriti (Figure 5.2), the area under built up area (0.1 km^2), bareland (0.38 km^2), water bodies (0.02 km^2), agricultural land (0.3 km^2), and grassland (1.50 km^2) increased while shrubland (0.74 km^2) decreased. Gullies had developed as shown in Figure 5.2 due to a decrease in vegetation cover.

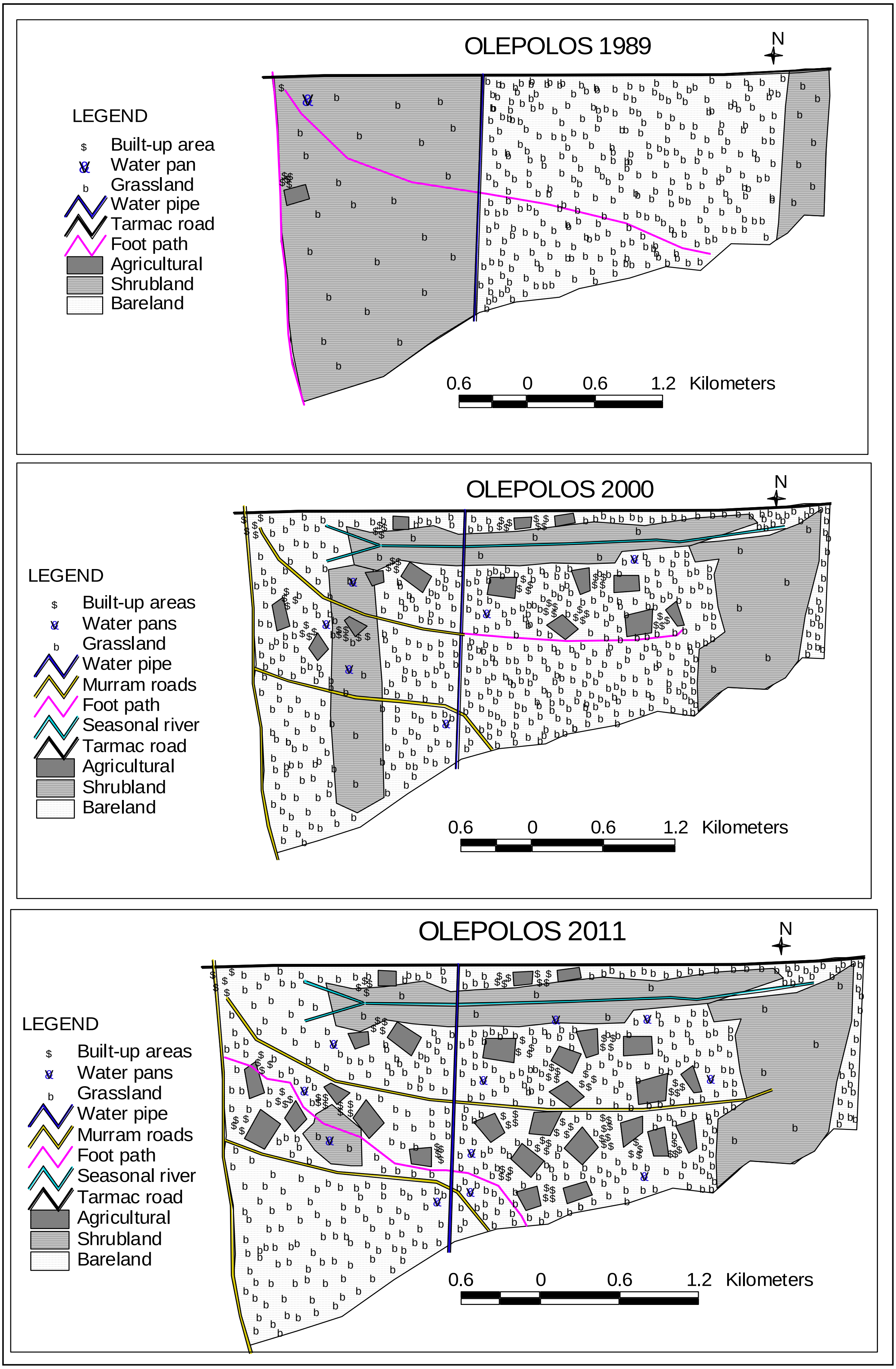

Figure 5. 3: Olepolos village

Six land use and land cover types were described in Olepolos in 1985 (Figure 5.3). The area under each land use type were: built up area (0.05 km^2), water bodies (0.04 km^2) and agricultural land (0.1 km^2), bareland (0.48 km^2), shrubland (3.62 km^2) and grassland (7.28 km^2). The major land use types at this time were shrubland and grassland. Gullies were not present at this time (Figure 5.3).

In Olepolos in 2000 (Figure 5.3), the area under built up area (0.52 km^2), water bodies (0.28 km2) and agricultural land (1.56 km^2), bareland (0.88 km^2) increased while shrubland (2.07 km^2) and grassland (6.16 km^2) decreased in 2000. Gullies had not formed in Figure 5.3. In the year 2011 in Olepolos in 2011 (Figure 5.3), the area under built up area (1.0 km^2), water bodies (0.44 km2) and agricultural land (3.0 km^2), bareland (1.17 km^2) increased while shrubland (1.19 km^2) and grassland (4.67 km^2) decreased. Gullies were present in Figure 5.3 due to a decrease in vegetative cover.

