THE IMPACT OF IRRIGATED AGRICULTURE IN DRY LANDS ON THE NATURAL ENVIRONMENT: A CASE STUDY OF CHALA WARD IN TAITA TAVETA COUNTY, KENYA

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A research project submitted in partial fulfillment of the requirements of the award of Masters of Arts degree in Environmental Planning and Management at the Department of Geography and Environmental Studies, University of Nairobi

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DECLARAION

I declare that this research project is my original work and that to the best of my knowledge it has never been presented for examination or award of degree in any institution, college or university.

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This research project paper has been submitted for examination with our approval as university supervisors.

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DEDICATION

This research project is dedicated to my wife, Beatrice, and our three sons; Timothy, Philemon and Paul for their perseverance during my undertaking of this study.

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ABSTRACT

This research project investigated the impact of irrigation on the environment. The research examined farming practices that could affect the environment, impact of irrigation on soil and water as well as examining the state of the environment in rivers whose water has been diverted for irrigation. Interviews, through the use of questionnaires, were held with 25 from each irrigation scheme: Chala Tuhire, Kithito, Njukini and the management of Ziwani Estate Gicheha Farms. The respondents were selected using a systematic random sampling method. Five composite soil samples, each composed of five core samples, were also collected from each irrigation scheme using the systematic random sampling method by taking a zigzag route across the irrigation fields. Soil properties from the irrigation fields were then compared with soils from the surrounding non-irrigated areas to find out the significant difference using the Mann-Whitney U-test. Two water samples from each irrigation schemes were also picked and taken for analysis to establish whether the diversion of water into irrigation farms affects its quality. Soil and water analysis were done at the University of Nairobi's Land Resource Management and Agricultural Technology (LARMAT) laboratories at Kabete. The results showed that there was a significant difference ($p \leq 0.05$) in soil pH levels between the non-irrigated areas and Chala Tuhire, Kithito and Njukini irrigation schemes. Water pH and calcium levels within the irrigation schemes were higher than at the diversion points. The results also showed that 100% (all) the farmers were using chemical fertilizers and pesticides/fungicides. The common fertilizers were DAP, CAN, NPK and granular urea. Pyrethroid insecticides, by the trade names of Polytrine, Tata Alpha and Karate Zeon were the most common ones, while the fungicides; Thiovit Jet, Bayleton and Tornado usually contain remarkable levels of sulfur. The study also showed that respondents relied on information on the choice and usage of insecticides from sources such as agro-chemical sellers, fellow farmers, extension officers and personal discretion. An assessment of the riparian ecosystems of the rivers diverted for irrigation showed that River Lumi had dried up completely and the aquatic vegetation; rushes and sedges, had completely disappeared. *Prosopis juliflora,* an exotic, invasive, dry land species was colonizing some dry sections of River Lumi. Irrigation therefore has negative impact on the environment. There is need therefore for local authorities and regulatory bodies such as National Environmental Management Authority (NEMA) and Water Recourse Management Authority (WARMA) to intervene by putting in place relevant mitigation and adaptation measures.

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ACRONYMS AND ABBREVIATIONS

ADB	African Development Bank
ASAL	Arid and Semi-Arid Lands
CAR	Central African Republic
CDF	Constituency Development Fund
CEC	Cation Exchange Capacity
EIA	Environmental Impact Assessments
FAO	Food and Agriculture Organization
GEO-5	UNEP’s Fifth Global Environmental Outlook
KIPPRA	Kenya Institute of Public Policy Research and Analysis
KNBS	Kenya National Bureau of Statistics
LARMAT	Land Resource Management and Agricultural Technology
NEMA	National Environmental and Management Act
NIB	National Irrigation Board
NGO	Non-Governmental Organization
SOM	Soil Organic Matter
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
WARMA	Water Resource Management Authority

CHAPTER ONE: INTRODUCTION

1.1 Background to the Problem

The population of the world, which reached 7 billion in 2009, is still increasing and is expected to be between 8 and 10.5 billion by the year 2050 (UNEP's GEO-5[1], 2012). In 2009, Africa's population exceeded 1 billion, and by 2050 is expected to reach 1.6 billion. Kenya's population reached 38.6 million in 2009, which was a significant increase from 28.7 million in 2009 (KNBS, 2010). It is projected that Kenya's population will reach 56.6 million by 2020; 65.9 million by 2030; and 85 million by 2050 (KIPPRA, 2013). This population needs to be fed through food produced through agricultural processes. In addition to the provision of food, agriculture is playing an important role in promoting development through trade and commerce involving edible and non-edible agricultural products. The continuous expansion of rain fed agriculture has reached a point where further development is harmful to the environment and therefore not viable. Much strain is experienced in agricultural areas where the acreage under cultivation has been increasing continuously, while at the same time putting more pressure on the already current agriculturally active areas to produce even more.

According to UNDP (2012), the problem of food scarcity is always addressed through expanding the area under cultivation. However, this approach has led to serious environmental problems that have contributed to the degradation of the environment through deforestation, soil erosion, and contamination of water bodies and other secondary or indirect problems. Agriculture is also playing a vital role in energy production as more agricultural land is being opened up, or converted to produce bio-fuels. The situation is further compounded by technology, which has made it easier to increase agricultural production through the use of fertilizer, modernized farming methods including irrigation.

Increasing agricultural production has now shifted to irrigation in dry lands. Due to the availability of modern technology, it has become easier to initiate irrigation projects in areas that were initially not viable for agricultural activities. Much of the potentially cultivatable and irrigable lands are found in the dry lands of Africa and Australia (Miller, 1996). Some of the major dams in Africa

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[1]The Fifth Global Environment Outlook (GEO-5) is a508-page environmental assessment report produced by UNEP in 2012, being the fifth such report following others produced in 1997, 1999, 2002 and 2007.

are in dry lands, the most noticeable one being the Aswan High Dam in Egypt, which is actually in Sahara Desert, a hyper-arid area. Most watershed areas in Sub-Saharan Africa are already tapped by large scale abstraction schemes, and that plans are underway to tap the remaining ones (Rached *et al*, 1996).

Irrigation, which is the application of water to the soil to make available essential moisture for plant growth, serves as an insurance against drought and provides a cooling effect on the soil environment for plant growth and development (Saliu, *et al*, 2008). However, irrigation has negative impacts on the environment. The continuous application of water on soils leads to soils degradation through soils salinization (Hegde *et al*, 2011).

Overuse of the soil leads to loss of humus content and farmers resort to the use of chemical fertilizers, which farther degrades the soils. The use of herbicides, pesticides and other chemicals also contaminates both the soil and water. Opening up of irrigation projects and schemes destroys the native flora and natural habitats of native fauna, and once farmers begin to irrigate, they consider wild animals that are native to the areas to be adversaries and therefore kill or chase them away from the irrigated fields.

The areas that are targeted for expansion of irrigation projects are dry lands which have very fragile and vulnerable ecosystems. Opening up irrigation activities in these areas would threaten the ecosystems. Additionally, irrigating dry lands increases the rate of soil degradation since the frequency of irrigation has to be very high to cope with the high evapotranspiration rates. Irrigation brings about soil salinization, and when the frequency of irrigation is high, the possibility of the soils becoming sodic increases. Irrigating dry areas would also require a lot of water, which is often inadequate. Water sources in dry areas would therefore be targeted for irrigation, which would affect the quantity of water available for environmental goods and services. On the same note, the quality of water would be affected by the irrigation activities, especially by diverting it from its traditional river courses into the irrigation canals. It is from this background that this research was done so as to evaluate the impact of irrigation on the environment.

1.2 Study Area

This study was carried out in Chala Ward, which is in Taveta Sub-County of TaitaTaveta County, Kenya. The ward is found along the Kenya-Tanzania border, with the border being on the western side of the ward. To the north, it borders Kajiado County and to the east it borders Tsavo West

National Park, while to the south it borders Mahoo Ward, which is also in Taita Taveta County. The Ward covers an area of 221.9 km^2. It is located between longitudes 37^O 69' E and 37^O 79' E and latitudes 3^O 17' S and 3^O 31' S.

According to the 2009 Kenya National Population and Housing Census, Chala Ward has a total population of 19,325 people. The Ward has two locations, Chala Location, with a population of 9,223 and Njukini Location with a population of 10,093. Chala Ward has an area of 221.9 km^2, with Chala Location being 149.8 km^2 while Njukini Location is 72.1 km^2

1.2.1 Topography

The topography of Chala Ward is generally characterized by slightly undulating plains that steepen towards the west (Tanzania) as it is found on the eastern side of Mt Kilimanjaro where the elevation of the mountain starts. The average elevation of the Ward is about 800 meters above sea level, and its gentle slopping plains are dissected by several permanent, perennial and seasonal rivers. There are several small volcanic cone shaped hills scattered in the area. The Mt Kilimanjaro elevation ends at River Lumi, near Ziwani Estate, and from there it slightly elevates towards Tsavo East National Park.

1.2.2 Geology and hydrogeology

Lying on the lower slopes of Mt Kilimanjaro, the rocks and soils of Chala Ward are mainly volcanic in nature. Surface soils are derived entirely from volcanic materials and are mainly volcanic ash, sometimes overlying stream deposits. However, the eastern side of Ziwani Estate, towards Tsavo East National Park, the rocks and soils are derived from basement complex formations and are sandy. Chala Ward lies over the Mt Kilimanjaro underground aquifer, and therefore has a number of springs that originate in the area, mainly at Njukini area. The springs maintain a constant flow of water throughout the year, even at the height of the dry seasons. The springs form streams that eventually drain into River Tsavo and River Lumi. River Tsavo is a tributary of Athi River in Kenya while River Lumi flows into Lake Jipe, which has an outlet that flows into River Pangani in Tanzania.

Chala Ward has a variety of soils with the major ones being Luvisols, Lithosols and Regosols (ADB, 2012). Luvisols are found in plains and gentle slopes. They have high humus content in the 'A' horizon and a clay accumulation in the 'B' horizon. Lithosols have a thin layer of soil mainly comprising of partially weathered rock fragments. They are mainly found around hills and steep slopes. Regosols are weakly developed and have unconsolidated materials. They are susceptible to erosion. The areas under irrigation in Chala fall under these soils.

1.2.3 Climate and vegetation

Rainfall received in the area ranges between 400 mm to 600 mm, and is often erratic (Mbau, 2013). This therefore qualifies Chala Ward to be an Arid and Semi-Arid Lands (ASAL) since dry lands are classified as areas that receive annual rainfalls below 800 mm (FAO, 1993). The annual temperature in Chala Ward ranges from $21.7^{O}C$ to $31.0^{O}C$ (ibid). The main natural vegetation type consists of savannah grassland with bushes and semi-arid scrubs and acacia woodlands. Vegetation along the permanent streams/rivers consists of belts riverine vegetation that is mainly broadleaved and appears very different from the surrounding areas. The potential annual evaporation in Chala Ward is 1950[2] mm.

1.2.4 Agro-ecological zones

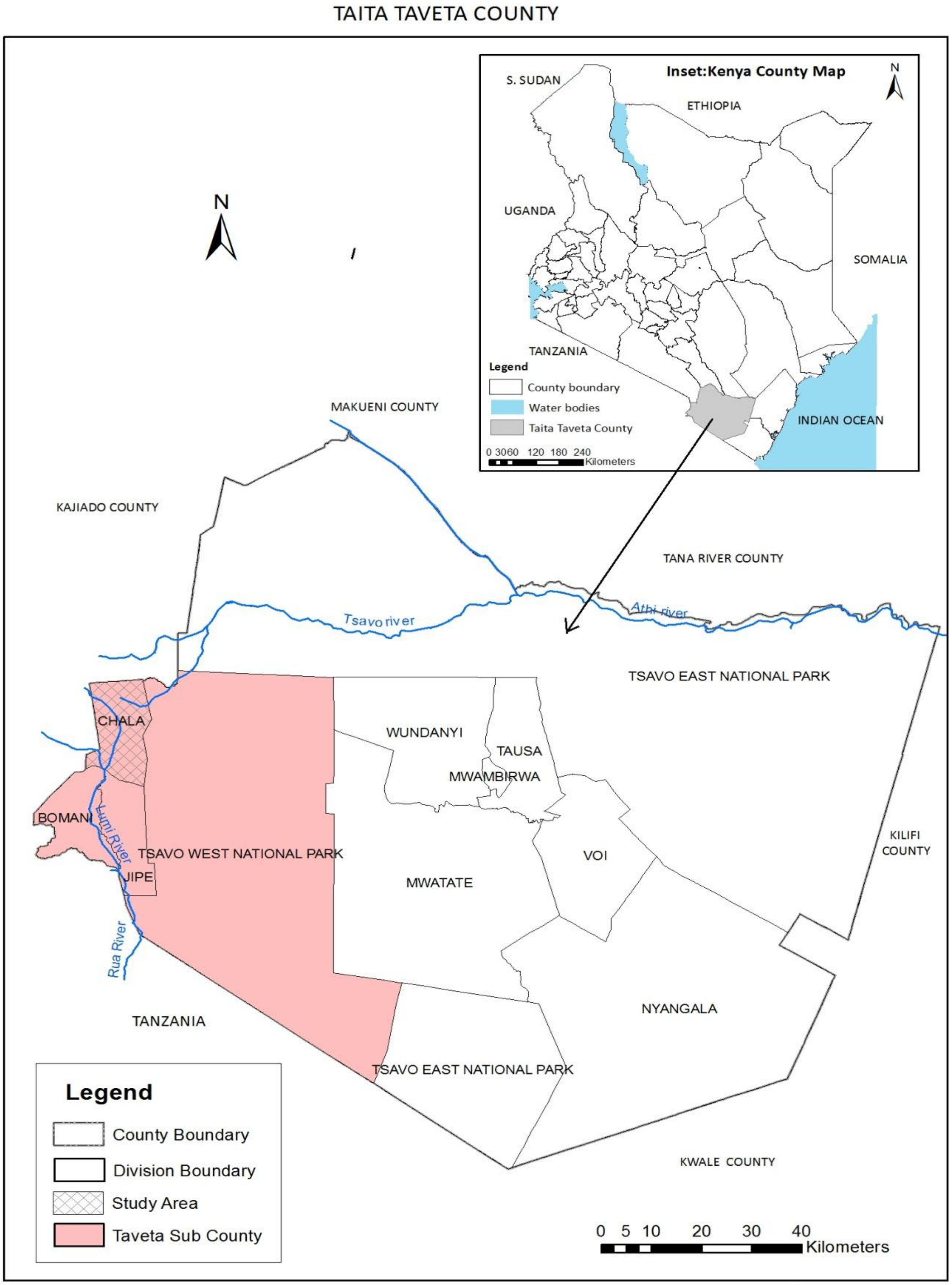
Chala Ward is found in Agro-Ecological Zone Five (AEZ-V). The main crops cultivated under rain fed agriculture in Chala Wars include early maturing maize, green grams and millet. Open range grazing is also practiced in the non-irrigated areas where cattle, goats and sheep are kept.

1.2.5 Land uses

The main land use activities in Chala Ward include irrigated and non-irrigated agriculture as well as pastoralism. Horticultural agriculture is quite developed in Chala Tuhire, Kithito and Njukini while Ziwani Estate Gicheha Farms specializes in seed maize farming.

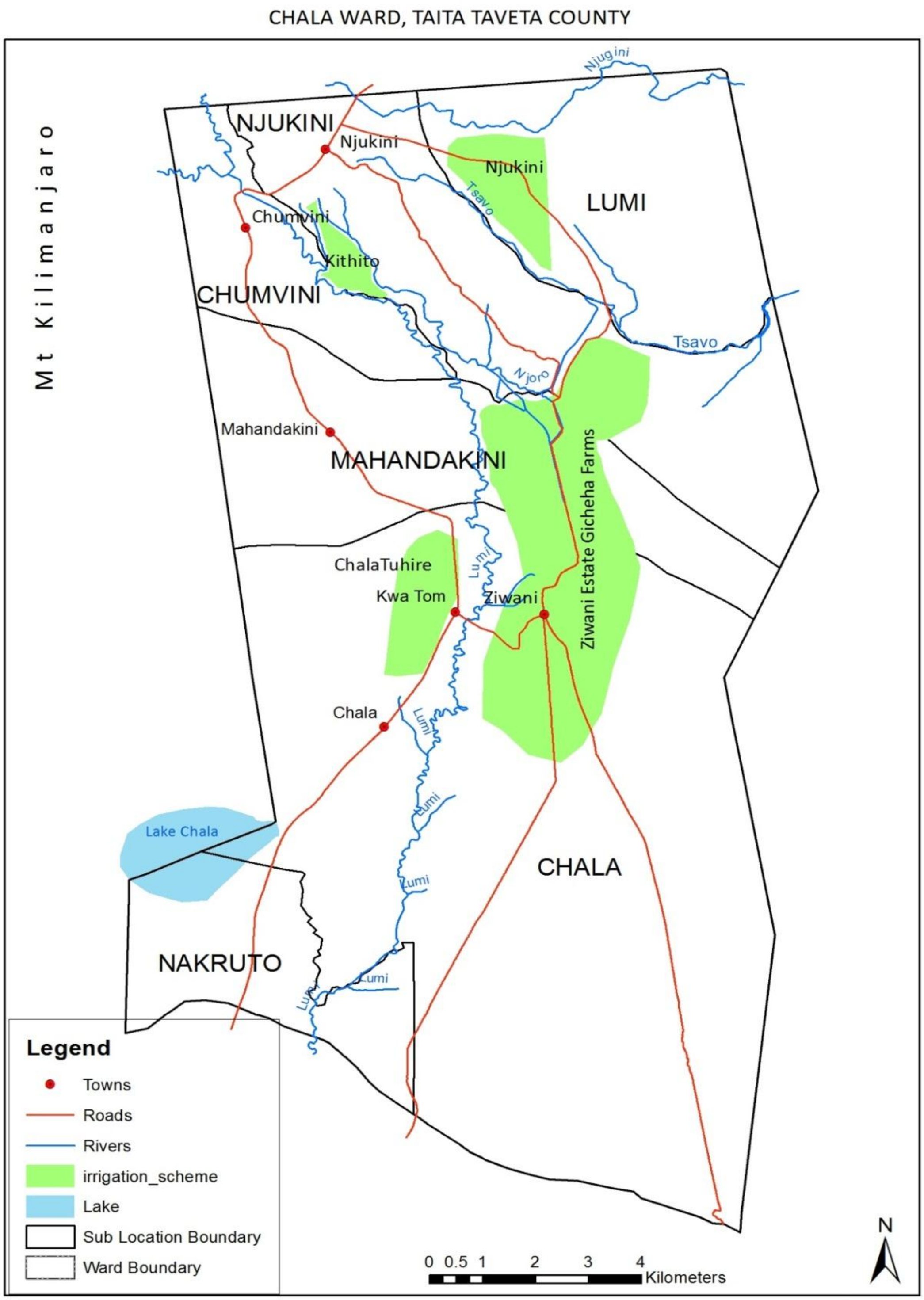
[2] National Environment Management Authority, Kenya, *Environment Action Plan: Taita Taveta District 2009-2013*

Figure 1: Map of Kenya showing location of Chala Ward



Source: Survey of Kenya 2011

Figure 2: Map showing distribution of irrigation schemes in Chala Ward



1.3 Statement of the research problem

The core problem analyzed in this study was the impact of irrigation in dry lands on the environment by using Chala Ward as a case study. Faced with the problem of feeding an ever increasing population, the government of Kenya has indicated that it will start a number of irrigation schemes in the country to address the issue. In 2011, the government of Kenya launched the Expanded Irrigation Programme (EIP) under the National Irrigation Board (NIB) with the aim of accelerating and expanding development of irrigation projects in the country. The objective of EIP is to attain national food security in Kenya and eliminate hunger amongst Kenyans by accelerating the development of irrigation projects in the 1.7 million acres potential irrigation land in Kenya (NIB website). Only 17% of Kenya's 582,646 km2 is suitable for rain fed agriculture while the remaining land is classified as ASAL (Blank, 2002).