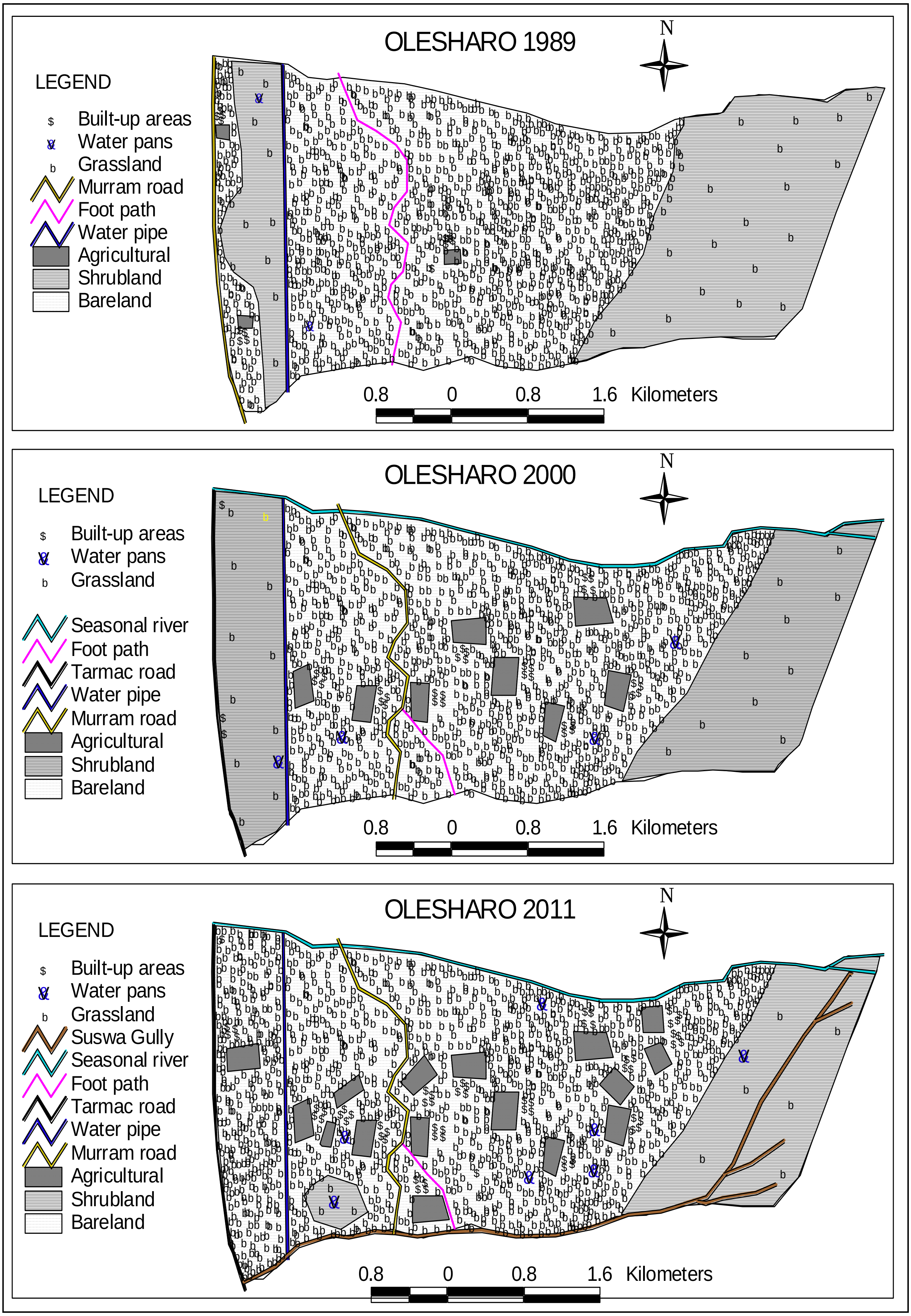

Figure 5. 4: Olesharo village

In Olesharo in 1985 (Figure 5.4), the areas under each land use and land cover type were: built up area (0.15 km2), water bodies (0.06 km^2), shrubland (5.67 km^2) and agricultural land (0.1 km^2) bareland (0.64 km^2) and grassland (9.6 km^2). The major land use types were shrubland and grassland in 1985. Gullies were not seen in Figure 5.4. Six land use and land cover types were described in Olesharo for 2000 (Figure 5.4). The area under built up area (0.52 km2), water bodies (0.12 km^2) and agricultural land (1.56 km^2) and shrubland (4.24 km^2) increased while bareland (1.22 km^2) and grassland (8.55 km^2) increased. Gullies were not present in Figure 5.4.

Land use and land cover types were described in Olesharo for 2000 (Figure 5.4). The area under built up area (1.13 km^2), water bodies (0.28 km^2) and agricultural land (3.38 km^2) increased while bareland (1.73 km^2), grassland (6.96 km^2) and shrubland (2.77 km^2) decreased at this time. Gullies had developed in Figure 5.4.

Table 5. 1: Land use and land cover change from PGIS maps

Village	Land use/cover	1989 Area (km^2)	2000 Area (km^2)	2011 Area (km^2)	Change (1989-2000) %	Change (2000-2011) %	Change (1989-2011) %	Chi-square test x^2	df	p
Olepolos	Built Up Area	0.05	0.52	1.0	+1200	+92.30	+ 1900	0.000	2	0.00
	Agricultural	0.1	1.56	3.0	+1460	+92.31	+2900	1.000	2	0.607
	Shrubland	3.62	2.07	1.19	-42.82	-42.52	-67.13	0.000	2	0.368
	Waterbodies	0.04	0.28	0.44	+600	+57.38	+1000	0.000	2	1.000
	Bareland	0.48	0.88	1.17	+83.33	+32.95	+143.75	0 .000	2	0.000
	Grassland	7.28	6.16	4.67	-15.38	-24.19	-35.85	0.333	2	0.846
Enkiloriti	Built up Area	0.01	0.02	0.1	+100	+400	+900	0.000	2	1.000
	Agicultural	0.001	0.01	0.3	+900	+200	+2900	0.000	2	1.000
	Shrubland	2.0	1.81	0.74	+95	-53.59	-58	0.400	2	0.819
	Waterbodies	0.001	0.01	0.02	+900	+50.00	+100	0.000	2	1.000
	Bareland	0.07	0.16	0.38	+100	+171.43	+442.86	0.000	2	1.000
	Grassland	1.05	1.14	1.50	+8.57	+31.58	+42.86	0.500	2	0.779
Eluai	Built up Area	0.1	0.13	1.70	+30	+1200	+1207.69	0.500	2	0.779
	Agricultural	0.01	0.1	5.07	+900	+5600	+50600	4.571	2	0.102
	Shrubland	29.71	28	8.06	-5.76	-71.25	-72.87	12.030	2	0.002
	Waterbodies	0.1	0.15	1.05	+50	+600	+950	0.0	2	1.000
	Bareland	0.70	2.05	5.78	+192.86	+181.46	+725.71	4.667	2	0.097
	Grassland	10.44	14.37	23.08	+37.64	+60.54	+127.97	5.660	2	0.059
Olesharo	Built up Area	0.15	0.52	1.13	+246.67	+117.31	+653.33	0.000	2	1.000
	Agricultural	0.1	1.56	3.38	+1460	+116.67	+3280	1.000	2	0.607
	Shrubland	5.76	4.24	2.77	-26.39	-34.67	-51.91	1.077	2	0.584
	Waterbodies	0.06	0.12	0.24	+100	+100	+300	0.00	2	1.00
	Bareland	0.64	1.22	1.73	+90.63	+42.62	+170.31	0.500	2	0.779
	Grassland	9.6	8.55	6.96	-10.94	-18.60	-27.50	0.540	2	0.764

In Olepolos village, built up area between 1985-2011 increased by 1900%. Shrubland change (1985-2011) decreased by 67.13%. Bareland between 1985-2011 increased by 143.75%. Overall agricultural land change (1985-2011) increased by 2900%. Water bodies change (1985-2011) increased by 1000%. In addition, there were significant changes ($p < 0.05$) in built up area and bareland and no significant changes in grassland, agricultural land, waterbodies and shrubland (Table 5.1). In Enkiloriti village, the overall built up area change (1985-2011) increased by 900%. Shrubland decreased between 1985 and 2011 by 58.00%. Bareland change (1985-2011) increased by 442.86%. Overall agricultural change (1985-2011) changed increased by 2900%. The overall change in water bodies between 1985-2011 increased by 100%. However, there were no significant changes ($p < 0.05$) in built up area, bareland, grassland, agricultural land, waterbodies and shrubland (Table 5.1).

In Eluai village, the overall built up area change (1985-2011) increased by 1207.69%. Shrubland change (1985-2011) decreased by 72.87%. Bareland between 1985-2011 increased by 725.71%. Overall grassland change (1985-2011) increased by 127.97%. Agricultural land between 1985-2011 increased by 50600 %. Overall water bodies between 1985-2011 increased by 950%. Also there were significant changes in shrubland ($p < 0.05$) and no significant changes in agricultural land, bareland, built up are, grassland and waterbodies (Table 5.1).

In Olesharo village, the overall built up area change (1985-2011) increased by 653.33%. Shrubland change (1985-2011) decreased by 51.91%. Bareland between (1985-2011) increased by 170.31%. Overall grassland change (1985-2011) decreased by 27.50%. Agricultural land between 1985-2011 increased by 3280%. Water bodies between 1985-2011 increased by 300%. In addition, there were no significant changes in built up area, bareland, agricultural land, waterbodies and shrubland (Table 5.1).

It was observed that between 1985 and 2011 (26 years), there was an overall increase in built up area and bareland and decrease in shrubland and grassland in the four villages (Olepolos, Enkiloriti, Eluai and Olesharo). In a remote sensing study in the same area by this author, it was observed that the overall change of settlement (built up area), shrubland, bareland, agricultural land expanded between 1985 and 2011, while grassland decreased during this period. Grassland area was therefore converted to built up area, shrubland, bareland and agricultural land during this time. Therefore remote sensing and PGIS agree that a decrease in grassland was a driver of gully erosion in the study area.

5.5 Participatory GIS community forums

Participants in community forums (20 participants in each of the 4 villages- Eluai, Olepolos, Olesharo and Enkiloriti) noted the following benefits and undesirable effects from land use change as shown in Table 5.2. The major land use change benefits were increased access to pasture land and firewood. Participants in the community forum noted undesirable land use change effects which included a decrease in shrubland, grazing area and rainfall, and an increase in wind erosion and flooding.

Table 5. 2 : Summary of benefits and undesirable effects of land use change by village

Benefits and undesirable effects	Eluai	Enkiloriti	Olesharo	Olepolos
(i) Food production	*	*	*	*
(ii) Availability of settlement area	*	*	*	*
(iii) Access to nursery/primary schools	*	*	*	*
(iv) Access to murram road/footpaths	*	*	*	*
(v) Increased pasture land	*	*	*	*
(vi) Access to firewood	*	*	*	*
(vii) Access to water (water pans)	*	*	*	*
(viii) Access to shops	*	*	*	*
(ix) Access to churches	*	*	*	*
(x) Access to police post/chief	*	*	*	*
(xi) Reduced rainfall	*	*	*	*
(xii) Increased wind erosion	*	*	*	*
(xiii) Reduced shrubland	*	*	*	*
(xiv) Floods (water erosion)	*	*	*	*
(xv) Reduced pasture	*	*	*	*
(xvi) Reduced food production	*	*	*	*
(xvii) Gully formation	*	*	*	*

Participants in the community forum were convinced on the importance of land use planning and gave recommendations to minimize the undesirable land use change effects which included a decrease in shrubland, grazing area, food production and rainfall, and an increase in wind erosion, gully formation and flooding. These recommendations included; (i) afforestation programmes (ii) construction of terraces for water harvesting (iii) training on the soil conservation measures (iv) use of alternative sources of energy other than charcoal.

5.6 Discussion

Participatory geographic information systems (PGIS) analysis showed that land use and land cover changes had occurred in the area between 1985 and 2011. Between 1985 and 2011 (26 years), there was an overall increase in built up area (Olepolos-1900%, Enkiloriti-900%, Eluai-1207.69% and Olesharo-653.33%), bareland (Olepolos-143.75%, Enkiloriti-442.86%, Eluai-725.71% and Olesharo-170.31%) and agricultural land (Olepolos-2900%, Enkiloriti-2900%, Eluai-50600% and Olesharo-3280%) and decrease in shrubland (Olepolos-67.13%, Enkiloriti-58.00%, Eluai-72.87% and Olesharo-51.91%) and grassland (Olepolos-1985 2011, Enkiloriti-1985 2011, Eluai-127.97% and Olesharo-27.50%) in the fou villages. In a remote sensing study in the area (by this author) it was observed that between 1985 and 2011 (26 years) in Suswa Catchment, shrubland increased by 2.90%, bareland by 103.31%, grassland decreased by 17.41%, agricultural land increased by 2216%. Grasslands were therefore converted to build up areas, shrubland, bareland and agricultural areas during this period. Therefore remote sensing and PGIS agree that a decrease in grassland was a driver of gully erosion in the study area.

Similar results to this study were observed by Kathumo *et al.*, (2012) who used PGIS to assess the trends in the decline of forest quantity and quality since 1970 of Lower Tana River Forest. The findings showed that land resource use changes from forestry to agricultural use, resulted in an increase in settlements, roads, schools and dispensaries in the area over time, which is similar to the current study. Between 1985 and 2011 (26 years) in Suswa, there was a decrease in shrubland (Olepolos-67.13%, Enkiloriti-58.00%, Eluai-72.87% and Olesharo-51.91%) to other land uses. PGIS therefore enabled communities in Lower Tana River to have an awareness of the magnitude of land use change, and a way forward to conserve the forest. Communities identified an increase in food production and settlement as the major benefits of land use and land cover changes. This is because the aim of the immigrants was to clear the forest and expand agricultural land for property rights. These benefits were however outweighed by undesirable effects such as reduced rainfall amounts, higher temperatures, reduction in water availability and river flows, human-wildlife and human-human conflicts. Therefore communities were aware of the effects of forest destruction which is similar to this study, because forests have a role in the hydrological cycle. In Suswa, participants in the community forum noted undesirable land use change effects which included a decrease in shrubland, grazing area and rainfall, and an increase in wind erosion and flooding.