Kenya's Vision 2030 envisages the construction of 22 medium-sized multi-purpose dams with the total capacity of 2 billion cubic meters to supply water to among other things open up more irrigation schemes in ASAL areas (Vision 2030). The forces pushing for the opening up of more irrigation schemes are evident from the manifestos of Kenya's leading political parties, an indication that the issue is becoming a major political agenda in the country, and therefore the expansion of irrigation projects is likely to persist. The Jubilee Manifesto (2013) calls for the establishment of a vibrant national irrigation scheme to open up more arable lands, while the Coalition of Reforms and Democracy (CORD) Manifesto (2013) calls for investment in innovative agriculture for improved yields. All these indications stress the fact that there is a thrust to increase irrigation projects in the country as a response to the various pressures.

Irrigation has negative impacts, key among them reduction of water levels in fresh water bodies/sources, soil salinity, destruction of aquatic ecosystems. The quality and quantity of water would also be affected as a result of diverting water from its natural courses to be used for irrigation, which would cause adverse impacts on the downstream areas. The implementation of such projects could come with negative impacts that could affect the quality of soil as a result of soil salinity, soil erosion and the addition of anthropogenic substances through the use of fertilizers and pesticides. The negative impacts associated with irrigation are already being manifested in many irrigation schemes in Kenya (Githaiga *et al,* 2003).

The four irrigations projects in Chala Ward: Ziwani Estate Gicheha Farms, Chala Tuhire, Kithito, and Njukini provide an excellent study area as negative impacts of irrigation are experienced in the area. This could be due to increased demand for agricultural production as the pressures for more production keep on increasing. The focus of this study is therefore to identify the impacts of irrigation because a degraded environment would not sustain agricultural productivity, a situation that could not augur well for human social wellbeing.

1.4 Goal and objectives

The overall objective of this research was to find out the impact of irrigation on the environment within Chala Ward. For the purpose of this study, irrigation as a variable will include the impact of irrigation on soils, water and the riparian ecosystems of rivers/streams whose water has been diverted for irrigation. Farming practices within the irrigated fields would also be examined since such practices could contribute to the impact on the environment.

1.4.1 Research questions

The main research question for this study is: Is the environment affected by irrigation? The specific research questions therefore are based on these three components, thus:

1. Are farmers in irrigation schemes using methods that might affect the environment?
2. Are properties of soils in the irrigated areas significantly different from the non-irrigated areas?
3. Does the diversion of water from the natural courses to the irrigated areas affect its quality?
4. What are the consequences of irrigation to the riparian ecosystems of streams/rivers used for irrigation?

1.4.2 Objectives of the research

The specific objectives of the research are therefore:

1. To find out the farming methods used by farmers in irrigation schemes and if they may affect the natural environment.
2. To establish whether there is a significant difference between soil properties in irrigated and non-irrigated areas.
3. To find out whether the diversion of water from natural courses to irrigation areas significantly affects its quality.
4. To assess the impact of irrigation on riparian ecosystems of rivers/streams diverted to the irrigation schemes.

1.4.3 Study hypotheses

The research hypotheses in this research presupposed that there was **no** relationship between irrigation activities in dry lands and the natural environment. In this case, irrigation was the independent variable while the environment was the dependent variable. The hypotheses were therefore formulated as follows:

1. **H_o** Farmers in irrigation schemes **do not** use farming methods that may affect the environment.

   H_1 Farmers in the irrigated areas use farming methods that can affect the environment.

2. **H_o** Soil properties in irrigated areas are **not** significantly different from those in non-irrigated areas.

   H_1 Soil properties in irrigated areas are significantly different from those in non-irrigated areas.

3. **H_o**: The diversion of water from the natural courses to the irrigated areas **does not** significantly effects the water quality.

   H_1: The diversion of water from its natural courses into the irrigated areas significantly affects its quality.

4. **H_o:** Irrigation in dry lands has **no** significant impact on the riparian environment of the rivers diverted for irrigation.

   H_1: Irrigation in dry lands has significant impact on the riparian environment of the rivers used for irrigation.

1.5 Justification of the study

Irrigation in dry lands is seen as the best way of addressing the problem of food insecurity caused by the ever growing population. Expanding the current acreage under irrigation in Kenya is being given priority by the government as it is argued that irrigation can help increase agricultural productivity to close the gap between growing population and food production. Ngigi *et al.* (2002)

observes that if irrigation utilization is increased to around 50%, Kenya can become not only self-sufficient in food production but also a major exporter of food. However, the plans to expand irrigated agriculture rarely do take into account the negative impacts to the natural environment that can be caused by opening up more irrigation schemes in dry lands.

Tadic (2009) categorized and identified the impacts of irrigation on the environment as flows:

- **Impacts on natural assets:** predominantly on water and soil (physical environment);
- **Socio-economic impact:** Impact on the quality of human life (social-economic impacts);
- **Duration of impact:** short term, middle or long term impacts;
- **Occurrence in time and space**: direct, when they occur on exact area which is being irrigated and during the period of irrigation, but also indirect, which means that they also impact the downstream and upstream soils, and frequently appear only after significant periods of time;
- **According to the number of impacts**: individual and cumulative impacts.

If the negative impacts of irrigation are not identified and proper mitigation and/or adaptation measures put in place, there is a possibility that the current gains could be short term and possibly could cause more problems in the long-term. There is a strong link between human wellbeing and the environment, but unfortunately policy makers don't give much thought to the environment as they do to socio-economic wellbeing as far as making a choice between increasing irrigated agricultural projects and preserving the environment. It is important for this link between the environment and human wellbeing to be strongly brought out since societies survive within an environment determined by physical limits of atmosphere, land, water, biodiversity and other material resources (GEO-5, 2012).

Negative environmental impacts of irrigation are almost always unnoticed as it they are outweighed by the anticipated improved quality of life and economic gains, and therefore the negative impacts are often overlooked or just ignored. The environment has its own 'rights', and its therefore important to understand how it can be affected by irrigation so that appropriate intervention measures can be advocated to protect, preserve and conserve it. Most irrigation schemes in Kenya, especially the small ones owned and controlled by small scale farmers, were initiated without any Environmental Impact Assessments (EIA) being carried out since the National Environmental and Management Act (NEMA), which ought to enforce the undertaking of

EIA before projects are undertaken, was enacted in 1999 when many of the current irrigation schemes were already in place.

This study is therefore being carried out to highlight the impacts that can result from irrigated agriculture so that the negative side of irrigation can as well be brought out so that in-depth analysis of irrigation could be carried out before more irrigation schemes are opened up. The delicate balance between agricultural gains and environmental degradation can easily be disrupted and cause unforeseen consequences that can undermine the sustainability of the projects.

1.6 Scope and limitations

The environment, consists of four segments namely; atmosphere, lithosphere, hydrosphere and biosphere (Singh, 2006). These are the areas this study endeavored to examine to see how they are affected by irrigation. Lithosphere was examined through soil test of both irrigated and none irrigated areas, while hydrosphere was examined through assessing the quality and quantity of water. The biosphere was assessed by examining how the riparian environment, especially the downstream sections of rivers whose water was diverted for irrigation, could end up affecting aquatic flora and fauna. However, this research did not look at the impact of irrigation on the atmosphere (air) due to the challenges involved in linking the quality of the air in the irrigated areas to the irrigation practices taking place there. The study excluded examining how irrigation affects underground water aquifers due to technical and financial challenges in carrying out such an undertaking.

In examining the impact of irrigation on soil, this study did not examine all the soil components. Soil components can broadly be divided into three parts: physical components that include organic matter, water and air. Biological components include living organisms like bacteria, roots and insects among others; and chemical components, which include primary soil nutrients which are nitrogen, potassium and phosphorous. This research project therefore limited its scope of soil properties examined to Nitrogen, Phosphorous, Potassium, Soil pH, Cation exchange capacity (CEC), and Soil Organic Matter (SOM). Similarly, water has a number of properties and characteristics, but in this study dwelt mainly on water pH, Electric Conductivity (EC), Sodium (Na), Potassium (K), Calcium (Ca), Magnesium (Mg), Bicarbonate (HCO_3), Chlorine (Cl) and Carbonate (CO_3).

Within the study area, some irrigation schemes were also not included in this research. These are Sir Ramson (also known as Saravo) and Kithito B. These two schemes are relatively new, having been started in 2009. It was therefore felt that the impacts might be minor compared to the areas irrigated over a long time.

The study involved analyzing soil and water samples in a laboratory, a process that has financial implications. This therefore led to the use of small sample sizes; five samples from each irrigation schemes and ten samples from the non-irrigated areas. Much bigger samples could have more ideal. Time limitation was also a factor since a comparative analysis of soil and water over a period of time, such as after a period of some years, would have provided a much more in-depth analysis of the problem.

During the administration of the questionnaires, the small scale farmers were unable to accurately identify the type of pesticides and fungicides they were using. They could only refer to pesticides as *'dawa ya sumu'* and to fungicides as *'dawa ya baridi'*, and it was hard for most of them to even recall the trademark names. This therefore made it difficult to get accurate data on the type of pesticides and fungicides used, yet the use was quite prevalent and as high as 100% in Chala Tuhire and Njukini irrigation schemes. Water analysis for Kithito Irrigation schemes was not done. This is because the schemes are served by two small streams and the water gets mixed *within* the farms, and not *before* entering the farms. This therefore makes it impossible to know the exact source of the water within the irrigation schemes.

1.7 Definition of terms

Irrigation: any process, other than by natural precipitation, which supplies water to crops, or any other cultivated plants. (*National Irrigation and Drainage Policy, Ministry of Water and Irrigation, 2009).*

Environment: a combination of the various physical, geographical, biological, cultural and political elements that affect the life of an individual or organism. *(National Irrigation and Drainage Policy Ministry of Water and Irrigation, 2009)*

Drylands: are lands with limited rainfall. They are characterized by low rainfall (100 to 600 mm annually), which are erratic and highly inconsistent. The main characteristic of dryness is the negative balance between annual rainfall and evapo-transpiration rates. They are zones falling between 1-74 and 75-119 growing days, representing arid and semi-arid lands, respectively. Rainfall is a problem because of amount, distribution and unreliability *(FAO).*

Environmental degradation: the deterioration in environmental quality from ambient concentrations of pollutants and other activities and processes such as improper land use and natural disasters *(Glossary of Statistical Terms Organization for Economic Co-operation and Development, 2007)*

Depletion: the part of the harvest, logging, catch (fish) and so forth above the sustainable level of the resource stock; for non-renewable resources, it refers to the quantity of resources extracted *(Glossary of Statistical Terms Organization for Economic Co-operation and Development, 2007)*

Soil degradation: a decrease in soil quality as measured by changes in soil properties and processes and the consequent decline in productivity in terms of production now and in the foreseeable future. *(Verbetem 1998)*

Soil salinity: refers to salt levels in soil. (*Glossary of Statistical Terms Organization for Economic Co-operation and Development, 2007)*

CHAPTER TWO: LITERATURE REVIEW

2.1 Benefits of irrigation

As the world population keeps on growing, the demand for food and other agricultural produce keeps on increasing. Irrigation reduces poverty through increased food output, higher employment, and higher real incomes, and it is therefore seen as the best solution to address the persistent problems of food insecurity. It also supports the poor through a multiplier effect which drives an increase in non-farm rural output and employment as the level of rural spending rises. Irrigation also contributes to risk reduction by reducing variability in output, employment and income, allowing for more productive investments and lessening the periodic liquidation of capital, such as livestock, during times of crisis (FAO, 2011). The increased reliance on irrigation can be attested by the fact that about one-third of the world's crops are grown on the one-sixth of the cropped area which is irrigated, and that irrigated land was, on average, more than twice as productive as rain-fed land (Stockle, 2001). Globally, 2 710 km^3 per year, or 70 percent of the total water withdrawn from rivers and aquifers, is used by agriculture, compared with 19 percent by industry and 11 percent by the municipal sector.

Growth in irrigation has been spectacular over the past 50 years, largely due to investment in necessary public goods as well as farmers' investment of capital in irrigation systems. It has enabled significant increases in productivity as well as reductions in hunger through increased food production and reductions in poverty through increased farm and non-farm rural employment (FAO, 2014). Developed countries, including the United States, irrigate up to 23% of their agricultural area, but in developing countries, irrigated acreage is lower – at about 10% (Stockle, 2001). However, growth of irrigated land is expected to occur mainly in developing countries, increasing their share from about 80% to 90% of the world's irrigated land (ibid).

In the African continent, it is estimated that irrigation is practiced on 6% of the total cultivated area (FAO, 2005). The percentage of agricultural land under irrigation varies greatly in Africa, ranging from the Central African Republic (CAR) which practically has no irrigation at all, to Egypt whose acreage under irrigation accounts for almost 100% of the country's agricultural land (ibid). The impact of irrigation on the environment varies greatly in Africa. This percentage is much lower than that for other regions: 38% in Asia, 27% in the Caribbean, and 12% in Latin America (FAO, 2005).

In Kenya, like most tropical countries, a rapidly increasing population and a consequent need for greater food production are some of the factors pushing the country to open up more irrigation schemes. In 2011 the National Irrigation Board (NIB) established the Expanded Irrigation Programme (EIP) as part of NIB's strategic plan to expand irrigation development in the country's 1.7million acres potential irrigation land.

2.2 Impact of irrigation on the environment

Irrigation has notable negative impacts to the environment. Globally, 2 710 km^3 per year, or 70% of the total water withdrawn from rivers and aquifers, is used by agriculture, compared with 19% by industry and 11% by the municipal sector (FAO, 2011). This reduction of river flows leads to loss of aquatic ecosystems and habitat, salinization of land as well as depletion and degradation of aquifers. About 20% of all irrigated land is facing the problem of soil salinity, and this percentage keeps on increasing (Lauchli, 2004). The estimated amount of water required to maintain ecosystem goods and services is 75% of the total water use while humans should use a maximum of 25% (Falkenmark, 2004). This balance, if not maintained, the environment could suffer from multiple pressures due to lack of adequate quantity, quantity as well as appropriate timing (GEO-5).In many areas, water is overcommitted, leaving very little for both humans and the environment. The environment is rarely recognized as a legitimate user of water, and even when it is recognized, it's hard to allocate it its adequate share of 75%, especially when the water in question is freshwater, therefore threatening freshwater ecosystems.

The impacts of irrigation on the environment, especially in dry lands, are being manifested across many parts of the world. Irrigated agriculture is characterized by intensive land use that includes the use of substantial external inputs that include pesticides, a situation that can lead to environmental degradation through pollution since farmers increase pesticide use as the pests increase their resistance (Blank, 2002). Pesticides can kill beneficial organisms that prey on pests and therefore increase population of old pests or making hazards out of organisms that had not threatened crops before (Kauffman, 1993). Pesticides can also enter water ways through agricultural runoffs and soil erosion. Fertilizers, when washed into waterways, can encourage growth of algae and other aquatic plants, therefore hastening eutrophication (ibid). In irrigated areas, over-irrigation can cause airspaces in the soil to fill with water for too long and prevent roots from getting oxygen, killing soil organisms and mold growth, a situation that inhibits normal plant growth (ibid). Extensive use of fertilizers by small scale farmers in irrigation schemes can provide avenues for the fertilizer to find its way to water courses (Blank, 2002).

Soil salinization is not a new problem and in fact the Mesopotamian civilization, which heavily depended on irrigated agriculture, is believed to have collapsed of the civilization. (Silvertow, 1990). Threats posed by soil salinization are evident in many parts of the world, with 20% of the irrigated farms in the USA being affected (Kauffman, 1993). Irrigation can affect soil properties that contribute to soil fertility. Overall, plants require sixteen soil elements, but this research will focus on six major soil properties that include three main chemical components, which are Nitrogen (N), Phosphorous (P) and Potassium (K). The others are Soil Organic Matter (SOM), soil pH and Cation Exchange Capacity (CEC). The others are Soil Organic Matter (SOM), soil pH and cation exchange capacity (CEC) (Nyanjom, 2008)

Soils can lose these soil elements (N, P and K) through various ways that include leaching, which is the transportation of soil nutrients downwards the soil profile as water moves through the soil either when it rains or when irrigation is carried out. Some of these elements, such as Nitrogen, are easily removed through leaching, while phosphorous is more resistant (Nyanjom, 2008). Harvesting of crops, especially continuous harvesting which is mainly practiced in irrigated areas, also removes these plant elements at a rate that is faster that natural regeneration rate (ibid). The situation is exacerbated by the use of fire in farms to burn crop stalks or to clear natural vegetation.

Other crucial soil properties are Soil Organic Matter (SOM), cation exchange capacity (CEC) and soil pH. Organic matter is the residue of plants, animals and organisms after they die. Organic matter is rich in phosphorous, nitrogen, sulfur and iron. Organic matter is also important because it improves water infiltration and decreases evaporation, hence improving the soil's water holding capacity. The amount of organic matter can therefore improve the ability of soil to sustain crop growth/production through the provision of essential nutrients and prolonging the time the soil can hold water (Hegde *et al,* 2011). The Cation Exchange Capacity (CEC) of soil is a measure of its ability to hold and release plant nutrients. It indicates the nutrient holding capacity of the soil. Soils with high CEC are considered to be more fertile than soils with low CEC (ibid). Soil pH is a measure of acidity or alkalinity of the soil. It has a scale of 1 to 14 where a pH of below 7 indicates the soil is acidic while a pH of above 7 shows the soil is alkaline. A pH of 7 shows the soil is neutral. Most crops grow within a range of 5 to 7 pH. Chemically fertile soils have a pH range of 5.5 to 7.5 (ibid).

Just like soil, irrigation can have effects on water quality, which in turn impacts on the environment. Water contains dissolved salts and in dry climates, water evaporates fast, therefore increasing the frequency of irrigation, therefore leaving salts such as sodium, in the topsoil stunting crop growth, lowering crop yields and eventually ruining the land (Miller, 1996). The quality of irrigation water was determined by assessing its pH, Electric Conductivity, as well as other water properties such as Calcium, Magnesium, Sodium, Potassium, Hydrogen Carbon Trioxide, Carbon Trioxide and Chlorine.

Water with an extremely high or low pH can be harmful to flora and fauna, including human beings. Water is alkaline in nature, with its optimum pH being between 7.0 and 8.2. This study sought to determine whether the flow of water along the irrigation canals has any impact on water properties, including pH. Total Dissolved Solids (TDS) in water includes all organic and inorganic substances that can pass through a 2 micron filter. These substances usually include carbonate, chloride, fluoride, calcium as well as anthropogenic substances like herbicides, hydrocarbons and other pollutants. A high concentration of TDS in irrigation water can lower the quality of water and affect the soil in the irrigated fields. Total Suspended Solids includes all particles suspended in water which will not pass through a filter. Suspended solids absorb heat and can reduce the quality of water, especially in dry lands. Conductivity is a measure of the ability of water to pass an electric current. Normally conductivity is affected by the presence of inorganic and organic dissolved and suspended solids. A significant change in conductivity could mean that the water has been polluted. Water conductivity increases with temperature (EPA, 2007).

The diversion of water from river/stream courses into irrigation canals or farms has both qualitative and quantitative impacts on both surface and underground water since any capture of water impacts on the water balance (Tadic, 2009). Reduced water levels in stream/river causes can increase the concentration of pollutants, especially through outflows from the irrigated field (ibid). The decline of water levels leads to decline in native vegetation and loss of animal habitats. This can result into a decline in wildlife fauna, as well as disappearance of some native plants. Loss of native vegetation could also affect the breeding sites of some animal species, including the nesting sites of some birds. Irrigation also reduces wetlands, which are habitats of some unique flora and fauna. Lack of water downstream can seriously affect the downstream riparian environment as the flora and fauna might be unable to cope with the new drier environment. Lack of water in river valleys could also lead to a loss of aesthetic value as well as tourist attraction sites.

In Latin America, improper agricultural water use is salinizing, waterlogging and eroding agricultural lands and polluting water for agricultural use, and by 1982, 196,550 km^2 in South America, Central America and Mexico were affected by salinization (Ringler, 2000). The situation is further aggravated by the fact that South America is experiencing one of the highest rates of deforestation as more and more forest land is converted to agricultural land. The region is endowed with water, and is embarking on irrigation at a very high rate so as to increase production in the already degraded areas where yields for rain fed agriculture have reduced (ibid).

As the demand for water for irrigation increases, underground water is being pumped and used for irrigation, thanks to the technological and scientific innovations currently available. However, this can threaten the environment due to the high salt contents of underground water in some areas. Besides, the use of underground water can cause subsidence, thus directly threatening the environment. In the USA, it is estimated that by 2060 all the ground water supplies that produce water for irrigation will decrease by 32% due to the declining water levels of the underground aquifers (Texas Water Resource Institute, 2012). This is a clear indication that irrigation is threatening water sources, including underground aquifers.

In Australia, 12% of the water used for irrigation by 2005 was underground water (Murray, 2007). This is an indication that all other sources of overland water have already been exploited. However, this excessive use of underground water has its negative side. In Queensland, water from the Great Artesian Basin was used for irrigation on an experimental basis so that its impact on soils could be assessed. After two years, the project was abandoned as the highly alkaline water had reacted chemically with the clay soils to produce a crust that was so hard that it had to be broken by dynamite (Briggs, 1997). This is an indication that irrigation can have very negative impacts on the environment if due care is not taken to evaluate the impacts.

In Turkey, modern irrigations were first established in 1908 in the Konya-Çumra plains, which are now suffering from soil salinity as a result of drainage problems (Verbeten, 1998). When the irrigation projects were initiated in these plains, they targeted the lowlands which were seen as more conducive for irrigation since they had good soils, but the negative impacts have now pushed up the cost of agricultural production in the area, and irrigation may not be viable in the plains in the near future. In Israel, where underground water accounts to about 50% of water used for irrigation, according to (Rached, 1996), irrigation systems pose major environmental problems due to agricultural runoffs that contain sediments, phosphorous, nitrogen and pesticides. This is because Israel has the highest per-hectare use of pesticides and fertilizers in the world, which have ended up not only affecting the environment, but the underground aquifer underlying Israel and Gaza Strip. In Syria, Lake Al-Sin, the main freshwater source in the country, is polluted by agricultural runoff (ibid).

India has a long history of irrigation. The renowned India Green Revolution was largely as a result of increased application of water on farmlands. The increased irrigation led to soil degradation. In a random sample of I10 farms from four villages in India's Uttar Pradesh, it was found that crop yields had declined by about 50% in some areas due to salinization and waterlogging in irrigation systems (Scherr, 1996).

Egypt nearly entirely depends on water from River Nile for irrigation (Oosterbaan, 1999). The only other sources of water are natural groundwater supplies in oases and the limited, and almost undependable, rainfall along the Mediterranean coast. The intensification of farming in Egypt has led to increased salinization, rise of water table and drainage problems. The Aswan High Dam, constructed in 1968, has been a major source of water used for irrigation in the country. The dam has had negative impacts that have affected downstream animal ecosystems and other life forms. Aswan High Dam is situated in a desert and therefore evaporation is very high (Türk, 2011). There is a lot of water that is lost as a result of this evaporation mainly from Lake Nasser, the reservoir of the dam. There has been a decreased water flow downstream that has had some impacts on the valley. These include increased erosion within the river valley and reduced water level, thus putting at risk the survival of some species as their habitats have been reduced or completely destroyed. Increased pollution was also noted on the Nile including the lakes around the delta (ibid).

Egypt has also embarked on using its underground aquifers for irrigation to supplement the waters of River Nile due to its growing demand for agricultural products. However, the aquifers are also being threatened, and the country has now embarked on complex underground water management systems. There is fear that if the trend to exploit the aquifers is allowed to continue, underground water levels may decline and lead to subsidence and the intrusion of saline sea water near the coastal areas (Türk, 2011). Egypt has therefore launched a programme to examine the feasibility of artificial recharge through the use of non-conventional water resources which include agricultural drainage water, desalinization of brackish groundwater and municipal wastewater (Arabi, 2012). However, the pumping of water to the aquifer could have some effects to the underground water systems within the country and in the nearby countries. Globally, there is also an increased reliance on underground water for irrigation, whose use now represents 40% of the irrigated area or 20% of farmlands (GEO-5, 2012). There is little knowledge about underground water, especially in Africa, and the continued overuse could have severe impacts on the environment, thus the need for a current study in Kenya to determine the sustainability of using underground water for irrigation as well as for domestic and industrial purposes.

Ethiopia is a country that relies heavily on rain fed agriculture. However, due to the fast growing population and the fact that the country has a number of rivers originating from its highlands, there is a growing tendency to shift to irrigated agriculture to supplement the rain fed agriculture. The country faces perennial food shortages and famine that often cause human and livestock deaths. The major cause of food insecurity in the country is its over-dependence on rain-fed agriculture and inability to develop the irrigation potentials (Bekele, 2013). Ethiopia has about twelve river basins with a potential to irrigate an estimated area of 3.5 million hectares, out of which only 190,000 hectares (4.3 %) is actually under irrigation (ibid). However, increased use of irrigation activities have begun to be manifested negatively in the country. Studies on irrigation mainly focus on technical evaluation of irrigation schemes, and very little is known about environmental issues, food security, and socio-economic implications (ibid). The danger of focusing on the technical evaluation of the schemes is that Ethiopia may end up initiating many irrigation schemes that might end up affecting the environment, notably concerning soil and water degradation as well as the destruction of ecosystems and animal habitats, to an extend that the schemes would not be viable (ibid).

Ethiopia’s resolve to continue with the expansion of irrigation projects without adequate consideration to the eventual negative environmental impacts can be attested by her determination to use the waters of River Omo, which drains into Lake Turkana, for the generation of electricity as well as irrigation. Ethiopia has already built two dams along the river: Gilgel Gibe I and Gilgel Gibe II. Plans to build Gilgel Gibe III, which will include a multipurpose dam, are already at an advanced stage. Once completed, Gilgel Gibe III is expected to have very adverse effects on Lake Turkana, which is the world’s largest desert lake (Wikipedia, 2014). River Omo provides the lake with around 90% of its waters, and therefore the lake would be adversely affected, especially if the irrigation scheme is established (Anonymous[3], 2013).

The impacts of irrigation on the environment are sometimes very complex and hard to predict since their occurrence and intensity may depend on properties of the watershed, water abundance, properties of soils, quality and quantity of water being used for irrigation, as well as the applied methodology and means of irrigation Tadic (2009). This implies that the application of irrigation may leave permanent and irreversible consequences on the environment if the impacts are not recognized, foreseen and possibly mitigated or completely prevented. However, some of the changes are easily noticed and quantified, but there is vast number of indirect impacts that are delayed in time after the prolonged application of irrigation and often appearing outside of irrigated area. The solutions lay in systematic planning, designing, construction and operation of undertaking. For this reason, Tadic (2009) added that undertaking of such large scale irrigation projects should include environmental impact assessment prior to the construction which will establish the possible alteration to the environment and assess the sustainability of the system.

Tadic (2009) observed that irrigation has both qualitative and quantitative impacts on water since any capture of water impacts on the existing water balance. Uncontrolled capture of water, especially in dry periods, may result in undermining of the minimum biological requirements of waterways. Impacts of capturing of water above renewable limits may appear after prolonged periods of utilization and may result in lowering of ground water levels on wider areas while continuous lowering of ground waters, along with changes in water balance, may have effect on low-lying forests and wetlands. Many irrigation projects commence with the construction of reservoirs. Such reservoirs, or dams, usually have negative impacts that include change in land use as land is turned into water surface and water ways, reduction of sediment transport downstream and concentration of water pollution in the reservoirs/dams which affects the water quality as well. On the general impacts on the environment, Tadic (2009) noted that changes in land use of area and changes within ecosystems for purposes of agricultural production, along with irrigation, have direct impacts on biosphere. Secondary or indirect impacts on biosphere as a consequence of

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[3]The author of this article indicated that he/she wished to remain anonymous. However, the work is credible based on the well-known individuals who endorsed it. They include Dr Richard Leakey, Prof. Eric Odada of the University of Nairobi, David Hales, a former Chair of UNESCO World Heritage Committee, among others. Further, International Rivers, the publishers of this work, is a well-known international organization that endeavors to protect rivers and the rights of communities that depend on them.

irrigation may appear with significant reduction of ground water levels which impairs biological conditions within ecosystem.

Kinfe (2012) examined the negative impact of small-scale irrigation schemes while using the Ethiopian Central Tigray region as a case study. In the study, it was realized that mass production of perishable vegetables within the irrigation schemes, within an area with poor infrastructural facilities, led to misunderstanding of communities on the profitability of irrigation and irrigation technology. The temporal production of crops had led to the reduction of market value of crops grown under irrigation. The full impact of irrigation on household livelihood was difficult to ascertain since some farmers taking their produce to the markets while others were selling them within the farms at much lower prices. On the impact of irrigation on livestock herd sizes, Kinfe (2012) found that farmers who were close to the irrigation schemes had reduced the size of their herds as well as grazing land. Kinfe (2012) further noticed that there was an increase in water use conflicts within the irrigated areas, especially between irrigation farmers and herders.

Pests and insects including large birds infestation, is the other problem faced by farm households in line with the implementation of schemes. As the experience of the farm households, pests and insects such as worms have increased significantly because the soil is not drying properly throughout the year for double cropping season and is a problem of irrigable land only. However, other pests such as birds have been introduced to the area due to the presence of water bodies, which the birds used for swimming and living and affect production from both irrigable and rain-fed. This becomes a problem of all farm households producing Teff, Tomato and Hot Pepper, which are easily consumed by bird predators.

The construction of dams also affected the communities as Kinfe (2012) observed that they had lost grazing and farming land. Additionally, the residents lost straight paths to their neighbours as well as to social facilities like churches, schools and health facilities. With the dams in place, different pests and insects mainly mosquitoes, has been introduced, thus making the irrigated areas prone to malaria and other water borne disease. This has therefore increased the expenses of medication thereby reducing labour force for the irrigation schemes. The flowing water in the irrigation canals often floods and enters into homesteads, causing unconditional humidity of living homes. This also leads to other fungal, viral and bacterial diseases that never used to be in the area before the irrigation schemes were established. The study also found out that irrigation schemes displaced farm households from their homes which were in the areas taken over by the dams. The study showed that 120 households were relocated to allow for the construction of the reservoir, and about 40% of them moved to urban areas where they bought property after compensation, thus posing a major challenge in adjusting from rural to urban life.

Closer to Chala Ward, a survey on water quality changes with land use in the Loitoktok area, of Kajiado County by Githaiga *et al,* (2003) identified a number of negative impacts of irrigation on the environment. For comparative purposes, the irrigation schemes that Githiga *et al,* (2003) researched on are very similar to those in Chala Ward, which borders Loitoktok on the northern side. The water used for irrigation in both cases comes from springs found in the slopes of Mt Kilimanjaro and they fall under the same geo-climatic zone. The topography, soils and natural vegetation is also similar, and therefore the research findings by Githaiga *et al* (2003) would form an excellent basis for comparison. Besides, the farmers grow similar crops and employ the same farming and irrigation techniques, as well as the fertilizers, pesticides/fungicides and herbicides used.

The research by Githaiga *et al* found out that warm and damp areas within Loitoktok attract a myriad of pests and diseases. In irrigated areas, there is a high proliferation of insects, mollusks and birds. Farmers in these areas therefore use high doses of pesticides to protect their crops in the hope of maximizing protection. Farmers blend several brands of pesticides, and they do all this with very little, if any, information on the pesticides and herbicides. Farmers mainly rely on the information they are given by the suppliers of the pesticide, who often happen to be traders and middle men who are solely after making quick profits. Within the irrigated areas, farmers use fertilizers, pesticides/fungicides and herbicides with little or no information from agricultural experts. Their main source of knowledge on the use of these chemical products is the dealers.

The research also found out that irrigation had negative impacts on soil. The irrigation system used in the study area is furrow irrigation, where water flows into the furrows in the irrigated areas. This system is cheap since it relies on gravity. However, irrigation efficiency is poor, and water logging and salinization risks are very high owing to the arid nature of the area. In such arid conditions, evaporation is very high, and it takes place very fast, without giving the water time to seep into the ground. This causes soil salinity. It was observed that some farm plots near the irrigation canals had been abandoned due to persistent water logging as a result of water that seeps to the plots from the irrigation canals. The soils therefore end up getting excessive water and become degraded.

Most of the irrigated fields within Loitoktok were reclaimed from swamps. Swamp soils, once exposed, undergo changes that affect their structure and fertility. They undergo oxidation as they were used to be under water always. These soils also lose their organic matter content, thus getting degraded. Leaching of nutrients as well as accumulation of salts takes place due to continuous irrigation process. All these degrade the soils and the general environment. Swamps act as special ecosystems and habitats for some specific flora and fauna, and when they are converted into irrigated farmlands, these living organisms are adversely affected. Most of the irrigated fields within Loitoktok were reclaimed from swamps, meaning that ecosystems and animal habitats were destroyed to pave way to farms. Among the animals that used to live in the swamps around the drained swamps in Loitoktok include hippos, pelicans and other small animals and birds. Once the areas are converted into farms, farmers consider the animals to be a threat to their crops, and they therefore kill or chase the animals away from their natural habitats. The streams/rivers around Mt Kilimanjaro, which include Rover Lumi and River Tsavo, maintain a constant flow of water throughout the year. A unique and rare flora and fauna is therefore able to survive in this area. Increased demand for water for irrigation is threatening these riparian ecosystems.

From this literature, it was evident that irrigation has major negative impacts on the environment. Blank *et al* (2002) highlighted some of the negative impacts when they say that irrigated agriculture contributes to excessive use of external inputs such as fertilizers and pesticides. However, their focus was not on the environment but on how to improve food production and to alleviate poverty in sub-Saharan Africa. While agreeing that these external inputs can harm the environment, they went ahead to recommend that farmers should be facilitated to access these inputs, including credit, seeds as well as being enabled to access markets for their products. Just like Blank *et al*. there is usually little or no focus on the environment, and most of the negative impacts to the environment are brought out incidentally, such as when environmental degradation affects and inhibits optimum production or resources get depleted. Apparently, by the time these impacts are noticed, the damage is already too great to be reversed.

Not much research has been done in Africa including Kenya, to identify the impact of irrigation on the environment, unlike in developed countries such as the USA, Australia and Israel. It is therefore essential that more research be conducted in developing countries where the pressures for opening up more irrigation schemes are immense, such as in Kenya. This literature review therefore pinpoints negative impacts which have been experienced in the stated developed countries, and it is important to see if the same impacts are being experienced in Kenya so that the right mitigation and adoptive measures could be considered in advance. Of great importance is that Kenya is in the tropics where physical and climatic conditions vary greatly from those of these countries where much research has been done, and there is therefore need to examine more intensely as the impacts could be to some extent different due to climatic and latitudinal variations.

In Kenya, if sustainable irrigated agriculture is to be realized, there is need to examine the impact of irrigation on the environment, with a clear focus on soil and water quality and quantity, as well as the impacts on riparian environments, and not merely on enhancing short-term agricultural productivity alone. Loss of environmental services and goods could bring about unforeseen environmental impacts that could roll back the developments being realized today. It is from this background that this study was done, since it was felt that the impacts of agriculture on the environment had not been adequately addressed in the previous studies.

2.3 Research Gaps

Most of the literature used was treating the various components of the environments singly. This is to say separate researches were done for water and soil, with the focus of the studies being the improvement of agricultural productivity. Much of the literature, such as the FAO documents, was addressing the problem of food insecurity and was focusing on the human environment or the socio-economic wellbeing and only mentioned the natural environment when affected human wellbeing. Subsequently, much of the literature stressed on the positive side of irrigation, and how it is the ideal way of addressing the problem of food insecurity and demand for other agricultural products. However, these irrigation projects, especially in Africa, were initiated without any EIA reports being carried out and therefore their viability cannot be ascertained. Environmental impacts may take long before they are felt, and might also be felt when it is too late to mitigate.

This research project therefore looks at the impact of irrigation on the environment by looking at how irrigation impacts on soil, water and the riparian environment, an area that was not given much emphasize in the literature, and when researched on, the focus not on the multiple elements of the environment that were the focus of this study.

Though Kinfe (2009), identified some impacts of irrigation on the environment, the focus of the study, as it has been the tradition with other researches on irrigated agriculture, focused on agricultural productivity and the socio-economic environment, and not on the impact of irrigation on the natural environment. The impacts identified in the study were mainly those with a bearing to human wellbeing. This research therefore failed to look directly at the impacts of irrigation on the natural environment. Githaiga *et al* focused on the impact of land use changes within Loitoktok on water quality, where incidentally irrigated agriculture happened to be one of the main activities. Though they identified a wide range of negative impacts of irrigation to the environment, their scope was wide as they focused on other land use activities such as wildlife, livestock and rain fed cultivation and how they affect water quality. On its part, this research project looks mainly at the impacts of irrigation on soil and water as well as the riparian environments. This present research project therefore makes a departure from the other since its primary focus is the impact of irrigation on the natural environment and does not look at the socio-economic impacts.

2.4 Theoretical perspective

In this study, it is hypothesized that irrigation in dry lands causes environmental degradation by affecting the quality and quantity of water, soil degradation and destruction of ecosystems and animal habitats in the downstream areas of rivers or streams diverted for irrigation. The Tragedy of the Commons, a theory by Garret Hardin that emanated from an article published in 1968 in the *Science Magazine*, will be used as a theoretical guide to explain how irrigation has negative impact on the environment.

According to Hardin, common resources can be depleted by those who access and use them. The users of these resources, acting independently and rationally according to their self-interests, can have unfettered access to the resources, thus depleting them. Despite a common understanding that the depletion of the common resource is contrary to the group's long term interests, the users will continue exploiting the resource as each wants to have a maximum gain. Hardin used the illustration of a common pasture where several livestock keepers have access. The farmers will keep on adding livestock, as the actions of each individual are informed by his own personal interests. Every extra animal in the pastureland directly harms others as it prevents them from enjoying the same benefit as before. The trend of exploitation is likely to continue until the pasture is completely depleted. Each individual focuses on his own benefits, and not on the gain of the society. The loss to the society would then translate into losses for all the individuals.