Syombua (2013) in Taveta used PGIS to trace the changes in land use and land cover to reduce human-wildlife conflict. Results showed that agricultural expansion (both rainfed and irrigated), charcoal burning, overgrazing, lead to decimation of wildlife and livestock habitats of woodlands, forests, shrublands and wetlands. In Suswa, between 1985 and 2011 there was an increase agricultural land (Olepolos-2900%, Enkiloriti-2900%, Eluai-50600% and Olesharo-3280%) thus affecting other land uses. The local community also identified an increase in crop destruction, temperatures, rodent and pest attacks and environmental degradation which is consistent with this study, as the negative effects of land use and land cover changes. In Suswa between 1985 and 2011 there was an increase in bareland (Olepolos-143.75%, Enkiloriti-442.86%, Eluai-725.71% and Olesharo-170.31%) indicating degradation. PGIS therefore enabled local communities to link decimation of wild habitats to the intensification of human-wildlife conflicts. Community perceptions are therefore crucial for effective land use planning in the study area.

Bassols *et al*., (2009) observed that participatory resource mapping provided the basis for generating a consensus land-use plan, which is required in the study area for sustainability. Mbile *et al*., (2003) in Cameroon used PGIS and observed that farmers were able to visualize that trees can be used to address problems of land management, which is important for the study area. McCall *et al*., (2005) in Cameroon found that PGIS enabled land use planning decisions beyond community forestry. Tripathi *et al*., (2004) showed similar relationships to the current study in which PGIS enabled better information about land management status and options, so that communities can build consensus on uses and management. In Suswa, between 1985 and 2011 there was a decrease in grassland (Olepolos-1985 2011, Enkiloriti-1985 2011, Eluai-127.97% and Olesharo-27.50%) indicating that communities need to build consensus on land use and management. Rambaldi *et al*., (2006) observed that indigenous communities need to adopt participatory mapping methodologies to regain control over land resources, which is what is needed in Suswa.

Udayakumara *et al*., (2010) in Sri Lanka found that participatory approaches enabled farm households perceive that improper soil management and crop management practices, deforestation, urbanization, industry and natural causes resulted in soil erosion. Participatory approaches therefore enable the inclusion of community views for effective land use planning. Ifenkwe *et al.*, (2013) in Chitravas, India, observed that participatory approach to soil erosion enabled involvement of community members in planning extension programmes for success to draw attention to gaps. Participants in the community forum in Suswa therefore suggested recommendations towards minimizing the undesirable land use change effects which included afforestation programmes, construction of terraces for water harvesting, training on the soil conservation measures and the use of alternative sources of energy other than charcoal. PGIS therefore enabled a closer look into the local situation for effective land use planning, crucial for the Suswa Catchment.

In a study conducted by Giménez (2002) in Nicaragua, showed that sustainable land management practices have been effective at building and conserving soil, water and vegetation over time. Participatory approaches can therefore contribute to sustainable land management systems, crucial for the study area. Brown (2012) in South Australia on Regional and Environmental Planning observed that PGIS can assist in land use zoning and planning. Alagan *et al.,* (2012) in Sri Lanka observed that social and infrastructural mapping helped in resettlement site selection after natural disasters, which may be needed in the study area due to flooding. In Suswa, between 1985 and 2011, there was an increase in built up area (Olepolos-1900%, Enkiloriti-900%, Eluai-1207.69% and Olesharo-653.33%), therefore land use zoning and planning is needed.

In Nyando Valley, Martin *et al.*, (2012) reported that participatory asset-mapping helped to highlight assets which are crucial for land use planning.

ERMIS Africa (2007) also did mapping with marginalized communities of the Yiaku Peoples (also known as Mukogodo Peoples) living in the Mukogodo Forest of Laikipia, Northern Kenya, the Bwindi Impenetrable National Park in Uganda , the Sengwer People, Cherangany Forest Kenya and Ogiek Peoples in the Mau Forest Complex to map their territories. Elders designed their maps with memories dating back to 1925 and reconstructed the landscape as it was at that time. PGIS therefore helped to reduce the marginalization of these communities and the conservation of land resources which is important for the study area. USAID (2012) conducted a participatory mapping process in the Boni-Lungi-Dodori forest areas in Lamu County and inventoried natural resources for the purpose of identifying community land boundaries, protecting/conserving area resources and creating a framework for establishing shared use and access rights. Therefore PGIS helped in mapping land resources for conservation.

5.7 Conclusions and Recommendations

In conclusion it was observed in this study that changes in land use and land cover for 1985-2000, 2000-2011 and 1985-2011 occurred in the four villages (Eluai, Olepolos, Olesharo and Enkiloriti). There were significant changes in Eluai and Olepolos villages and no significant changes in built up areas, bareland, agricultural land, waterbodies, grassland and shrubland in Enkiloriti and Olesharo villages. It was observed that between 1985 and 2011 (26 years), there was an overall increase in built up area and bareland and decrease in shrubland and grassland in the 4 villages (Olepolos, Enkiloriti, Eluai and Olesharo).

Land use change benefits noted by communities included increased access to grazing areas and firewood. Undesirable land use change effects were a decrease in shrubland, food production, grazing area and rainfall, and an increase in wind erosion, gully formation and flooding (water erosion). Community recommendations included afforestation programmes, construction of terraces for water harvesting, training on soil conservation measures and use of appropriate alternative sources of energy other than charcoal. There is a need for land use zoning and planning in the study area for sustainability. Also early warning signs of erosion particularly in highly prone areas should be emphasized. The community also needs capacity building for effective land use planning and gully rehabilitation.

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CHAPTER 6

Effect of gully erosion on livelihoods in Suswa Catchment, Narok County

6.1 Introduction

A livelihood is sustainable when it can cope with and recover from stresses and shocks, maintain or enhance its capabilities and assets, while not undermining the natural resource base (Tang *et al.,* 2013). Sustainable livelihoods thus encompass the protection and assurance of the means of livelihood for people and society. In addition, a sustainable livelihood avoid depletion of natural resources to a level which results in a permanent decline (Forsyth, 2007). Sustainable livelihoods define environmental risk and resources. Therefore working with communities to define risks may build sustainable livelihoods. Sustainable livelihood approaches therefore seek to gain an understanding of resource access, use, and allocation and on the way in which individuals and households can transform resources into livelihoods (Thomsen *et al.*, 2001). Therefore the ways in which livelihood strategies relate to natural resource potentials at the community level are important in explaining environmental change.