Hardin's theory focused on human population growth and the use of natural resources. Each individual maximizes on the use of the resource, while the cost of depletion is borne by all those to whom the resource is available, whether they are within the resource area or outside. As each individual gains, demand for the use of the resource keeps on increasing, until, according to Hardin, the common resources collapses. This is because unrestricted demand for a finite resource leads to overexploitation, or collapse of the resource.

According to Hardin, three factors; number of users, consumptiveness and robustness of the resources will determine the collapse of the resource. If the number of users is small, the resource will be replenishing faster than it is being used, and its use will be sustainable. However, if the number of users is high, the resource might be used faster than it can replenish, thus getting depleted.

The nature of consumption, or consumptiveness, can also determine the sustainability of a resource. A resource that has a very high consumption rate is likely to be depleted while a resource that is used in a much slower pace could be sustainably used since it will be getting time to replenish. As for robustness, a resource that is delicate can be easily depleted, as opposed to a resource that is in a sound situation.

Within Chala Ward, soil and water are used as common resources. Though individual farmers have their own plots where they cultivate, each person acts individually when it comes to cultivation and each individual is not concerned about what the others are planting or how their individual activities can cumulatively have negative impacts. The farmers apply fertilizers, pesticides and herbicides individually, and they don't put into account the stock of the damage these chemical products can cause to the environment, be it in their individual plots or beyond the areas of applications. These fertilizers and pesticides often get washed into the irrigation canals, and they affect other farmers and water users outside the areas where they were applied. As the farmers apply fertilizers and pesticides, they don't take into consideration that damage that these elements can cause to the soil, as the farmers are obsessed with getting maximum gains from the fields. Such a trend can be harmful to the soils as they could become unproductive. Additionally, since the demand for the irrigated products is very high, farmers cultivate their plots continuously, thus subjecting the soils to maximum strain. The soils are thus treated as commons.

As for water, several streams in the area have been blocked completely and the water directed to irrigation fields. This happens in little or no regard, to downstream environmental impacts that may result from the reduced water flows, or complete blockages of streams. Once in the irrigated fields, the water circulates in the fields nonstop, even during the night, as each individual farmer seeks to get maximum gain from it. As this happens, no noticeable measures are taken to protect the water sources. Farming has taken place even in the river channels, thus threatening the quality and quantity of water. The farmers have a rota for irrigation. However, this rota is not meant to protect the water or soil, but it is for ensuring that each individual accesses the water for his own individual benefit and gains maximally from the use of water. Reduced water-flows in the streams impact negatively on the downstream environment, whose damage can have wider impacts that can include destruction of tourist sites.

The water used in Chala Ward for irrigation, whether from rivers, streams, springs or shallow tube wells, comes from the Kilimanjaro aquifer. There is an increased use of water from this aquifer in both Kenya and Tanzania, with the aquifer being treated as commons. The uncoordinated and extensive use of the aquifer could result into a drop in the water level in the aquifer, something that could cause reduced water from springs, or the springs drying up altogether. Such an eventuality would be equated to the collapse of a commons as envisaged by Hardin.

Taking into account that agriculture is a major cause of non-point pollutant; the activities of farmers in the irrigated areas are a major threat to the delicate environment of the ASAL area. The externalized costs are therefore borne by many people beyond those in the irrigated areas. The collapse of an irrigation projects could mean having a high number of people who will need to be supported from outside, thus extending the effects beyond the irrigated areas.

2.5 Conceptual framework

The conceptual framework for this study borrows heavily from the DPSIR Framework. DPSIR, as outlined in GEO-5 (2012), are initials standing for Driving forces, Pressures, States, Impacts and Responses.

The **Drivers** are factors that will trigger the demand for the production of more food and more agricultural produce. These factors include population growth, scientific and technological innovation, and economic processes such as consumption, production and markets. These factors are present in Chala Ward. The population of the Ward has grown very fast as more and more people are lured by the irrigation schemes to come and settle there for the purpose of practicing agriculture under irrigation. Chala Ward, being in an ASAL area, provides the farmers with a ready market for their products, especially vegetable and horticultural products which cannot do well under the unpredictable seasonal rains in the area. The ready markets for these products further serve as driving forces as farmers get the urge to satisfy the market demands. Besides, the availability and access to technology such as the use of center pivot irrigation systems and petrol or diesel engine powered water pumps increases the urge to produce more.

Pressures are ways in which drivers are expressed physically, reflecting the inter-linkages between a human activity and the surrounding natural environment. They are human interventions to the environment. These are the actual actions undertaken as a result of the driving forces above. These pressures include increasing the areas under cultivation, which is by itself an environmental threat since natural vegetation in cleared to provide farms. As expansion of agricultural production through increasing the acreage under cultivation becomes difficult due to scarcity of rain fed arable land, farmers resort to increasing production by forcing the already cultivated areas to produce more. This is done through the use of fertilizers and chemical pesticides. As the pressure further increases, irrigation is brought in as the most viable option since it will target the marginal areas that are agriculturally less production. At this point, more irrigation schemes are opened in these areas. This therefore explains why irrigation projects and schemes have been opened in Chala Ward. The use of chemical fertilizers as well as herbicides and pesticides is very common in these schemes, the aim being maximization of production.

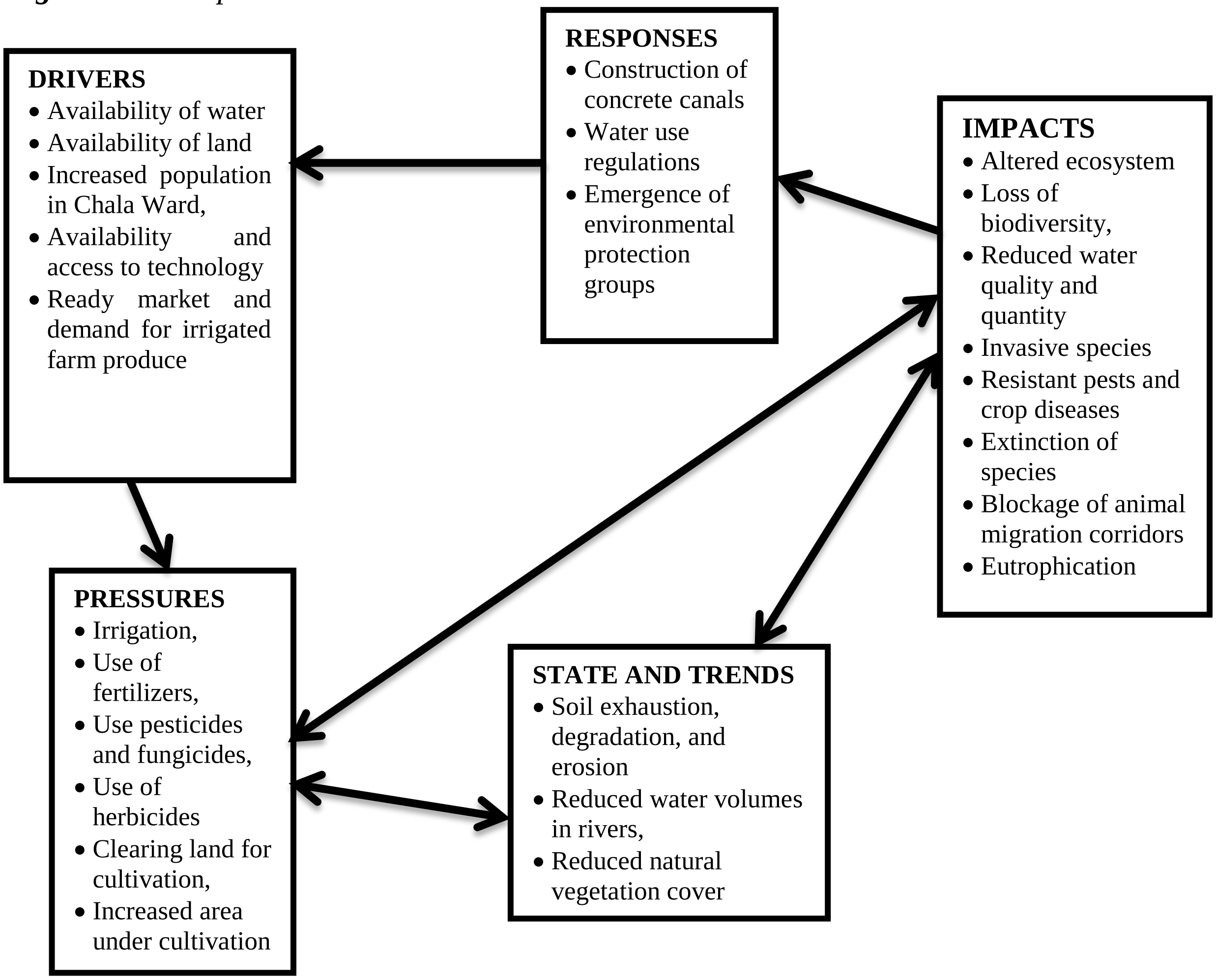
State and trends are the properties of the ecosystem itself when pressures exerted by human activities influence the ecosystems. They are the results of too much pressure to produce. States include the status of the environment when it is strained far beyond its capacity. It is a descriptive explanation of the current state of the environment when under pressure to produce. State and trends include degradation, pollution and depletion of environmental resources such as land, water, biodiversity and air. Within Chala Ward, the pressures are evident. The environment has been degraded. The continuous application of fertilizer is an indicator that the soils are degraded. Water has also been affected. The diversion of water to irrigation fields means that quantity of water in rivers is decreased, thus affecting the environment. Water within the irrigated fields is also affected due to passage through the irrigation canals as well as being affected by fertilizers, pesticides and herbicides used in the fields. The conversion of large tracts of land for irrigated agriculture means the destruction of some delicate ecosystems and animal habitats. The decrease of water in rivers has affected aquatic organisms, including hippos, crocodiles and birds.

Impacts include the alterations and interruptions of environmental systems. At the global level, they include alteration of the global cycles of carbon, methane, nitrogen, phosphorous and other. At localized levels it includes disruptions of river flows, destruction of ecosystems and extinction of species. It also includes the presence of diseases and pests. These impacts are already being manifested in Chala Ward. Rivers that have been blocked to provide water for irrigation are expected to remain blocked, thus they have been permanently altered. Areas that have been converted into irrigated fields have had their environments permanently altered. New crop diseases have sprang up in the area, and pests are building resistance against pesticides, thus rendering many conventional pesticides ineffective in the area.

Responses are formal and informal adaptations and mitigation measures to address or cope with the new environmental status. They are actions taken by society or governments to prevent, compensate, or adapt to changes in the state of the environment. Responses usually aim at changing the drivers so as to avoid pressures. They usually include restoring the destroyed environment as well as altering and restricting human activities with the aim of stopping further damage to the environment. Effects to response to environmental degradation at the global level include the reduction of carbon dioxide and other greenhouse gases that are responsible for prevailing environmental challenges. In Chala Ward, some efforts are already in place to address the problem of environmental degradation. Kwa Tom Lumi Natural Springs Environmental Conservation Group is a case in point where, through the efforts of villagers, a section of River Lumi that had some streams which dried up as a result of human encroachment was fenced. The environment regenerated and the streams started flowing again. Concrete irrigation canals have also been constructed so as to reduce water salinization.

Once the environment regenerates, the DPSIR process starts once again. New **drivers** will come into place, followed by pressures, and eventually the **state** of the environment will change and impact negatively on the environment regenerated environment again. The regenerated section of River Lumi that was fenced by Kwa Tom Lumi Natural Springs Environmental Conservation Group is already coming under **pressures** as farmers have begun pumping the water and using it for irrigation.

Figure 3: *Conceptual Framework*



Adopted and modified from GEO -5 (2012)

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Irrigation schemes in Chala Ward

The main objective of this research project was to establish the impact of irrigation on the environment. The dependent variable, environment, is a composite term that consists of four segments namely; atmosphere, lithosphere, hydrosphere and biosphere (Singh, 2006). This research therefore endeavored to find out the farming methods used by farmers within the irrigation that may affect the environment, whether there is a significant difference between soil properties in irrigated and non-irrigated areas, whether the diversion of water from natural courses to irrigation areas significantly affects its quality and assess the impact of irrigation on riparian ecosystems of rivers/streams diverted to the irrigation schemes. The research was carried in four irrigation schemes in Chala Warrd. These are Ziwani Gicheha Farms, Chala Tuhire, Kithito and Njukini.

3.1.1 Ziwani Estate Gicheha Farms

Plate 1: *Center pivot irrigation system in Ziwani Estate Gicheha Farms*

The center pivot irrigation system (A and B), also called water wheel or circle irrigation, is a modern irrigation method that is highly efficient and uses less water compared to furrow irrigation. The method is employed in Ziwani Estate Gicheha Farms

(Researcher 2014)

Ziwani Estate Gicheha Farms has about 4,000 acres already under irrigation, with about 2,000 acres being irrigated using the center pivot irrigation systems[4] ***(Plate 1)***. Highly mechanized farming and irrigation techniques, including center pivot irrigation, are employed. By the time this research was being carried out, Ziwani Estate Gicheha Farms had eight farms, each being about 240 acres, irrigated through center pivot irrigation systems.

3.1.2 Chala Tuhire

Chala Tuhire irrigation scheme is 1,250 acres and has 610 members[5]. Horticultural products grown in the area have a ready market in the nearby surrounding areas incuding the urban centers and towns of Taveta, Voi, Mombasa. The main crops currently grown are maize, beans, tomatoes and onions.

3.1.3 Kithito

Kithito irrigation scheme acreage is about 600 and it has 390 members[6].The irrigation scheme was started in 1974[7] by individual small scale farmers who used sacks filled with soil to create a weir along Sante Stream of Lumi River. The land under this irrigation scheme is disputed as it is alleged to belong to an absentee landlord, Sir John Ramsden. The main crops grown in the area, just like in Tuhire irrigation scheme, are maize, beans, tomatoes and onions.

3.1.4 Njukini

Njukini irrigation scheme, whose acreage is 694, was started in 1976 and has 347 members[8]. The water used for irrigation is drawn from Njukini River, another upstream tributary of Tsavo River. Crops grown in the scheme are mainly horticultural, just like in the other schemes.

3.2 Farming methods that may affect the environment

In order to find out if farmers in Chala Ward employ practices that could affect the environment, a set of survey questionnaires were designed. The main objective was to establish the extent of use

[4] Oral interview with Peter Murimi, the assistant production manager, Ziwani Estate Gicheha Farms

[5] Oral interview with Patrick Mrisha, the chairman of Chala Tuhire irrigation scheme
[6]Interview with Justus Makenzi, Chief Njukini Location. The real acreage of the area under irrigation has never determined
[7] Oral interview with Juliana Muli, who began farming in the area in 1975
[8] Oral interview with Justus Makenzi, Chief Njukini Location

of chemical fertilizers, pesticides/fungicides and herbicides such as chemical fertilizers, pesticides/fungicides and herbicides as could have impacts on the environment. At the same time, the frequency of irrigation, the number of times crops are irrigated before harvest, was also established. This is because ASAL areas have high rates of evaporation and the frequent application of water to the soil could increase the alkalinity of the soil. A total of 25 farmers from each irrigation scheme were selected for interview using the systematic sampling, and getting the five respondents was not a challenge as the farmers were cooperating and were willing to be interviewed. The systematic sampling method used in this section was guided by the systematic soil sampling method where five soil samples were picked from the irrigated areas by taking a 'zig zag' path through the irrigated fields. Every point where a soil sample was picked, five farmers from the surrounding area were interviewed through the questionnaire in ***Appendix 2.*** In Ziwani Estate Gicheha Farms, five soil samples were picked but it was only one person, the production manager, who was interviewed because the farm has a centralized management. Twenty-five (25) farmers in the surrounding non-irrigated areas were interviewed through questionnaires to determine agricultural practices in the areas.

The unreliability of rain fed agriculture has therefore led to intensive farming within the irrigated areas within Chala Ward as farmers seek to produce a variety of crops both for consumption and for commercial purposes. Crops grown within the irrigation schemes are irrigated several times before harvest, and being a dry area, evaporation is high, leading to a higher frequency of irrigation so as to cope with the evaporation rate. Irrigation methods used in Chala Ward are basin, furrow and center pivot. Small scale farmers in Chala Tuhire, Kithito and Njukini use basin and furrow irrigation method, while Ziwani Estate Gicheha Farms use center pivot in addition to the two other methods.

During the research, 25 farmers in each of the three irrigation schemes: Chala Tuhire, Njukini and Kithito were interviewed, while the production manager at Ziwani Estate Gicheha Farms was interviewed. The interviews sought to find out the following:

- **The type of crops grown under irrigation since** this determines the number of times the crop is irrigated, the type and number of times fertilizers, pesticides/fungicides and herbicides are applied;
- **Number of times each crop is grown within a year** as it determines the extend of pressure applied to the field;

- **Number of times each crop is irrigated before harvest.** This determines the impact of water on the soil as well as the riparian ecosystem. A high frequency of irrigation leads to drawing more water from the streams/rivers leaving no water for environmental services;
- **Frequency of using chemical fertilizers, pesticides/fungicides and herbicides** like chemical fertilizers, pesticides/fungicides and herbicides since they have both direct and indirect impacts on the environment.

The results on this section, about farming practices, were represented through the use of percentages, tables and bar graphs.

3.3 Soil Properties in Irrigated and Non-Irrigated Areas

This research project sought to establish the significant difference between soil properties. A total of five composite soil samples were collected from Ziwani Estate Gicheha Farms, Chala Tuhire, Kithito and Njukini irrigation schemes. Another set of ten composite samples from the non-irrigated farms near the irrigation schemes was collected to serve as a control sample. Each composite sample was composed of five core samples. All the samples, 30 of them, were then taken for laboratory analysis at LARMAT to find out the values of the following soil properties: Nitrogen, Phosphorous, Potassium, Soil pH, Cation exchange capacity (CEC), and Soil Organic Matter (SOM). The systematic sampling method was used to collect the samples by taking a zig zag[9] route across the irrigation scheme. According to Carter M.R and Gregorich E. G (2008), the systematic sampling method through the use of a zig zag path is a method recommended by a number of prominent soil researchers such as Marx and Sabbe (1987), Calvin and Petersen (1987) and Melsted and Peck (1973).

In collecting the core samples, a hand hoe and a spade were used. First, a U-shaped furrow was dug, with a depth of about 20 cm, for picking the sample. The depth of about 20 cm is the tillage depth of most crops grown in Chala Ward such as maize, beans, tomatoes and onions. Before the hole was dug, the loose, powdery soil at the top was scrapped away. Using the shovel, a slice of soil of a three-cm slice of soil was cut vertical at the edge of the hole from the top to the bottom of the hole. From every hole, about a half (½) kilogram of soil was then picked, packed in a small khaki envelopes, and then air dried. For each sampling point, five core samples were collected from a distance of about 100 meters from the point that was identified through the zig zag method.

[9] Marx D.B and Sabbe W. E (1987) *Soil Sampling: Spatial and Temporal Variability* Soil Science Society of the U.S.A, Taylor and Francis Group, LLC, U.S.A

The core samples from each point were then thoroughly mixed before it was taken to LARMAT for analysis.

The Mann-Whitney U test statistical method was then used to find out the significance difference between the samples from the irrigated areas and those from the non-irrigated areas. This method was used because it is a non-parametric, and the soil values being compared are not parametric values. The method is also ideal for making comparison of data with few categories.

This section specifically looked at the second hypothesis which presupposed that irrigation in dry lands has no significant effects on soil chemical properties. Five composite soil samples were therefore collected from the irrigated farms through a random sampling method where a zigzag path was taken across the irrigation schemes. Ten other composite samples, to act as the control sample, were collected from the non-irrigated areas around the irrigated areas that have never been irrigated. The calculated values of the soil chemical properties from the irrigated areas were then compared with those from the non-irrigated areas. Each soil property from each irrigation schemes was compared with its equivalent from the control sample which was the samples from the non-irrigated areas. The assumption here was that any significant difference that would be found between the samples sets would be caused by irrigation, and therefore it would be considered to be the impact of irrigation on soil.

Since the objective of this research is to examine the impact of irrigation on the environment, the soil properties examined were mainly those associated with soil fertility, since degraded and infertile soils can lead to further environmental degradation since more land would be required to meet the declining production, thus leading to increased encroachment on forest and other uncultivated areas. These soil properties are:

- Nitrogen
- Phosphorous
- Potassium
- Soil pH
- Cation exchange capacity (CEC), and
- Soil Organic Matter (SOM)

The analysis of the samples was done at the Soil Physics Laboratory at the Department of Land Resource Management and Agricultural Technology, College of Agriculture and Veterinary Sciences, University of Nairobi.

3.3.1 Soil Analysis methods

The soil samples were taken to LARMAT for analysis. There are different methods used to analyze the different soil properties. These include:

- **Soil pH:** This was determined by using a pH meter and glass electrodes;
- **Soil Organic Matter:** This was determined using the Walkely-Black method;
- **Nitrogen:** The Kyedhal method was used;
- **Phosphorus:** The Mehlich method was used;
- **CEC:** Ammonium ethanoate and potassium chloride solutions were used;
- **Potassium:** just like CEC, Ammonium ethanoate and potassium chloride solutions were used.

The soil analysis methods indicated were used because they are the ones available in LAMART and are the most commonly used methods across the world as they have been proved to be the best[10].

3.3.1 Mann-Whitney U test

After getting the calculated values of the soil properties, computations were done using the Mann-Whitney U test to determine whether there were any significance differences between soil chemical properties between irrigated and non-irrigated areas of Chala Ward. The test from each irrigation scheme was run separately since all the irrigation schemes get their irrigation water from different streams/rivers and therefore the impacts could be different based of the source of water. The Mann-Whitney U test was also used to see the significance difference between all the soil parameters from the irrigated fields and those from the non-irrigated fields. In this case, soil nitrogen, phosphorous, potassium, Soil pH, Cation exchange capacity (CEC), and Soil Organic Matter (SOM) levels from each irrigation schemes were compared with those from the non-irrigated areas.

The statistical data analysis method used to test the level of significance between the two samples (one from the irrigated areas and the other one from non-irrigated areas) was used. Mann-Whitney U test was chosen because of the following reasons:

- The Mann-Whitney U test assumption is that the two samples being compared are from a common population;
- It is a non-parametric test, and the values of the soil properties being compared are not parameterized values of probability distribution such as mean or standard deviation;

[10] This explanation was given by John Kimotho, a senior laboratory technician in LARMAT

- The sample sizes are small and this test can be used to validate significance of small samples;
- All the observations from the samples being compared are independent of each other, meaning the largeness or smallness of a sample in either group will not affect the size of a sample in the other group;
- The values are ordinal which means it is easy to distinguish each values magnitude;

The steps used for the computations using the Mann-Whitney U test are as follows;

1. Identify the number of scores in each group.
2. Combine and rank all the scores in an ascending order;
3. Assign ranks to the score in an ascending order;
4. Calculate the sum of these ranks separately for each sample ($\sum R_1$ and $\sum R_2$);
5. Calculate U_1 and U_2 using the formula given below;
6. Designate the group with the higher ranks as R2;
7. Of the two Us, take the smaller U and compare it with the critical value of U test at 0.05 significance level for hypothesis testing.

Formula

$$U_1 = N_1N_2 + \frac{N_1(N_1+1)}{2} - \sum R_1$$

$$U_2 = N_1N_2 + \frac{N_2(N_2+1)}{2} - \sum R_2$$

N_1 = Number of observations in the first group

N_2= Number of observations in the second group

R_1= Sum of ranks assigned to the first group

R_2= Sum of ranks assigned to the second group

H_0 There is no significance difference between the two groups

H_1 There is a significance difference between the two groups

If calculated value is **smaller than or equal to the critical** value shown in ***Table 1***, reject the null hypothesis. There is a significance difference between the two samples. If the calculated value **is greater than** the critical value, don't reject the null hypothesis. There is no significance difference at the stated significance level.

Table 1.Mann-Whitney Table, Alpha at 0.05, two tailed test

n1\n2	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
2							0	0	0	0	1	1	1	1	1	2	2	2	2
3				0	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8
4			0	1	2	3	4	4	5	6	7	8	9	10	11	11	12	13	13
5		0	1	2	3	5	6	7	8	9	11	12	13	14	15	17	18	19	20
6		1	2	3	5	6	7	10	11	13	14	16	17	19	21	22	24	25	27
7		1	3	5	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34
8	0	2	4	6	7	10	13	15	17	19	22	24	26	29	31	34	36	38	41
9	0	2	4	7	10	12	15	17	20	23	26	28	31	34	37	39	42	45	48
10	0	3	5	8	11	14	17	20	23	26	29	33	36	39	42	45	48	52	55
11	0	3	6	9	13	16	19	23	26	30	33	37	40	44	47	51	55	58	62
12	1	4	7	11	14	18	22	26	29	33	37	41	45	49	53	57	61	65	69
13	1	4	8	12	16	20	24	28	33	37	41	45	50	54	59	63	67	72	76
14	1	5	9	13	17	22	26	31	36	40	45	50	55	59	64	67	74	78	83
15	1	5	10	14	19	24	29	34	39	44	49	54	59	64	70	75	80	85	90
16	1	6	11	15	21	26	31	37	42	47	53	59	64	70	75	81	86	92	98
17	2	6	11	17	22	28	34	39	45	51	57	63	67	75	81	87	93	99	105
18	2	7	12	18	24	30	36	42	48	55	61	67	74	80	86	93	99	106	112
19	2	7	13	19	25	32	38	45	52	58	65	72	78	85	92	99	106	113	119
20	2	8	13	20	27	34	41	48	55	62	69	76	83	90	98	105	112	119	127

Notes for Certified Reliability Engineer http://creprep.wordpress.com/2014/04/06/mann-whitney-u-test/ Accessed on 20th September 2014

Using the Mann-Whitney computation, comparisons between the samples from the non-irrigated areas were compared with those from the four irrigated areas. The values of soil Nitrogen, Phosphorous, Potassium, Soil pH, Cation exchange capacity (CEC) and Soil Organic Matter (SOM) from the irrigated fields and those from non-irrigated fields were compared. Each soil property from each irrigation scheme was compared with the value of its equivalent soil property from the non-irrigated areas.

3.4 Effect of Diversion of Water on Its Quality

In this section, water samples were collected from three streams/rivers used for irrigation in Ziwani Estate Gicheha Farms, Chala Tuhire and Nuukini irrigation schemes. Six water samples, two from each irrigation scheme, were collected using the purposive method since the objective of this section was to find out the significant difference caused by the diversion of water from the main stream/river courses into irrigation schemes. One sample was collected at the diversion point (weir) and the other from within the irrigation canals in the irrigation schemes. Kithito irrigation scheme was left out since it is irrigated by two streams. Water from these two streams mixes within the irrigation scheme and it is difficult to make a comparison between water in the irrigation scheme and at the diversion point since the diversion points are two. The control samples for Chala Tuhire irrigation scheme was drawn at the weir in River Lumi where the water is diverted from the main river into the irrigation canal that flows into the irrigated fields. The other sample was drawn from the irrigated fields. For Njukini, the control sample was drawn from the weir at River Njugini while the other one was drawn within the irrigated fields. Ziwani Esate Gicheha Farms are also served by water drawn from two streams – Tsavo and Njoro. However, water from the two streams flows for about 2 kilometers before getting into the dam from where water is drawn to be used by the center pivots. The control sample was therefore drawn at the point where the two streams join each other, while the other sample was drawn from the dam. Kithito irrigation scheme was left out since water from two different streams mixes within the irrigation scheme and at different sections, hence making it difficult to determine the exact source of water within the schemes. It took about six hours to deliver the six water samples to LARMAT for analysis, which was quite within the eight hours that were recommended by the laboratory technicians.

In LARMAT, the samples were analyzed for the following properties: pH, Electric Conductivity (EC), Sodium (Na), Potassium (K), Calcium (Ca), Magnesium (Mg), Bicarbonate (HCO_3), Chlorine (Cl), and Carbonate (CO_3).

Since this research project sought to determine whether the quality of water is affected by diversion from the natural course, two samples were collected from each water sources for analysis and then a comparison was done. One sample was collected at the diversion point, where the water is directed to the irrigation schemes. This was to act as the control sample. For the small holder irrigation schemes of Chala Tuhire and Njukini, the water sample from within/inside the irrigation scheme was collected at centermost part of the irrigation from the irrigation canals. Ziwani Estate Gicheha Farms gets its water from two streams; Tsavo and Njoro. However, water from the two streams mixes before it gets into the irrigation fields. The point where the two streams come to contact was treated as the diversion point, and the control sample was picked from there. Water from Tsavo and Njoro streams then flows into a small dam from where it if fed into the center pivot irrigation systems through metal pipes. The other sample was collected from this dam.

It was communicated to the researcher by the laboratory technicians in LARMAT that for water samples to reflect accurate results, the samples must be delivered to them not more than eight hours after they are drawn. The samples were bottled, properly corked, and put in a cold box that had ice cold water and were delivered to LARMAT within six hours, which was within the time limit provided for by LARMAT.

3.4.1 Water analysis methods

Each water parameters were analyzed using different methods. These are:

- **EC:** Ammonium ethanoate and potassium chloride solutions were used;
- **Hydroxide:** Titration of hydroxide method was used;
- **Carbonate:** The titration of carbonate method was used;
- **Bicarbonate:** The titration of bicarbonate method was used;
- **Chloride:** The titration of chloride method was used;
- **Calcium:** Atomic absorption spectrophotene method was used;
- **Potassium:** Atomic absorption spectrophotene method was also used;
- **Sodium:** Atomic absorption spectrophotene method was used.

The water values of the following water properties were obtained: pH level, Electric Conductivity (EC), Sodium (Na), Potassium (K), Calcium (Ca), Magnesium (Mg), Bicarbonate (HCO_3), Chlorine (Cl) and Carbonate (CO_3). Bar graphs were used to present the result.

3.5 Impact of Irrigation on Streams and Rivers

The diversion of water from the main stream/river courses into irrigation canals ends up affecting the riparian ecosystems. The estimated amount of water required to maintain ecosystem goods and services is 75% of the total water use (Falkenmark and Rockstrom, 2004). This section sought to examine current state of the riparian environment, especially the downstream sections which have been affected by the diversion of water to the irrigation schemes. The data on this section was collected through key informants, 20 people mainly farmers who witnessed the inauguration of the irrigation schemes. In addition, photographs, accompanied by explanations, of some key features of the study area, especially along the rivers, were taken and used in this research project.

This therefore means that any diversion of water that exceeds 75% would be harmful to the environment. This percentage is likely to be exceeded in many places, especially in drylands, since the pressure to produce fresh farm produce, whose demand is always high, will be there it will be hard for human beings to take only 25% of the water and leave the rest to “go to waste”. This study assessed the impact of the reduced water levels, or lack of water, within the streams and rivers whose water has been diverted for irrigation. It also assessed the possible impacts as a result of the way the weirs are constructed and how they could impact on the riparian environment. An explanation from the key informants and explanations of photographs taken by the researcher are used to convey the findings.

CHAPTER FOUR: RESULTS AND DISCUSSION

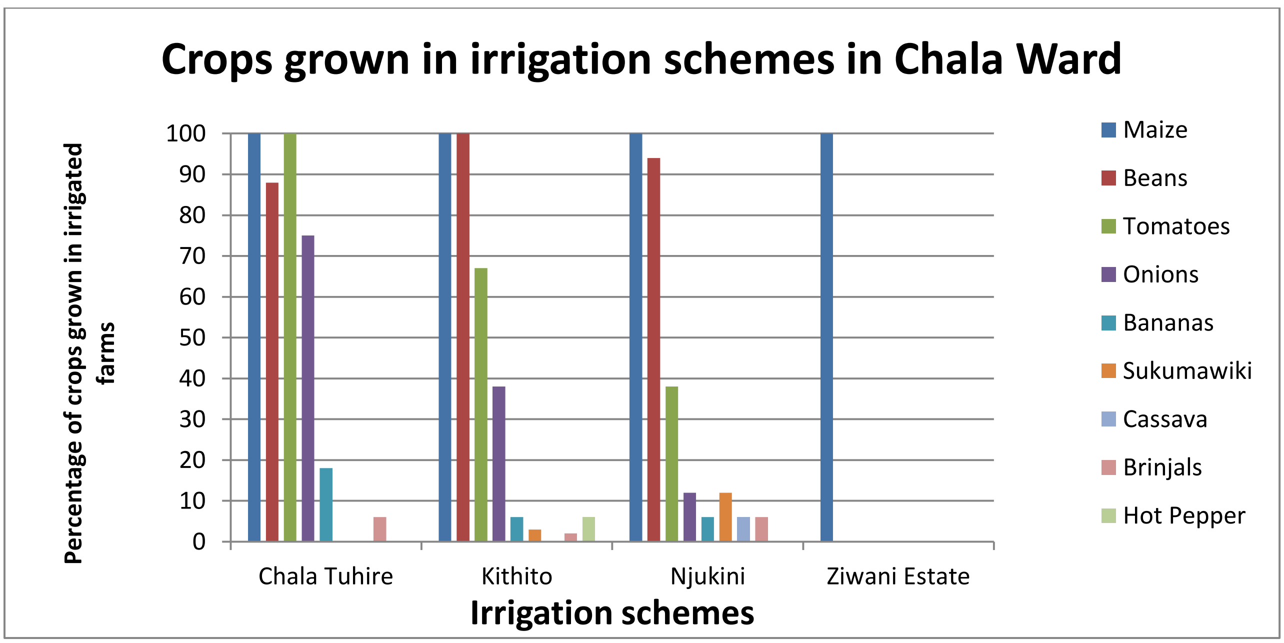
The chapter is divided into four sections where the first section looked at the farming practices employed by farmers within the irrigation schemes. The second section looks at the effects of irrigation on soil, while the third section examines how diverting water from the main/original stream/rivers courses into irrigation schemes affects the quality of water. The final section looks at the impact of irrigation on the streams/rivers whose water has been diverted for irrigation.

4.1 FARMING METHODS THAT MAY AFFECT THE ENVIRONMENT

The availability of water within Chala Ward has prompted intensive farming in the irrigated areas. Farmers in Chala Ward tend to concentrate more on the irrigated portions, though they always prepare and plant their farms in the non-irrigated during the long rains of around March and April as well as during the short rains around November and December.

4.1.1 Crops grown under irrigation in Chala Ward

Figure 4: Crops grown, in percentage[11], in irrigation schemes in Chala Ward



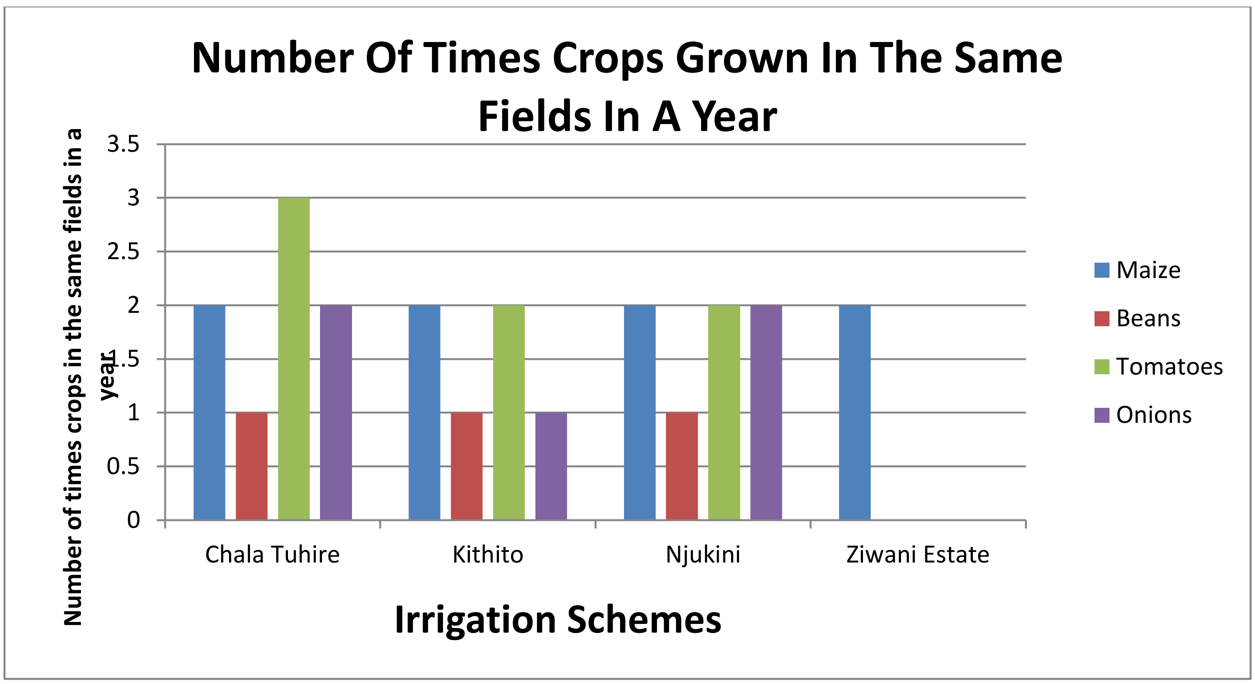
[11] Percentages of crops grown was used instead of the actual number of farmers growing crops since farmers divide their farms into small portions to plant different crops as well as planting different crops in different seasons of the year. Additionally, actual number of farmers would have failed to correctly represent Ziwani Estate Gicheha Farms, where it was only the production manager who was interviewed owing to the centralized management of the farm.

(Researcher 2014)

The results obtained during the interviews showed that famers mainly grow maize, beans, and tomatoes as the principal crops, as indicated in ***figure 4***. The other crops are bananas, sukumawiki, cassava, egg plants (brinjals) and hot pepper. Farmers usually subdivide their land so that they can grow a number of crops simultaneously, or they grow them in different seasons of year. Almost all the small scale farmers in Chala Tuhire, Kithito and Njukini divide their farms so that they can grow food crops, usually maize and beans, and cash crops, normally horticultural products like tomatoes and onions. However, Ziwani Estate Gicheha Farms only grow seed maize as it has been contracted by Kenya Seed Company. Since maize, beans, tomatoes and onions are the principal crops grown in irrigation schemes within Chala Ward, the focus of the research project concentrated on these four crops.