Discussions on sustainable livelihood approaches have been on environmental risk, rather than being a way to specify risk of vulnerable people. Sustainable livelihood approaches have been used to build institutions in regard to resources and vulnerability. This approach is therefore a response to environmental stress. Soil erosion is one of the causes of risks to individual households. Responses to soil ensure that erosion is not as damaging as it might be. According to Oumer *et al.,* (2013) investing in soil management provides opportunities for diversification of livelihood options that minimize resource degradation. Households not investing in sustainable soil management practices are less likely to diversify their livelihoods, are trapped in poverty and have fewer opportunities. Consequently, these households are forced to pursue very risky and resource-degrading livelihood activities which include overexploitation of resources and overgrazing to sustain their livelihoods. Sustainable livelihood approaches emphasize reduced vulnerabilities to soil erosion inorder to influence future livelihood strategies.

According to Valentin *et al.,* (2008) as the pace of social change accelerates, large tracts of forest may be converted to agricultural land with potentially critical environmental implications that include a higher frequency of floods, droughts leading to crop failure and soils become subjected to misuse and unsustainable farming practices, resulting in degradation. As the land resource base becomes less productive, food security is compromised and competition for dwindling resources increases. Thus a downward spiral is created. This trend is both avoidable and reversible in many circumstances. Communities can seek innovations to stabilise or improve the resource base, or to compensate for their welfare effects by depending less on the degrading resource.

The enhancement in social–ecological systems can ameliorate and mitigate the impacts of hazardous processes significantly. Social–ecological systems can enable livelihoods to be more sustainable in the face of change (Gardner *et al.,* 2007). A household's experience of an environmental shock or change and how they cope with the event, may result in a dramatic change in livelihood activities with potentially negative welfare outcomes or may provide opportunities for learning and welfare improvement (Eakin *et al*., 2012). Livelihood responses to stress can therefore affect ecological and social functions including erosion control. This study investigated the effect of gully erosion on livelihoods in Suswa catchment, Narok County, Kenya.

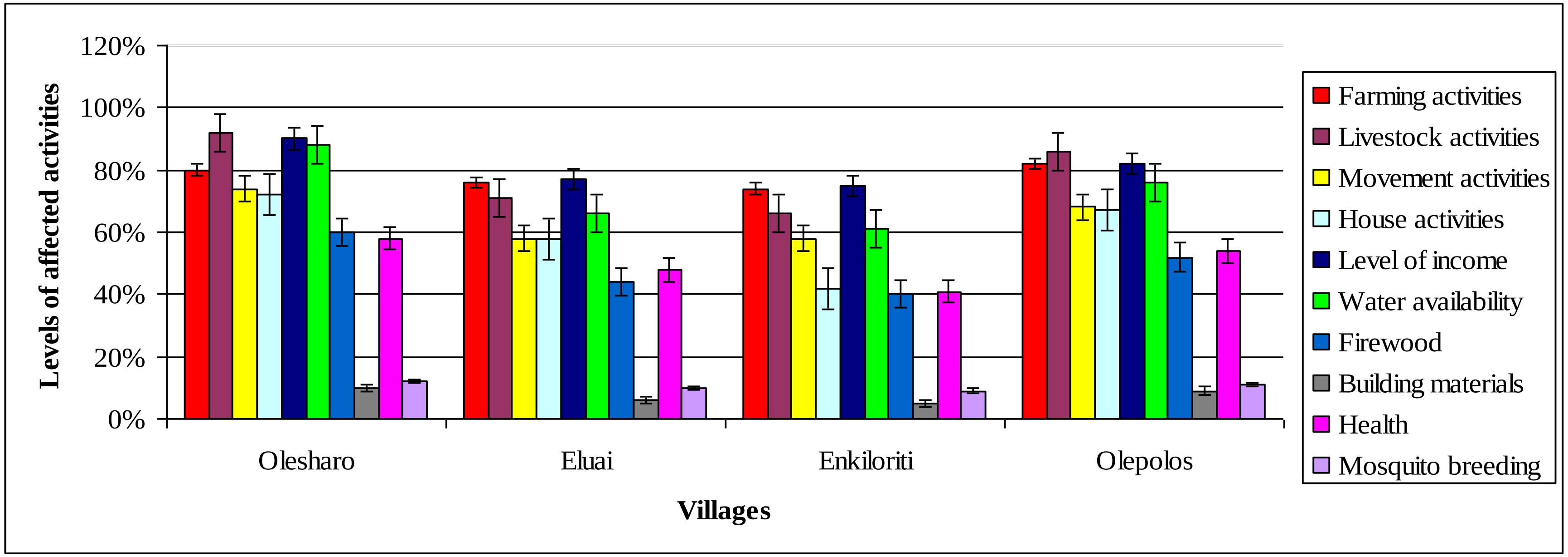
6.2 Materials and Methods

The description of the study area and methodology is given in Chapter 3.

6.3 Results and Discussion

The effect of gully erosion on livelihoods in Suswa Catchment are shown in Figures 6.1

Figure 6. 1: Percentage of the effect of gully erosion on livelihoods in Suswa catchment



The effect of gully erosion on livelihoods is shown in Figure 6.1. In Olesharo village, gully erosion had the greatest effect on livestock activities (92%), income levels (90%), followed by water availability (water pan-88%), farming activities (80%) and movement (74%). In Eluai village, gully erosion had the greatest effect on level of income (77%), farming activities (76%) followed by livestock activities (71%), water availability (water pan-58%), movement and house activities (58%). In Enkiloriti village, gully erosion had the greatest effect on level of income (75%), farming activities (74%), followed by livestock activities (66%), water availability (water pan-61%) and movement (58%). In Olepolos village, gully erosion had the greatest effect on livestock (86%), farming activities and level of income (82%), followed by water availability (water pan-76%), movement (68%) and house activities (67%). Majority of community members in the four villages earned less than Ksh. 10,000 per year. Respondents interviewed were aware of the effect of gully erosion on their livelihoods.

The Standard Error Bars in Figure 6.1 show that Olesharo village has a significant difference between Eluai and Enkiloriti villages but not Olepolos village in all the activities because of the close proximity of the gully to Olesharo and Olepolos villages. In addition there is no significant difference between Eluai and Enkiloriti in all activities because the two are far from the gully. There is also a significant difference between Olepolos and Enkiloriti in all activities because Olepolos is closer to the gully than Enkiloriti. Renschler *et al.*, (2002) showed similar results to this study in that erosion leads to yield reduction and sediment removal operations which affected farming activities. Lestrelin *et al.*, (2007) in Laos observed that erosion resulted in decreasing yields and land lost to gullies. Kusimi *et al.*, (2011) in Ghana showed that soil erosion results in socio-economic problems such as overgrazing, fuel wood fetching, land clearance for farming, food insecurity, low levels of income and drought. Therefore there was an increase in erosion without subsequent increase in agriculture productivity. In a Participatory Geographic Information Systems (PGIS) study in the area it was observed that between 1985 and 2011, there was an overall increase in built up area and bareland and decrease in shrubland and grassland in the 4 villages (Olepolos, Enkiloriti, Eluai and Olesharo). Therefore respondents felt that the effect on their livelihoods was due to gully erosion and land use and land cover changes (built up area, bareland, shrubland and grassland).

Table 6. 1: Effects of the gully on activities within the four villages

	Farming activities	Livestock activities	Movement activities	House activities	Level of income	Water availability	Firewood	Building materials	Health	Mosquito breeding
X^2	0.513	5.567	2.899	8.715	1.654	5.866	4.816	2.267	3.279	0.268
df	3	3	3	3	3	3	3	3	3	3
p value	0.916	0.135	0.407	0.033	0.118	0.647	0.186	0.519	0.351	0.966
Significance	Not significant	Not significant	Not significant	Significant	Not significant	Not significant	Not significant	Not significant	Not significant	Not significant

The effect of gully erosion on house activities (Table 6.1) differed significantly between the villages ($P < 0.05$). This could be due to the fact that houses near to the gully were the most affected by runoff. The effect of gully erosion on farming, livestock, level of income, water availability, firewood collection, building materials, health (mosquito breeding) did not differ significantly between the villages. This is because the effect on these activities was minimal in the four villages.

6.3.1 Level of damage within Suswa Catchment

Table 6. 2: Level of damage within the villages

Village	Olesharo (N=30)	Eluai (N=30)	Enkiloriti (N=30)	Olepolos N=30
Farming activities				
Severe	86	78	76	82
Moderate	12	14	14	14
Mild	2	8	10	4
Livestock activities				
Severe	90	78	76	82
Moderate	9	17	16	15
Mild	1	5	8	3
House activities				
Severe	76	42	40	68
Moderate	20	50	53	17
Mild	4	8	7	5
Water pans				
Severe	86	77	72	84
Moderate	12	16	19	11
Mild	2	7	9	5
Roads/foot paths				
Severe	84	78	75	8
Moderate	12	13	15	13
Mild	4	9	10	6

In Olesharo village the respondents interviewed (Table 6.2) felt that the level of damage to farming activities (maize, beans, wheat) was severe (86%), moderate (12%) and mild (2%) respectively. In Eluai village, the respondents felt that the level of crop damage (maize, beans, watermelon, tomatoes, potatoes, onions, kales and carrots) was severe (78%), moderate (14%) and mild (8%) respectively due to gully erosion. In Enkiloriti village, 76%, the respondents interviewed felt that the level of damage to farming activities (maize, beans, watermelon, tomatoes, potatoes, onions, kales and carrots) was severe (76%), moderate (14%) and mild (10%) respectively. In Olepolos village, the respondents felt that the level of damage (maize, beans, wheat) was severe (82%), moderate (14%) and mild (4%) respectively. The level of damage to farming activities in the villages could be due to runoff from the gully which uproots the crops. Community members therefore experienced losses in crop production. Majority of community members in the four villages owned farms of about 30 acres.

Amsalu *et al.*, (2006) in Ethiopia observed that farmers perceived soil problems as moderate, severe and mild. This shows that farmers understand erosion problems which influence their soil conservation decisions. Amsalu *et al.*, (2006) in Ethiopia showed that soil erosion was constraining crop production. Hella *et al*., (2003) in Tanzania observed that there was an increase of erosion without subsequent increase in agriculture productivity. Boardman *et al.*, (2009) in the UK reported that soil erosion on agricultural land is a growing problem and constitutes a threat to soil quality and to the ability of soils to provide environmental services. Gicheru *et al.*, (2012) in Narok, observed that increased soil erosion reduced nutrient availability to crops and pasture. Zegeye *et al.*, (2010) in Ethiopia indicated that farmers perceived soil erosion as a problem constraining crop production.

The level of damage to livestock activities in Olesharo village was 90% (severe), 9% (moderate) and1% (mild), Eluai 78% (severe), 17% (moderate) and 5% (mild), Enkiloriti 76% (severe), 16% (moderate) and 8% (mild) and in Olepolos 82% (severe), 15% (moderate) and 3% (mild). The level of damage to livestock activities and health in the villages was due to livestock falling inside the gully, dust getting into the eyes of livestock and livestock getting colds. Runoff from the gully could also have affected pasture with grass being uprooted by runoff. Majority of community members in the 4 villages in total, kept less than 50 cows, goats, sheep and chicken each.

Mekuria *et al.,* (2009) in Ethiopia observed that erosion contributed to poor health of livestock due to lack of pasture grass to feed on, loss of grazing land and poor bush regrowth. Ighodaro *et al.,* (2013) in South Africa found that soil erosion resulted in a negative effect on animal health, shortage of grazing land and farmland and poor production of crops. Agricultural land was also being reduced due to erosion activities. Farmers also indicated that soil erosion affected their profitability, product quality, yield and sustainability due to the effects on grazing land, production of crops and on animal health. Amman *et al.,* (2004) in Narok reported that high livestock levels caused degradation, which lead to high livestock mortalities, especially during critical periods of drought.

The most severely affected village in terms of damage to house activities was Olesharo (76%), Olepolos (68%), Eluai (42%) and Enkiloriti (40%). Those affected moderately and mildly were Olepolos (17%), Olesharo (20%), Eluai (50%) Enkiloriti (53%) and Olesharo (4%) Enkiloriti (7%), Olepolos (5%) and Eluai (8%) respectively. According to the communities, the severe damage to house activities (including the store) was due to flooding/runoff from the gully in Suswa catchment. Boardman *et al.,* (2009) in the United Kingdom observed that erosion resulted in the flooding of households.

According to community members the level of damage to water pans (Table 6.2) in Olesharo village was severe (Olesharo- 86%, Eluai-77%, Enkiloriti-72%, Olepolos-84%), moderate (Olesharo-12%, Eluai-16%, Enkiloriti-19%, Olepolos-5%) and mild (Olesharo-2%, Eluai-7%, Enkiloriti - 9%, Olepolos-5%). The severe damage to water pans within the villages could be due to siltation of the water pans from the gully in the study area. In Northern Thailand, Forsyth (2007) found that gullies were contributors to sedimentation. Boardman *et al.,* (2009) in the United Kingdom also observed erosion resulted in damage to the water reservoir. Gicheru *et al.,* (2012) in Narok observed that runoff polluted the water used for both livestock and human consumption. Udayakumara *et al.,* (2010) in Sri Lanka found that soil erosion resulted in deposition of sediment in the water bodies and led to deterioration of water quality. Felfoul *et al.,* (2003) in Tunisia indicated that limited rainfall combined with severe soil erosion was jeopardizing the efficiency of water reservoirs. Cantón *et al.,* (2011) in Spain reported that erosion lead to siltation of the water reservoir. Nalule (2010) in Uganda showed that erosion is resulting in silting of water structures.