4.1.2 Number Of Times Crops Grown In The Same Field in A Year

Figure 5: ***Number of times crops grown in a year***



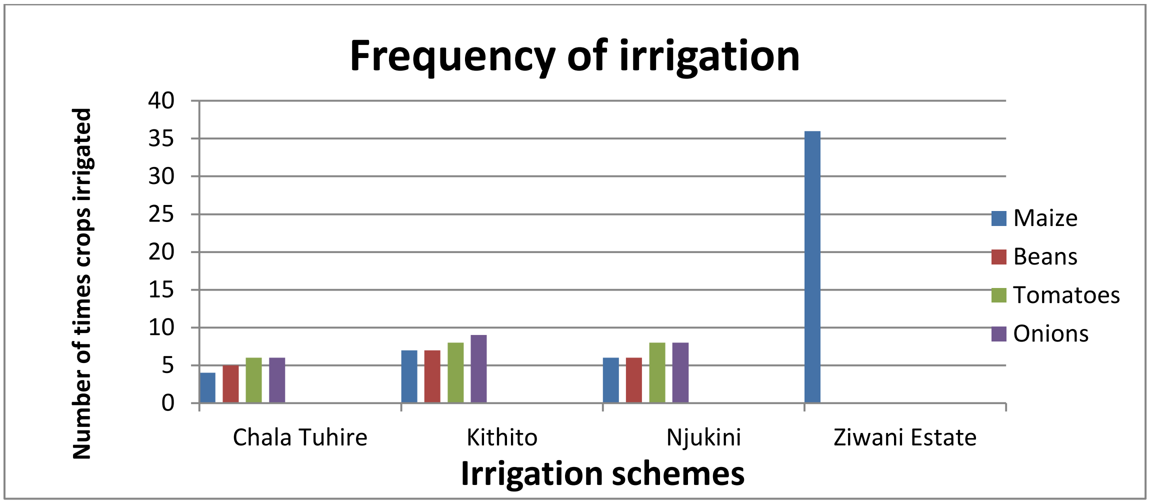
(Researcher 2014)

Figure 5 shows the number of times each crop is grown in the same field within a year. Maize, tomatoes and onions are grown more than once in a year, while beans are grown only once. It emerged that farmers consider June, July and August as the season for beans and after that they continue growing other type of crops. In Chala Tuhire, it was realized that farmers grow tomatoes three times in a year.

From these results, it's apparent that the farms, except for Ziwani Estate Gicheha Farms, are never left to lie fallow, and the soils are easily exhausted or become alkaline as indicated by results from soil analysis.

4.1.3 Irrigation frequencies

Figure 6: Number of times crops irrigated before harvest



(Researcher 2014)

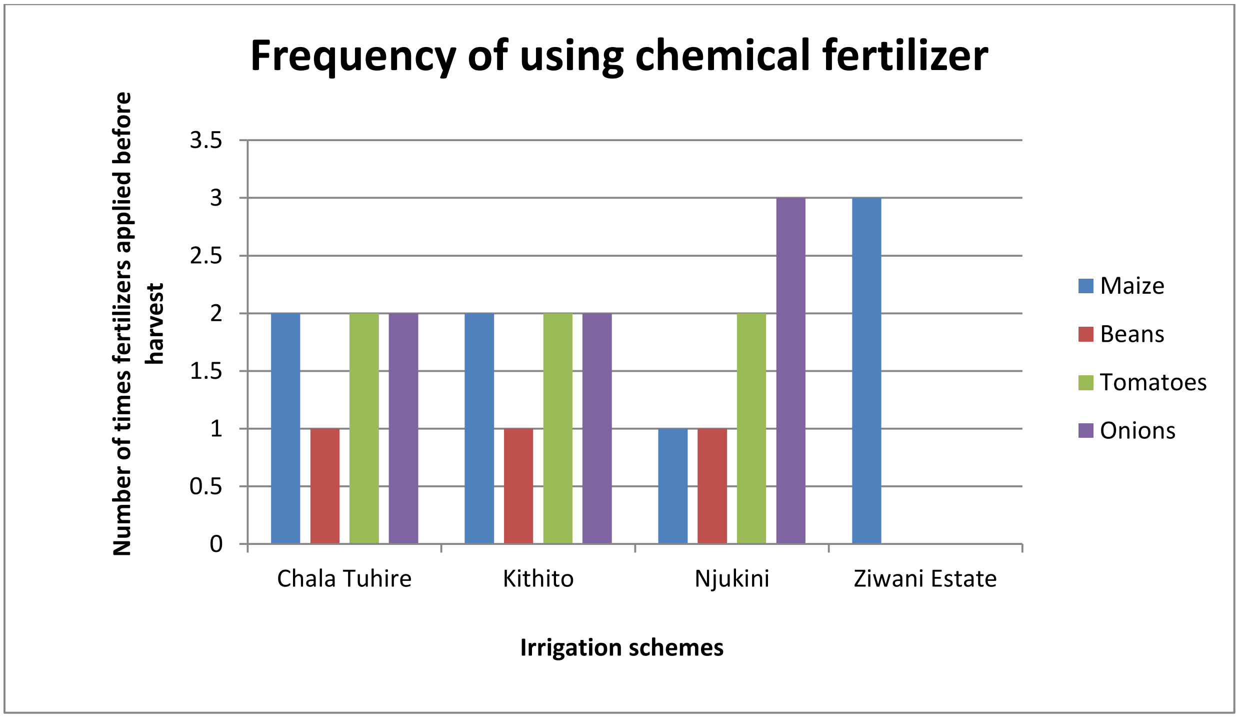
Figure 6 shows the number of times each crop is irrigated before harvest. Beans are irrigated five to seven times; tomatoes between six and eight times, and onions between six and ten times before harvest. The frequency of irrigation varies slightly in Chala Tuhire, Kithito and Njukini. The frequency is determined by the amount of water available in the streams/rivers as well as the number of farmers and area under cultivation. Maize is irrigated between four and seven times before harvest. However, in Ziwani Estate Gicheha Farms, it was found out that maize is usually irrigated about 36 times, usually after every four or five days. This is because the maize produced must meet the high standards of seed maize, and therefore the farm is professionally managed. Additionally, the use of modern technology in irrigation, including center pivot irrigation methods, is employed in the farms.

The number of times crops are irrigated is the major reason why the irrigation schemes do not have outflows since there appears to be a scarcity of water, and the available water is usually fully utilized. This indicates why some rivers, like Lumi and Njoro, have completely dried up as all the water is diverted to the irrigation schemes or pumped with petrol/diesel water pumps..

4.1.4 Frequency of using chemical fertilizers, pesticides/fungicides and herbicides

Figure 7 shows the frequencies of using chemical fertilizers, pesticides/fungicides and herbicides within the irrigation schemes

Figure 7: ***Frequency of fertilizers use in irrigation schemes***



(Researcher 2014)

Fertilizers can be harmful to the environment in a number of ways, including affect soil and water quality. The common fertilizers used in the area are Diammonium Phosphate (DAP), Calcium Ammonium Nitrate (CAN) and Nitrogen Phosphorous Potasium (NPK). Farmers apply the fertilizer at the roots of the plants ***(Plate 2A)*** as well as foliar feeding by spraying the plant leaves. In Ziwani Estate Gicheha Farms the fertilizers are dissolved in water and then fed into the center pivot irrigation systems where they are sprayed mixed with the irrigation water ***(Plate 2B)***. When washed into water bodies, fertilizers cam cause eutrophication. They can also stimulate the growth of some plants and alter the general ecosystem. The research results showed that all the small holder farmers in Chala Tuhire, Kithito Njukini were using chemical fertilizers. The same was the case in Ziwani, where fertilizers are also used. It was also realized that fertilizer was used with all the four principal crops.

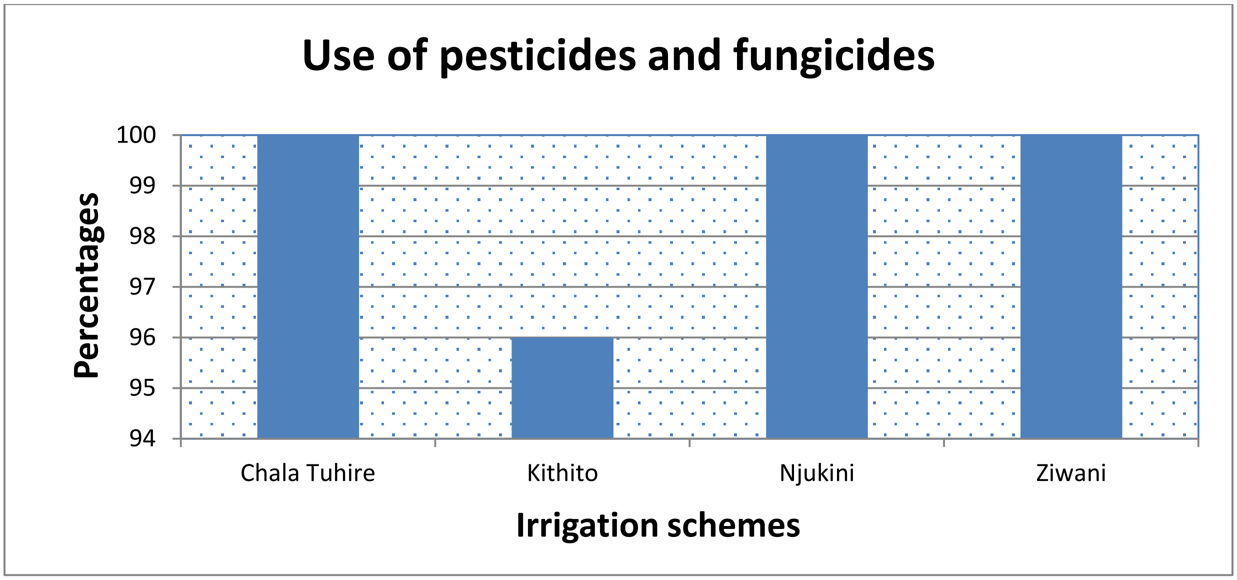
Plates 2A and B: *Application of fertilizers within irrigation schemes in Chala Ward*

Freshly applied chemical fertilizer in Chala Tuhire (A) and a tank containing liquefied fertilizer for feeding into the center pivot irrigation systems (B) at Ziwani Estate Gicheha Farm. The use of chemical fertilizer is very common in the irrigated areas.

(Researcher 2014)

Pesticides and fungicides are also widely used in the irrigation schemes as shown in ***Figure 8.***

Figure 8: Percentage[12] of farmers using pesticides and fungicides in Chala Ward



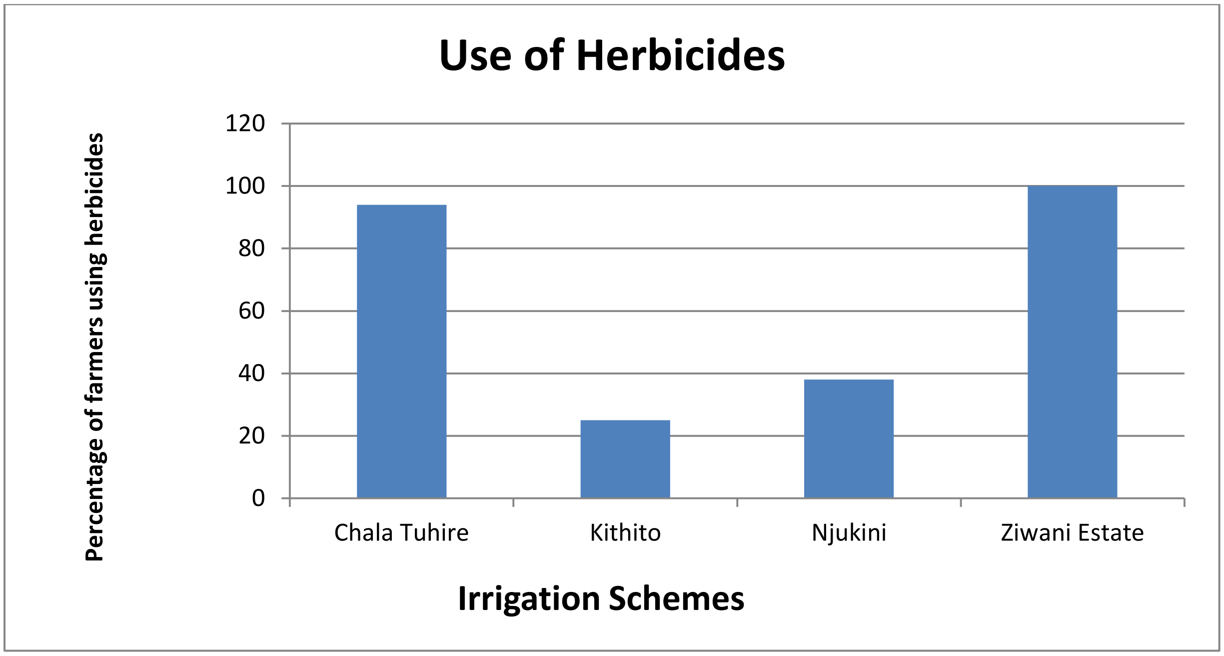
Researcher 2014

The most common pesticides, by their trade names, are Polytrine, Tata Alpha and Karate Zeon, all of which are pyrethroids. Common fungicides include Theovit Jet, Wettable Sulphur, and Bayleton which have some level of toxicity, especially Bayleton, if applied in high dosages. The pesticides are considered harmful to the environment as they kill other organisms that were not intended to be killed, such as bees, which play a crucial role in the pollination of plans, both in the agricultural areas and the general wilderness. Pesticides and fungicides are widely used in Chala Ward. The area, being an ASAL, attracts a number of living organisms when due to the increased humidity levels. This therefore calls for high dose of pesticides so that it can eliminate a combination of known and unknown pests and fungi. Due to the continuous irrigation activities which means crops are always in the irrigated fields, pesticides and fungicides are applied continually, hence posing a real threat to the environment.

The use of pesticides and fungicides is wide also equally high within the irrigated schemes. In Chala Tuhire, Kithito and Ziwani, 100% of the farmers use pesticides, while at Kithito the use of pesticides stands at 94%, which is equally high. Within the non-irrigated areas there is also a high use of pesticides, with 94% of farmers using them. However, it is worth noting that in the irrigated areas, crops are always in the fields, and pesticides and fungicides are used lesser strain.

[12] Percentage, and the actual number of farmers, was used so as to capture Ziwani Estate Gicheha Farms where only the production manager was interviewed as the farm is centrally managed.

Figure 9: Use of Herbicides



(Researcher 2014)

Figure 9 shows the frequencies of using pesticides within the irrigation schemes. A glysophate herbicide by the trademark name of Roundup is the most in the area, especially among the small holder farmers. The herbicide is non-selective as it kills both broadleaved and grass weeds. In the small holder irrigation schemes, it was found out that 94% of the farmers in Njukini, 25% in Kithito, 38% in Njukini and 100% in Ziwani Estate Gicheha Farms were using herbicides. The herbicides were mainly used clear weeds, especially in Ziwani Esate Gicheha Farms where there is an apparent shortage of farmworkers. Herbicides can affect ecosystems and animal habitats both through direct and indirect impacts.

The interviews also sought to know how the farmers in the small holder irrigation schemes acquired knowledge about the use of the chemical fertilizers, pesticides/fungicides and herbicides they were using. Among the answers given were:

- Other farmers;
- Relatives, especially the young ones who learned from their parents;
- From agriculture lessons taught in school;
- Shopkeepers and vendors;
- Agricultural extension officers;
- Reading instruction on the containers;
- Using their judgments.

4.1.5 Agricultural Activities in Non-Irrigated Areas

The use of chemical fertilizers, pesticides and herbicides is not as extensive as in the irrigated areas. Though maize and beans are grown in the non-irrigated areas, tomatoes and onions are not grown in these areas. This therefore means that there is less pressure on the soils to produce cultivated crops. In these areas, farmers keep livestock, mainly cattle, goats and sheep. Within Ziwani Estate Gicheha Farms, a superior breed of goats shown in ***plate 3***, which are used to upgrade local breeds, kept and sold to different organization that distribute them to farmers in different parts of Kenya.

Plate3: Goats in the non-irrigated areas within Ziwani Estate Gicheha Farms

Goats in Ziwani Estate Gicheha Farms. High breed goats are kept in the non-irrigated areas. (Researcher 2014)

Concerning the use of chemical fertilizers, pesticides/fungicides and herbicides, only 20% were using chemical fertilizers, 90% were using pesticides/fungicides and 5% were using herbicides. Further, unlike in the irrigated areas, the non-irrigated areas had only two short rainy seasons, usually from March to May and from November to December. This therefore means the soils in the non-irrigated areas are not under much pressure to produce like soils in the irrigated areas.

It is apparent that most farmers lack adequate knowledge about the chemical fertilizers, pesticides/fungicides and herbicides. In Ziwani Estate Gicheha Farms, which is managed by agricultural experts, soil and water analyses are frequently done so that right fertilizers are used. This knowledge is clearly lacking among the small holder irrigation farmers.

4.2 SOIL PROPERTIES IN IRRIGATED AND NON-IRRIGATED AREAS

The laboratory results of soil samples are shown in ***Table 2***.

Table 2: Soil analysis results

	Sample No.	pH	Organic Matter	CEC	Nitrogen	Potassium	Phosphorous
Non-irrigated area	No.1	7.43	2.80	10.60	0.30	0.4	27.72
	No 2	7.27	1.16	10.05	0.17	0.15	92.96
	No 3	7.02	2.11	14.30	0.14	1.10	44.68
	No 4	6.94	2.12	20.56	0.27	2.10	101.10
	No 5	6.64	3.32	21.00	0.43	2.00	176.0
	No.6	6.28	0.79	14.5	0.06	1.8	84.5.00
	No.7	7.39	1.12	16.8	0.12	1.01	27.70
	No.8	6.5	0.70	14.5	0.06	1.05	154.50
	No.9	6.55	0.88	13.4	0.09	0.92	54.40
	No.10	7.04	1.37	15.4	0.13	1.75	180.00
Ziwani Estate	No.1	6.90	1.10	15.60	0.25	1.10	45.00
	No 2	6.94	1.70	10.45	1.95	1.70	158.00
	No 3	6.6	0.77	12.6	0.09	1.45	151.00
	No 4	7.05	1.52	18.5	0.15	2.7	135.00
	No 5	6.01	0.55	12.6	0.04	0.95	69.00
Chala Tuhire	No.1	8.22	2.12	17.54	0.27	1.00	13.62
	No 2	8.58	2.78	11.50	0.15	0.70	87.48
	No 3	8.03	1.45	16.00	0.11	2.4	171.00
	No 4	8.55	0.90	10.4	0.11	0.4	57.50
	No 5	8.09	1.61	14.6	0.14	0.75	21.50
Kithito	No.1	8.13	1.54	15.50	0.18	2.2	130.47
	No 2	7.67	2.54	17.40	0.23	2.6	104.58
	No 3	7.51	1.92	15.00	0.20	1.9	169.50
	No 4	7.4	0.93	18.20	0.10	1.3	159.70
	No 5	7.41	1.70	16.8	0.16	1.5	142.70
Njukini	No.1	7.85	1.75	18.00	0.18	1.00	9.40
	No 2	7.91	2.86	18.50	0.25	0.75	11.28
	No 3	8.17	2.16	11.60	0.24	0.9	34.00
	No 4	7.27	1.24	16.60	0.11	1.8	112.00
	No 5	7.69	1.54	18.20	0.14	1.9	188.00

(Researcher 2014)

The Mann-Whitney U test was also carried out to determine the significant difference between the samples from the non-irrigates areas ant the irrigated areas and were tested at a significant level of 5%.

4.2.1 Soil pH

Computation for soil pH levels in Ziwani Estate Gicheha Farms, Chala Tuhire, Kithito and Njukini were done to determine the significance difference. The hypothesis for the purpose of testing the significant difference between the samples from the irrigated fields and the non-irrigated fields, at a significance level of **0.05,** states as follows:

H_o: There is **<u>no</u>** significance difference between soil pH levels of samples from the irrigation fields and those from the non-irrigated areas.