The level of damage to roads/footpaths in Olesharo village ranged from 84% (severe), 12% (moderate) and 4% (mild), Eluai village, 78% (severe), 13% (moderate) and 9% (mild), Enkiloriti village, 75% (severe), 15% (moderate) and 10% (mild), and in Olepolos village, 81% (severe), 13% (moderate) and 6% (mild). The severe damage to roads/footpaths could be due to runoff/flooding from the gully, hence further affecting movement of community members, livestock, vehicles and motorcycles. Boardman *et* *al.,* (2009) in the United Kingdom indicated that erosion had noticeable impacts on roads. Stocking *et al.,* (2000) in the United Kingdom observed that footpaths can become gullies, which is the case in the study area. Gobin *et al.,* (2004) found that erosion resulted in deposition of sediments on roads and damage.

Table 6. 3: Responses (%) on the causes of the gully per each village

	Causes															
	Rainfall		Overgrazing		Farming		Deforestation		Roads		Topography		Soil type		Settlement	
Village	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Olesharo	99.0	1.0	90.0	10.0	84.0	16.0	92.0	8.0	78.9	22.0	76.0	24.0	54.0	46.0	28.0	72.0
Eluai	95.0	5.0	86.0	14.0	77.0	23.0	86.0	14.0	57.0	43.0	58.0	42.0	42.0	58.0	10.0	90.0
Enkiloriti	94.0	6.0	86.0	14.0	71.0	29.0	82.0	18.0	54.0	46.0	55.0	45.0	40.0	60.0	9.0	91.0
Olepolos	97.0	3.0	88.0	12.0	80.0	20.0	89.0	11.0	66.0	34.0	65.0	35.0	51.0	49.0	20.0	80.0

6.3.2 Causes of gully erosion in Suswa Catchment

In Olesharo village, respondents interviewed felt that the major cause of the Suswa gully (Table 6.3) was rainfall and deforestation, followed by overgrazing, farming, roads/footpaths, topography, soil type and settlement. In Eluai village, respondents felt that the major cause was rainfall, farming and overgrazing, followed by farming, topography, roads/footpaths, soil type and settlement. In Enkiloriti village, respondents interviewed felt that the major cause of the Suswa gully was rainfall and overgrazing, followed by deforestation, farming, topography, roads, soil type and settlement. In Olepolos village, respondents felt that the major cause was rainfall, overgrazing and deforestation, followed by farming, roads, topography, soil type and settlement. Respondents interviewed were therefore aware of the risk of erosion and its effects on their livelihoods. In a Participatory Geographic Information Systems (PGIS) study in the area it was observed that between 1985 and 2011, there was an overall increase in built up area and bareland and decrease in shrubland and grassland in the four villages (Olepolos, Enkiloriti, Eluai and Olesharo). Therefore an increase in built up area, bareland and agricultural land and a decrease in grassland are therefore likely drivers of gully erosion which is affecting the area. Respondents felt that rainfall, overgrazing, deforestation, farming, roads, topography, soil type and settlement contributed to gully formation and the effects on their livelihoods.

Julien *et al.,* (2011) in Benin found that local perception on the causes of erosion was due to deforestation, settlement, agricultural degradation, and animal stamping in the dry season. Okoba *et al* (2006, 2005) in Runyenjes Division observed that farmers identified erosion indicators as rainfall, runoff, steep slopes and soil surface conditions. Local knowledge of on-site erosion indicators could be useful in assessing site-specific erosion risk before planning any conservation measures. Amsalu *et al.,* (2006) in

Ethiopia reported that the major causes of soil erosion mentioned by farmers included erosive rains, steep slope, damaged conservation structures, and tillage which makes the soil loose and bare.

6.3.3 Soil conservation measures used in the farms

In Olesharo village, 2% and 1% of respondents interviewed had brushwood in their farms and practiced tree planting activities. In Eluai village, 1% and 1% had brushwood in their farms and practiced tree planting activities. In Enkiloriti village, 1% and 2% of respondents interviewed had brushwood in their farms and practiced tree planting respectively. In Olepolos village, 2 % and 1% of respondents had brushwood in their farms and practiced tree planting respectively. The low use of soil conservation measures in the Suswa catchment contributed to the gully in the study area. Fentie *et al,* (2013) in Ethiopia, observed similar results in that decisions to retain conservation structures are related to soil erosion perceptions, yield on farms, attitudes towards new technologies, exposure to new practices, productivity of technology, which is the case in the current study area. Mariara *et al.,* (2010) in Murang'a, Maragua and Narok observed that listening to extension agents affected the willingness to invest in soil conservation. Okoba *et al.,* (2005) in Runyenjes found that the main constraints to adoption soil conservation measures were lack of money, insufficient labour force, lack of tillage tools and poor knowledge about the benefits of soil conservation measures. Bielders *et al.,* (2003) in Belgium indicated that farmers most affected by erosion are also more likely to take measures.

Table 6. 4: Rehabilitation of the Suswa gully within the villages

	Mitigation measure (%)											
	By grazing		By advice from soil and water officer		By use of indigenous knowledge		By reducing livestock numbers		By soil conservation measures		By financial support	
Village	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Olesharo	90.0	10.0	99.0	1.0	91.0	9.0	90.0	10.0	97.9	3.0	96.0	4.0
Eluai	88.0	12.0	95.0	5.0	82.0	18.0	82.0	8.0	91.0	9.0	93.0	7.0
Enkiloriti	87.0	13.0	94.0	6.0	80.0	10.0	81.0	9.0	90.0	10.0	93.0	7.0
Olepolos	90.0	10.0	97.0	3.0	86.0	14.0	96.0	4.0	95.0	5.0	95.0	5.0

In Olesharo village, respondents interviewed felt that the major focus for the rehabilitation of the Suswa gully (Table 6.4) should be the use of soil and water extension services (99%), followed by the use of soil conservation measures (97%), financial support (96%), indigenous knowledge (91%), training (91%) and the reduction of livestock numbers (90%). In Eluai village, respondents felt that the focus for the rehabilitation should be the use of soil and water extension services (95%), financial support (93%), followed by the use of soil conservation measures (91%), training (88%), the use of indigenous knowledge (82%) and the reduction of livestock numbers (82%). In Enkiloriti village, respondents interviewed felt that the major focus of rehabilitation of the Suswa gully should be the use of soil and water extension services (94%), financial support (93%), followed by soil conservation measures (90%), training (87%), reduction of livestock numbers (81%) and the use of indigenous knowledge (80%). In Olepolos village, respondents felt that the major focus should be the use of soil and water extension services (97%), financial support (95%) and soil and conservation measures (95%), followed by training (90%), the use of indigenous knowledge (86%) and reduction of livestock numbers (86%). Respondents interviewed were therefore aware of the major ways/benefits to minimize the negative effects of gully erosion in the Suswa catchment.

Oumer *et al.,* (2013) in Ethiopia observed that households perceive soil degradation in a number of ways and will react differently when adopting management practices. Fentie *et al.,* (2013) in Ethiopia found that extension education motivated the use of soil conservation measures. Also providing information on long term impact of soil erosion and project assistance had positive and significant influence on conservation decisions. Barungi *et al.,* (2013) in Uganda reported that access to extension services increases the likelihood of adopting soil erosion control technologies. Alufah *et al.*, (2012) in Ngaciuma Sub-Catchment, Kenya observed that access to information and extension services leads to the adoption of soil conservation technologies.

6.4 Conclusion and Recommendations

It was observed that the effect of gully erosion on houses differed significantly between the four villages - Eluai, Olepolos, Olesharo and Enkiloriti. This could be due to the fact that houses near the gully where the most affected by runoff. The effect of gully erosion on farming, livestock, level of income, water availability, firewood collection, building materials, health and mosquito breeding did not differ significantly between the villages. This is because the effect on the mentioned livelihood activities was more or less the same in the four villages. According to community members the level of damage to farming, livestock, house activities, water pan and road/footpath was severe. Community members were also aware of the risk of erosion and its effects on their livelihoods.

The low use of soil conservation measures in the Suswa catchment could have contributed to negative effects on livelihood activities. Community recommendations for the rehabilitation of the gully included the use of soil and water extension services, soil and conservation measures, training, the use of indigenous knowledge and reduction of livestock numbers and financial support. Vulnerable periods for erosion need to be identified by the community in order to minimize threats to their livelihoods. Community members need capacity building particularly in the adoption of soil conservation measures and water pan management in order to minimize the negative effects on their livelihoods. Also the community needs to diversify their activities for a more sustainable livelihood.

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APPENDIX 1: Questionnaire

Division…………………………………Location…………………………………
…..

Sub-
Location……………………………Village……………………………………….

PART A: PERSONAL INFORMATION

1. Sex Male ( ) Female ( )
2. Age Less than 20 ( ) 21-29 ( ) 30-39 ( ) 40 -49 ( ) 50-59 ( )

   60-69 ( ) 70-80 ( ) Above 81 ( )
3. Household head Male ( ) Female ( )
4. Education level Primary ( ) Secondary ( ) Tertiary ( ) University ( )

   None ( )
5. How long have you lived in this area? Less than 5 years ( ) 6-10 years ( )

   11-15 years ( )Over 16 years ( )
6. Number of children Less than 5 ( ) More than 5 ( )
7. Number of wives 1 ( ) 2 ( ) More than 2 ( )

PART B: LAND USE

8. Farm size ……………………………………(acres)
9. Do you have a title deed for this farm? Yes ( ) No ( )
10. What crops do you grow? Maize ( ) Beans ( ) Other ( )………………….
11. What animals do you keep? Cows ( ) Goats ( ) Sheep ( ) Chicken( )

    Other ( )…………………..
12. How many animals do you keep? Cows …….. Goats……….. Sheep………..

    Chicken……. Other ………………….

13. How do you keep your animals? Zero grazing ( ) Free grazing ( )

14. Where do your animals drink water? Water pan ( ) Homestead ( )

15. Where do you get water for the household?

    Water pan ( ) Rainwater harvesting ( ) Other ……………………………

16. What is the source of our income?

    Goats ( ) Sheep ( ) Cows ( ) Chicken ( ) Employment ( )

    Business ( ) Other ………………………………………………..

17. What is your annual income?

    Less than 10,000 ( ) 20,000 ( ) More than 20,000 ( )

18. Where do you graze your animals? Near the gully ( ) Migration ( )

PART C: SOIL EROSION

19. Do you have the following soil erosion problems in your farm?

    Gullies Yes ( ) No ( )

    Runoff Yes ( ) No ( )

    Exposed tree roots Yes ( ) No ( )

    Rocks Yes ( ) No ( )

    Other ………………………………………

20. In your opinion, what do you think causes the soil erosion problem in your farm?

    Rainfall Yes ( ) No ( )

    Overgrazing Yes ( ) No ( )

    Farming Yes ( ) No ( )

    Deforestation Yes ( ) No ( )

    Road Yes ( ) No ( )

    Suswa Gully Yes ( ) No ( )

Other ………………………………..

21. What soil conservation measures do you have in your farm?

Terraces Yes ( ) No ( )

Mulching Yes ( ) No ( )

Grass strips Yes ( ) No ( )

Other ……………………………………………………….

PART D: SUSWA GULLY

22. Has the gully affected your activities?

Farming activities Yes ( ) No ( ) Loss of Income ( )

Livestock activities Yes ( ) No ( ) Declined water availability ( )

Movement Yes ( ) No ( ) Lack of firewood ( )

House Yes ( ) No ( ) Lack of building materials ( )

Health ( )

Other …………………………………………

23. If yes, what type of damage?

Farming activities Severe ( ) Moderate ( ) Mild ( )

Livestock activities Severe ( ) Moderate ( ) Mild ( )

House Severe ( ) Moderate ( ) Mild ( )

Water pan Severe ( ) Moderate ( ) Mild ( )

Road/footpaths Severe ( ) Moderate ( ) Mild ( )

Other …………Severe ( ) Moderate ( ) Mild ( )

24. In your opinion, what do you think is the cause of the gully?

Rainfall Yes ( ) No ( ) Topography ( )

Overgrazing Yes ( ) No ( ) Soil type ( )

Farming Yes ( ) No ( ) Fire ( )

Deforestation Yes ( ) No ( ) Settlement ( )

Road Yes ( ) No ( ) Footpath ( )

Other ………………………………..

PART E: MITIGATION MEASURES

25. In your opinion, what can be done to reduce the soil erosion problem in your farm?

Training Yes ( ) No ( )

Advice from soil and water officers Yes ( ) No ( )

Use of Indigenous Knowledge Yes ( ) No ( )

Reduce livestock numbers Yes ( ) No ( )

Soil conservation measures Yes ( ) No ( )

Financial support Yes ( ) No ( )

Other ………………………………………………………………….

26. What can be done to rehabilitate the Suswa gully?

Training Yes ( ) No ( )

Advice from soil and water officers Yes ( ) No ( )

Use of Indigenous Knowledge Yes ( ) No ( )

Reduce livestock numbers Yes ( ) No ( )

Soil conservation measures Yes ( ) No ( )

Financial Support Yes ( ) No ( )

Other……………………………