H_1: There is a significance difference between soil pH levels of samples from the irrigation fields and those from the non-irrigated areas

Table 3: Computed results of soil pH

Irrigation Scheme	**Calculated Value (The smaller U)**	**Critical Value**	**Significance Difference**	**H_o Not Rejected Or Rejected**
Ziwani Estate Gicheha Farms	10.5	8	No Significant Difference	H_o is not rejected
Chala Tuhire	0	8	Significant Difference	H_o is rejected in favour of H_1
Kithito	2	8	Significant Difference	H_o is rejected in favour of H_1
Njukini	2.5	8	Significant Difference	H_o is rejected in favour of H_1

Researcher 2014

Table 3 contains a summary of the final results after carrying out computations using the Mann-Whiteny U test. The values of the smaller Us, which were used as the calculated values, is given in this table. The critical value in this case was 8 because the sample size from each irrigation field was 5 and 10 from the non-irrigated fields. When two samples, one with 5 scores and the other 10, are compared at a non-direction significance level of 5% using the Mann-Whitney U test the critical value is 8. The smaller U for Ziwani Estate Gicheha Farms was 10.5. This value is greater than 8. The null hypothesis, which stated that there is **<u>no</u>** significance difference between soil pH levels from the irrigation fields and those from the non-irrigated areas, is therefore not rejected as there is no significance difference at a significance level of 5%. As for Chala Tuhire, Kithito and Njukini irrigation schemes, there was significance difference. The calculated value for Chala Tuhire was 0 (zero), for Kithito it was 2, and for Njukini it was 2.5. in these three irrigation schemes, H_o was rejected in favour of H_1, which means there is a significance difference between pH levels of soil samples from the irrigation schemes and those from the non-irrigated areas.

4.2.2 Soil Organic Matter

Computations for Soil Organic Matter (SOM) in Ziwani Estate Gicheha Farms, Chala Tuhire, Kithito and Njukini irrigation schemes were also carried out. The hypothesis for the purpose of testing the significance difference between the level of SOM in the samples from the irrigated fields and the non-irrigated fields, at a significance level of 0.05 states as follows:

H_o: There is **no** significance difference between soil organic matter levels from the irrigated fields and the samples from the non-irrigated areas.

H_1: There is a significance difference between soil organic matter levels from the irrigation fields and those from the non-irrigated areas

Table 4: ***Computed results of soil organic matter***

Irrigation Scheme	**Calculated Value (The smaller U)**	**Tabulated Critical Value**	**Significance Difference**	**H_o Rejected Or Not Rejected**
Ziwani Estate Gicheha Farms	16	8	No significant Difference	H_o is not rejected
Chala Tuhire	45	8	No significant difference	H_o is not rejected
Kithito	20	8	No significant Difference	H_o is not rejected
Njukini	16	8	No significant Difference	H_o is not rejected

Researcher 2014

Table 4 contains a summary of the final results after carrying out computations using the Mann-Whitney U test to determine the significance difference or SOM levels between samples from the irrigated fields and from the non-irrigated fields. The values of the smaller Us, which were used as the calculated values, is given in this table. The critical value in this case was 8 because the sample size from each irrigation field was 5 and 10 from the non-irrigated fields. When two samples, one with 5 scores and the other 10, are compared at a non-direction significance level of 5% using the Mann-Whitney U test, the critical value is 8. The smaller U for Ziwani Estate Gicheha Farms was 16, Chala Tuhire was 45, Kithito was 20 and Njukini was 16. All these values are greater than 8. This shows that there is no significance difference on the levels of SOM in the four irrigation schemes and the surrounding non-irrigated areas. The null hypothesis, which stated that there is **no** significance difference between SOM levels from the irrigation fields and those from the non-irrigated areas, is therefore not rejected as there is no difference at a significance level of 5%.

4.2.3 Cation Exchange Capacity

The hypothesis for the purpose of testing the significant difference between the CEC level in the samples from the irrigated fields and the non-irrigated fields, at a significance level of 0.05 states as follows:

H_o: There is **no** significance difference between CEC levels from the irrigated fields and the samples from the non-irrigated areas.

H_1: There is a significance difference between CEC levels from the irrigation fields

Table 5: Computed results of soil CEC

Irrigation Scheme	**Calculated Value (The smaller U)**	**Tabulated Critical Value**	**Significance Difference**	**H_o Rejected Or Not Rejected**
Ziwani Estate Gicheha Farms	20	8	No Significant Difference	H_o is not rejected
Chala Tuhire	15	8	No significant difference	H_o is not rejected
Kithito	10	8	No significant Difference	H_o is not rejected
Njukini	17	8	No significant Difference	H_o is not rejected

Researcher 2014

Table 5 contains a summary of the final results after carrying out computations using the Mann-Whitney U test to determine the significance difference of CEC levels between samples from the irrigated fields and from the non-irrigated fields. The values of the smaller Us, which were used as the calculated values, is given in this table. The critical value in this case was 8 because the sample size from each irrigation field was 5 and 10 from the non-irrigated fields. When two samples, one with 5 scores and the other 10, are compared at a non-direction significance level of 5% using the Mann-Whitney U test, the critical value is 8. The smaller U for Ziwani Estate Gicheha Farms was 20, Chala Tuhire was 15, Kithito was 10 and Njukini was 17. All these values are greater than 8. This shows that there is no significance difference on the levels of CEC in the four irrigation schemes and the surrounding non-irrigated areas. The null hypothesis, which stated that there is no significance difference between soil CEC levels from the irrigation fields and those from the non-irrigated areas, is therefore not rejected as there is no difference in CEC levels in the two samples at a significance level of 5%.

4.2.4 Soil Nitrogen

The hypothesis for the purpose of testing the significance difference between the Nitrogen level in the samples from the irrigated fields and the non-irrigated fields, at a significance level of 0.05 states as follows:

H_o: There is **no** significance difference between Nitrogen levels from the irrigated fields and the non-irrigated areas.

H_1: There is a significance difference between Nitrogen levels from the irrigation fields and the non-irrigated areas.

Table: 6 .Computed results of soil nitrogen

Irrigation Scheme	Calculated Value (The smaller U)	Critical Value	Significance Difference	H_o Rejected Or Not Rejected
Ziwani Estate Gicheha Farms	18.5	8	No Significant Difference	H_o is not rejected
Chala Tuhire	24.5	8	No significant difference	H_o is not rejected
Kithito	20	8	No significant Difference	H_o is not rejected
Njukini	19.5	8	No significant Difference	H_o is not rejected

Researcher 2014

Table 6 contains a summary of the final results after carrying out computations using the Mann-Whitney U test to determine the significance difference of Nitrogen levels between samples from the irrigated fields and from the non-irrigated fields. The values of the smaller Us, which were used as the calculated values, is given in this table. The critical value in this case was 8 because the sample size from each irrigation field was 5 and 10 from the non-irrigated fields. When two samples, one with 5 scores and the other 10, are compared at a non-direction significance level of 5% using the Mann-Whitney U test, the critical value is 8. The smaller U for Ziwani Estate Gicheha Farms was 18.5, Chala Tuhire was 24.5, Kithito was 20 and Njukini was 19.5. All these values are greater than 8. This shows that there is no significance difference on the levels of Nitrogen in the four irrigation schemes and the surrounding non-irrigated areas. The null hypothesis, which stated that there is no significance difference between soil Nitrogen levels from the irrigation fields and those from the non-irrigated areas, is therefore not rejected as there is no difference in Nitrogen levels in the two samples at a significance level of 5%.

4.2.5 Soil Potassium

The hypothesis for the purpose of testing the significant difference between the soil potassium level in the samples from the irrigated fields and from the non-irrigated fields, at a significance level of 0.05 states as follows:

H_o: There is **no** significance difference between potassium levels from the irrigated fields and the non-irrigated areas.

H_1: There is a significance difference between potassium levels from the irrigation fields and the non-irrigated areas.

Table 7: Computed results of soil potassium

Irrigation Scheme	Calculated Value (The smaller U)	Critical Value	Significance Difference	H_o Rejected Or Not Rejected
Ziwani Estate Gicheha Farms	19.5	8	No Significant Difference	H_o is not rejected
Chala Tuhire	18.5	8	No significant difference	H_o is not rejected
Kithito	10	8	No significant Difference	H_o is not rejected
Njukini	22	8	No significant Difference	H_o is not rejected

Researcher 2014

Table 7 contains a summary of the final results after carrying out computations using the Mann-Whitney U test to determine the significance difference of potassium levels between samples from the irrigated fields and from the non-irrigated fields. The values of the smaller Us, which were used as the calculated values, are given in this table. The critical value was 8 because the sample size from each irrigation scheme was 5 and 10 from the non-irrigated fields. When two samples, one with 5 scores and the other 10, are compared at a non-direction significance level of 5% using the Mann-Whitney U test, the critical value is 8. The smaller U for Ziwani Estate Gicheha Farms was 18.5, Chala Tuhire was 18.5, Kithito was 10 and Njukini was 22. All these values are greater than 8. This shows that there is no significance difference on the levels of potassium in the four irrigation schemes and the surrounding non-irrigated areas. The null hypothesis, which stated that there is no significance difference between soil potassium levels from the irrigation fields and those from the non-irrigated areas, is therefore not rejected as there is no difference in potassium levels in the two samples at a significance level of 5%.

4.2.6 Soil Phosphorous

The hypothesis for the purpose of testing the significance different between the soil potassium level in the samples from the irrigated fields and from the non-irrigated fields, at a significance level of 0.05 states as follows:

H_o: There is **<u>no</u>** significance difference between **Phosphorous** levels from the irrigated fields and the non-irrigated areas.

H_1: There is a significance difference between **Phosphorous** levels from the irrigation fields and the non-irrigated areas.

Table 8: Computed results of soil phosphorous

Irrigation Scheme	Calculated Value (The smaller U)	Critical Value	Significance Difference	H_o Rejected Or Not Rejected
Ziwani Estate Gicheha Farms	21	8	No Significant Difference	H_o is not rejected
Chala Tuhire	17	8	No significant difference	H_o is not rejected
Kithito	13	8	No significant Difference	H_o is not rejected
Njukini	26	8	No significant Difference	H_o is not rejected

Researcher 2014

Table 8 contains a summary of the final results after carrying out computations using the Mann-Whitney U test to determine the significance difference of potassium levels between samples from the irrigated fields and from the non-irrigated fields. The values of the smaller Us, which were used as the calculated values, are given in this table. The critical value was 8 because the sample size from each irrigation scheme was 5 and 10 from the non-irrigated fields. When two samples, one with 5 scores and the other 10, are compared at a non-direction significance level of 5% using the Mann-Whitney U test, the critical value is 8. The smaller U for Ziwani Estate Gicheha Farms was 18.5, Chala Tuhire was 18.5, Kithito was 10 and Njukini was 22. All these values are greater than 8. This shows that there is no significance difference on the levels of phosphorus in the four irrigation schemes and the surrounding non-irrigated areas. The null hypothesis, which stated that there is no significance difference between soil Phosphorous levels from the irrigation fields and those from the non-irrigated areas, is therefore not rejected as there is no difference in Phosphorous levels in the two samples at a significance level of 5%.

The results of these tests indicate that soil organic matter, cation exchange capacity, potassium, nitrogen and phosphorous are not affected by irrigation as the results indicate that there is no significance difference between samples from the irrigated areas and those from the non-irrigated areas. Concerning soil pH, significant differences were noted in Chala Tuhire, Kithito and Njukini irrigation schemes. However, no significant difference was found in Ziwani Estate Gicheha Farms. This coul be explained through the management style of the farm where soil analysis is done on a regular basis and mitigation measures put in place in advance to reverse such situation. Ziwani Estate Gicheha Farms also practices some kind of ‘shifting irrigation’, where irrigated areas are left to lie fallow for some years before cultivation resumes again. However, in Chala Tuhire, Kithito and Njukini farms are rarely allowed to lie fallow.

The overall assumption here is irrigation has notable effects on soil pH. This can have severe consequences to the environment. Crop production could be lowered by the soil alkaline levels. This will in turn push the farmers to seek other means of livelihood, including encroaching into the environment to harvest biomass fuels, thus leading to environmental destruction and degradation.

4.3 IMPACT OF DIVERSION OF WATER FROM NATURAL COURSES TO IRRIGATED AREAS

The objective of this section was to find out if the diversion of water from the natural courses into irrigation canals and eventually into irrigation fields affects its quality. The results are shown in ***table 9.***

Table 9: Water analysis parameters

Stream /River	Irrigation Scheme	Where sample was drawn	pH	EC	Na	K	Ca	Mg	HCO_3	Cl	OH	CO_3
Tsavo/ Njoro streams	Ziwani Estate Gicheha Farms	Weir/diversion point	7.91	0.6	2.40	0.10	0.33	0.29	2.10	1.50	Trace	Trace
		irrigated field (dam feeding center pivots)	8.06	0.6	2.52	0.10	0.37	0.28	2.10	2.00	Trace	Trace
River Lumi	Chala Tuhire	Sample at diversion point	7.84	0.6	3.13	0.10	0.30	0.29	2.10	1.85	Trace	Trace
		Sample from irrigated field	7.98	0.5	3.13	0.09	0.37	0.28	2.30	1.78	Trace	Trace
River Njugini	Njukini	Sample at diversion point	7.15	0.3	1.65	0.07	0.28	0.28	2.00	1.40	Trace	Trace
		Sample from irrigated field	8.01	0.4	1.56	0.09	0.36	0.28	1.90	1.80	Trace	Trace

(Researcher 2014)

The results in ***table 9*** show that in the three irrigation schemes, Ziwani Estate Gicheha Farms, Chala Tuhire and Njukini, there is a marked difference for pH and Calcium levels between the samples drawn at the diversion point and those drawn from within the irrigation schemes. The PH and Calcium values within the irrigation schemes are higher than at the diversion points. In Tsavo and Njoro streams, which are used for irrigation in Ziwani Estate Gicheha Farms, the pH level at the diversion point was 7.91 while within the farms (the dam from where the center pivots draw water) was at 8.06. In Chala Tuhire, the pH value at the diversion point was 7.84 while in the farms it was 7.98. In Njukini the pH at the diversion point was 7.15 while at the farms it was 8.01.

The Calcium levels also appear to differ, and they are higher in the samples drawn from the irrigation fields. In Ziwani, the value at the diversion point was 0.33 while in the irrigated fields it was 0.37. In Chala Tuhire the value at the diversion point was 0.3 while within the irrigated farms it was 0.37. In Njukini, the value at the diversion point is 0.28 while within the irrigation fields it is at 0.36.

The persistent results in which pH and Calcium levels are higher in water in the irrigated leads to the conclusion that the diversion of water from its main river/stream course into irrigation canals and eventually into the fields increases it pH level, thus making the water more alkaline. The increase could be caused by the increase in Ca levels in water as it flows from the diversion point to the irrigation fields since Calcium is alkaline in nature. The results of the other water parameters did not show a consistency across the three irrigation schemes, which is an indication that they are not affected by diversion.

It's apparent therefore that diverting water for irrigation causes the alkaline level of the water to increase. Based on the previous results of soils in the four irrigation schemes, the alkaline levels appeared to be high. This could be as a result of the continual use of the water that is being affected by the diversion. Alkaline soils can affect farming by rendering some crops unable to grow in the soils. This can lead to lower crop production, taking into account that the small holder farmers are not carrying out soil analysis in their farms. Low crop yields could make farmers seek for alternative sources of livelihoods, which could include prying into environmental resources such as burning of charcoal and illegal hunting, thus affecting the environment.

4.4 IMPACT OF IRRIGATION ON RIVERS/STREAMS USED FOR IRRIGATION

The diversion of water from the main river/stream courses can have profound effects on the riverine environment. The manner in which the water diversions (weirs) are constructed, as well as encroachments and human activities in the downstream sections, are some of the factors that can cause negative impacts on the riparian ecosystems.

4.4.1 Diversion Points (Weirs)

Weirs constructed along the rivers and streams so as to divert water to the irrigation schemes can affect the movement of aquatic animals. The earth weirs along Njoro and Sante streams blocked and diverted all the water from the original courses, leaving no water to trickle downstream.

Plate 4A and B: Concrete weirs along River Lumi and River Njugini

The weir at River Lumi (A) allows the water to flow downstream through a narrow opening, thus gushing out at a high speed/pressure, while the water flowing downstream from the weir in River Njugini (B) flows through a very steep slope. In both cases, the upstream movement of aquatic life is jeopardized.

(Researcher 2014)

This therefore led to obliteration of the riparian environment in the downstream sections of these streams. River Lumi ***(plate 4A)*** has a concrete weir that diverts most of the water to the water to Chala Tuhire Irrigation schemes. The little water that is allowed to flow downstream does so through a small opening in the concrete weir. The opening appears to be too small to allow aquatic animals to swim upstream, and moreover, water gushes out of this opening with a lot of pressure, a situation that would frustrate any living organisms from swimming upstream. In River Njugini, ***(plate 4B)*** the water that flows downstream is let out through a very steep concrete slope that would definitely make it hard for aquatic organisms to move upstream beyond the weir. Tsavo stream too lets some water to trickle down into the main river course. However, this is after diverting the entire river course into a canal, and the water that flows back to the main course does so in a very steep place, reminiscent of a waterfall, that has the potential to frustrate any upstream movement of aquatic lives. The ultimate result is that these weirs have led to the fragmentation of habitats for some aquatic organisms.

4.4.2 Encroachment into Riparian Environment

When farmlands are established close to the river, the crops are exposed to animals whose habitats are along the river ecosystems. Within Chala Ward, some of the animals, as identified by farmers who have been farming there since the establishments of the irrigation schemes, include monkeys, baboons, hippos, wild pigs, crocodiles, antelopes and wild rabbits among others. To keep these animals away from their farms, farmers employ a number of methods. These methods include chasing away the animals from along the river, hunting and killing them, scaring them away from the farms using scare crows and lighting fire during the night. The farmers also built some structures ***(plate 5)*** along the river to enable them to be almost permanently present along the river to make sure animals do not encroach into their farms.

Plate 5: A farmhouses near river bank

Farmhouses are used to protect crops from wild animals whose natural habitat if is the riparian ecosystem. This literally renders the original riverine habitats quite uninhabitable, thus threatening the survival of the animals. (Researcher 2014)

All these activities by the farmers, though geared towards protecting their farms, have major effects on the river ecosystems and the animals found in these areas. It is worth noting that the riverine environment that is already facing the challenge of lack of water and fragmentation, besides encroachment through other human activities, are the only natural habitats to these animals. When the animals are chased away from their natural environment into the drier environment within the National Park, or into settled areas, they can hardly cope, and therefore are faced with the threat of disappearance or extension. When asked what could have happened to animals that used to be found along the river, the key informants gave the following responses:

- The animals migrated into the nearby National Park;
- Crocodiles migrated downstream to some of the larger water bodies such as Lake Jipe;
- They were killed by the locals, especially snakes which were considered dangerous;
- They died when their natural habitats along the river were cleared.
- fragmentation, lack of water under threat these animals are in their natural habitats, being chased away

It was observed that there is a proliferation of petrol-powered water pumps within Chala Ward. These pumps are used to pump water from either shallow open wells or from the rivers and streams. River Lumi, which passes through an inhabited area, is the most affected as the presence of water pumps was evident both in the upstream and downstream sections. Though the diversion of water from the river for irrigation has contributed to the decline of water levels in the river, the water pumps are apparently the main reason why the river has dried downstream as the farmers use them to pump the little water that flows beyond the weir. Without the water pumps, the water would be flowing a longer distance and may not be reaching a point of completely drying out since the river has several springs downstream that would be replenishing it.

It was further observed that aquatic vegetation tends to grow along the irrigation canals by extending from the sections between the weirs and the springs where the flow of water was not affected by the diversion. However, farmers are very keen to make sure that the flow of water in the canals is unhindered, and they therefore endeavour to clean the canals by cutting down or manually removing the plants from water ***(plate 6).*** This therefore makes it hard for the aquatic vegetation to spread, and ends being confined to the small upstream sections that are under increased human activities.

Plate 6: Clearing aquatic vegetation from irrigation canals

Aquatic vegetation that grows along irrigation canals is seen as inhibiting the flow of water. In this photo, a farmer at Kithito irrigation scheme is clearing an irrigation canal to facilitate the movement of water along the canal. Aquatic vegetation tend to grow along the irrigation canals as it is used to growing where there is adequate water. However, to the farmers, the vegetation is seen as a hindrance to agricultural production, hence cleared. Such vegetation, together with other aquatic fauna, could easily become extinct. (Researcher 2014)

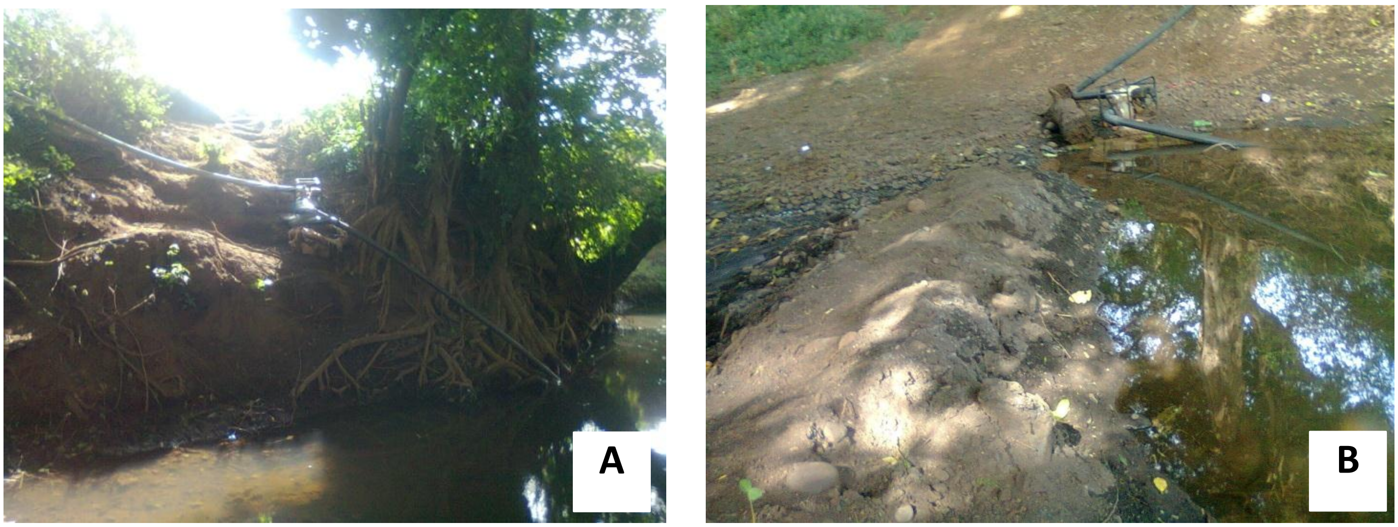
In the upstream sections where some of the plants are still surviving, it was observed that they are threatened by the ever shrinking ecosystems as a result of encroachment by human activities. Farmers at some areas have even planted crops right into the water in the river/stream beds ***(plate 7)*** and therefore clear the aquatic vegetation that is now considered to be weeds.

Plate 7: Crops growing in the river bed

An upstream section of a stream where crops have been planted right in the middle of river bed. The original aquatic vegetation is in this case treated as weeds (Researcher 2014)

Encroachment into the riparian ecosystem for the sake of drawing the water left to trickle downstream has also increased as farmers using petrol and diesel powered engines ***(Plate 8 A and B)*** to draw the water and use it for irrigation. The main consumers of the water flowing downstream are farmer who pump the water with petrol-powered water pumps to irrigate their farms along the river banks.

Plate 8: Petrol/diesel powered water pumps drawing water from rivers



Petrol/diesel powered water pumps drawing water from the downstream section of the Chala Tuhire irrigation scheme weir. The farmers continue drawing the water until the river completely dries up. (Researcher 2014)

The farmers continue pumping water from the river bed, until it reaches a point where the water can no longer be pumped. The little trickling water is then accumulated through the creation of embankments Water pump farmers create some embankments (small weirs) along the river bed so that the water flowing beyond the weir can form a pond, and then it is pumped to farms. The researcher observed that about one kilometer from the main weir, the water in the river dries up completely.

In the downstream sections of the river, beyond the weir, there is also a notable absence of all forms of aquatic vegetation. In the sections with no water, the river bed is completely bare since the water plants died and other type of vegetation has adapted to surviving in the bare river bed. Some sections of the river completely lack any green vegetation, and are beginning to resemble the surrounding dry environment**.**

Plate 9: A dry section of River Lumi

About 2 kilometers downstream from the Chala Tuhire weir, the aquatic vegetation died, and no new type of vegetation has adapted to the new environment at the river bed. There are plenty of dry leaves in the river bed from trees with broad leaves which seem to be shading leaves to try to cope with the new human induced drier environment. *(Researcher 2014)*

The downstream section of River Lumi completely dries up less than 2 km from the weir ***(plate 9).*** As the vegetation along the river valley dries, there is a notable increase of erosion along the river banks. In the upstream sections, even where herders use to access the water, some resilient vegetation can be found, so long as it has access to water. When compared to the upstream sections, vegetation downstream also appears to be weaker and less dense. Some of the trees in the upstream sections of the river have their roots partially submerged in water, an indication that they continuously draw water from the river. In the downstream sections, such roots are now exposed as they are no longer covered by water. Compared to the upstream sections, the trees in the downstream section appear to be losing their leaves as evidenced by the many leaves that have fallen on the ground. Additionally, the dense and evergreen vegetation along the river seems to be disappearing, and its place is being taken by plants that usually grow in the dry environments, mainly the acacia species. *Prosopis juliflora,* an invasive species that usually grows in dry areas, was spotted in some sections of the river, and it seems to be thriving well even at the river banks ***(plate 10)***.

Plate 10: Dry land vegetation in dry river valley

Prosopis juliflora, *in Kenya commonly known as* ***mathenge,*** and in Chala Ward known as ***mirashia****, is here seen luxuriously growing along the river banks where the original riparian vegetation used to grow and has now dried up. The downstream sections are therefore threatened by this invasive species that is likely to continue colonizing the river banks.*

(Researcher 2014)

Twenty (20) resident/farmers within Chala Ward who are old enough to have witnessed the commencement of the three small older irrigation schemes of Chala Tuhire, Kithito and Njukini were interviewed with the objective of understanding how much the environment has changed. According to the respondents, River Lumi and and River Njugini had plenty of fish and other aquatic life forms. Some said fishing was a major activity in the area before the water was diverted into the irrigation schemes. That no fishing activities were noticed during the study is an indication that the population of fish and other aquatic life forms are either unavailable or their numbers are so small that it will be uneconomical to engage in fishing. The respondents identified some plants, using local names, which used to exist in plenty but have become scarce, or completely disappeared, after the reduction, or absence, of water in the downstream sections of the rivers and streams

CHAPTER FIVE: RESPONSES MEASURES

Responses are formal and informal adaptations and mitigation measures adapted by the local community, local government, national government and international organizations to respond to the noted environmental degradation in an area. The aim is to address or cope with the new environmental status by trying to prevent further degradation. Responses usually include restoration of destroyed environment as well as altering and restricting human activities with the aim of stopping further damage to the environment.

5.1 Concrete Irrigation Canals

In Chala Ward, some measures are being put in place to respond to the degraded environment. Within the irrigation schemes, concrete canals have been constructed in Chala Tuhire ***(plate 11 A)*** and Njukini ***(plate11 B)*** irrigation schemes.

Plate 11A and B Concrete irrigation canals

In responding to the deteriorated state of the environment include the construction of concrete canals, as seen in this photos of irrigation canals in Chala Tuhire (A) and Njukini irrigation scheme (B). The concrete canals have reduced interaction between the water and the surrounding soil, thus reducing the possibility of soil chemical properties co9ntaminating the flowing water.

(Researcher)

According to the residents, the canals are built to increase the amount of water getting into the farms by reducing the underground seepage of water as it flows through earth canals. They also pointed out that the concrete canals would reduce the amount of ‘salt’ that would be getting into the farms. From the soil analysis results, it was revealed that soils in the irrigated fields are more alkaline than those in the non-irrigated areas. This was also supported by the water analysis results which showed that the alkalinity level of water increased as the water flows along the irrigation canals.

The construction of concrete canals is therefore a response measure as they are actions taken by local community or government, though Constituency Development Fund (CDF) funding. The aim of constructing the concrete canals is to prevent further salinization of the soil.

5.2 A Case of Kwa Tom Lumi Natural Springs Environmental Conservation Group

Kwa Tom Lumi Natural Springs Environmental Conservation Group[13] is perhaps the best example of response measures to environmental degradation by the locals within Chala Ward. The group, which is registered as self-help, has been trying to conserve and preserve the environment along a stretch of about 2 km along river Lumi stretching from Kwa Tom village to Chala Secondary School. The section is part of the downstream portion that is affected by the diversion and excess pumping of water from River Lumi, thus leading to the drying up of the river. According to the officials, there were some small springs along the banks the river that used to produce enough water to cause some water to trickle down the river bed for quite some distance. However, by 2008 the springs dried up completely, causing residents of the area to get concerned since the springs used to be their main source of fresh water for domestic and for use their livestock.

In 2009 some resident of Kwa Tom village came together and resolved to conserve the area along the river where the springs were with the hope that water would start flowing again. The group started with 16 members who decided to protect the environment along the river where the springs used to be. At first it received resistance from farmers who were farming up to the river banks as well as farmers who were pumping water using petrol/diesel water pumps. Furthermore, livestock kept on encroaching to the area and feeding on the seedlings they had planted. The seedlings were

[13] Information about this groups is based on oral interview with EvansonMwadime, Paulo Onyango and Patrick Mlei, who are among the founding members and officials of Kwa Tom Lumi Natural Springs Environmental Conservation Group

provided by the Forestry Department in 2009.The group then sought support and assistance from various government departments and other well-wishers and non-governmental organizations. Among the organizations was National Environmental Management Agency (NEMA), which pledged to support the fencing of an area of 30 meters from the river valley. A fence was put up in 2012, the contract having been given by NEMA itself. The fence now covers an area of 60 meters wide along both sides of the river, and stretches for about two kilometers. A cattle trough was also built to supply water to livestock at some distance from the river so that the animals are not allowed on the river banks and river bed as they try to access water.

So far, several organizations have provided support to Kwa Tom Lumi Natural Springs Environmental Conservation Group. This support has been coming in the form of fencing material, seedlings and seminars on environmental awareness, conservation and protection. Among these organizations are:

- Kenya Forestry Department;
- Kenya Wildlife Services (KWS);
- National Environmental Management Authority (NEMA);
- Kenya Forestry Research Institute (KEFRI);
- Kenya Coastal Development Authority (KCDA);
- World Vision.

The group members prepare seedlings of indigenous trees and plant them along the fenced section, especially the degraded areas ***(plate 12A and B).*** degraded planting trees in the protected area. All the trees being planted are native ones, and are doing so under the guidance of NEMA and Kenya Forestry Department. The intention is to restore the original vegetation as it was before the degradation took place.

Plate 12A and B: Restoration of the natural envrionment along River Lumi

Members of Kwa Tom Lumi Natural Springs Environmental Conservation Group preparing and planting seedlings of indigenous trees (A) and planting them in degraded areas (B) within the fenced area along River Lumi near Chala Secondary School.

(Researcher 2014)

The initiatives of Kwa Tom Lumi Natural Springs Environmental Conservation Group have registered some success. Some sections of the river where vegetation was planted in 2009 have recovered, and are now healthy with all types of the original riparian vegetation, ie grass, shrubs, rushes, sedges and trees with dense undergrowth ***(plates 13 A and B).***

Plate 13A and B: ***Recovering ecosystems along river Lumi***

Restored vegetation cover along River Lumi within the section that was fenced in 2009 by Kwa Tom Lumi Natural Springs Environmental Conservation Group. The vegetation has improved and sedges and shrubs have reappeared.

(Researcher 2014)

Some small springs along the river banks have started flowing again, and water has begun trickling again ***(plate 14).***

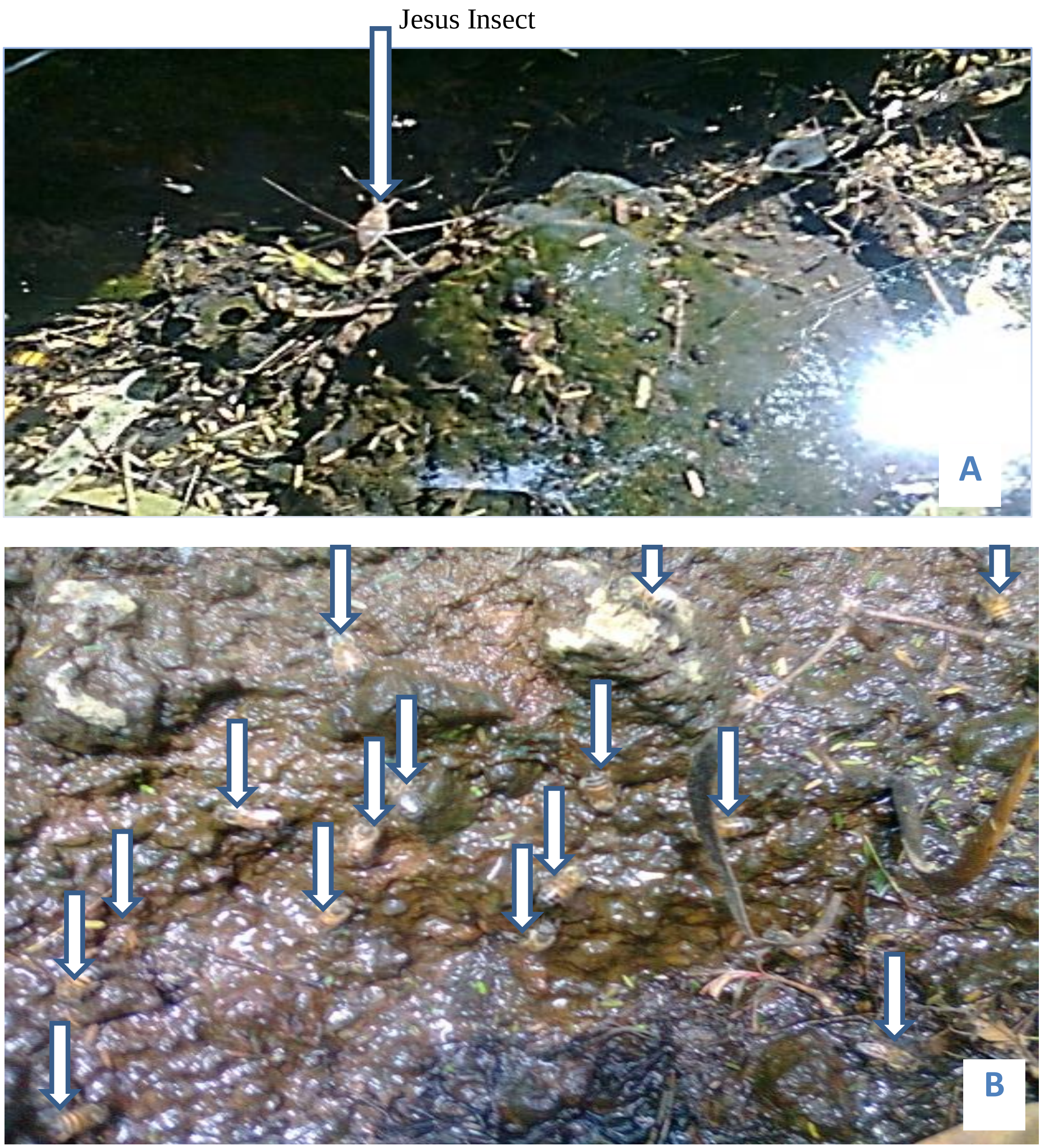
Figure 14: Flowing Springs within the Fenced Area

Flowing water along a section of River Lumi that had initially dried up. This is a success story for Kwa Tom Lumi Natural Springs Environmental Conservation Group that is worth emulating not only across Chala Ward, but everywhere where riparian environments are under threat. (Researcher 2014)

Although Kwa Tom Lumi Natural Springs Environmental Conservation Group has made some progress in restoring the degraded environment, the group is facing some challenges that could undermine the progress realized.

There is also a notable increase of biodiversity, especially insects, within the fenced area. Among these were bees and the Jesus Insects, which 'walk' on water, which were noticed in large numbers in the small, crustal clear pools of water along the river bed ***(plate 15A and B).***

Plate 15A and B: increased presence of biodiversity in the fenced area



There is a noticeable increase of both flora and fauna in the fenced area, especially where springs have started producing water once more. The Jesus Insect, has seen the reemergence of some rare water insects, e.g. the Jesus insect (A). It was also observed that there were plenty of bees (B) as the springs were now providing bees with a source of fresh, uncontaminated water.

(Researcher 2014)

Effects to response to environmental degradation include the reduction of carbon dioxide and other greenhouse gases that are responsible for prevailing environmental challenges. In a localized environment like Chala Ward, measures to address environmental degradation could be achieved through the enactment of water use regulation and practicing farming techniques that reduce soil and water degradation as well as preserving and protecting sensitive ecosystems such as swamps and river ecologies. Unfortunately, all efforts in Chala Ward appear to be geared towards enhancing agricultural productivity, and the environment is not given any due regard.
Though Kwa Tom Lumi Natural Springs Environmental Conservation Group has registered some admirable successes, there are still some challenges being experience which could undermine the success realized so far. First, some residents of the area have failed to understand the importance of preserving the environment, especially those who used to farm up to the river and have now been prevented from doing so.

Now that there is water, many locals are yearning to use the water for irrigation. Already, farmers using diesel/petrol water pumps are pumping the little water in the river and using it for irrigation by passing the pipes through the fenced area into the adjacent areas. Secondly, there is persistent interfering from herders and firewood collectors who keep on encroaching into the area. When livestock sneak into the area, they cause damage, especially by feeding on seedlings and young trees. Third, the local administration appears to be unexcited about supporting such initiatives. There seem to be little efforts in enforcing environmental protection laws that could protect the degraded areas within Chala Ward judging by the destruction of the riparian environment. Farming along the river banks appears to be very common. Additionally, the Constituency Development Fund (CDF) and the office of the Governor of TaitaTaveta County, though they have expressed support to Kwa Tom Lumi Natural Springs Environmental Conservation Group, not much support has been provided, and the group survives on external funding. It would be more appropriate if such group could be fully depended on local funding such as CDF and the governor's office.

While at the area that has been conserved through the efforts of Kwa Tom Lumi Natural Springs Environmental Conservation Group, it was observed that petrol and diesel water pumps were being used to pump water from the area that has already been conserved. The availability of water in the streams is therefore acting as new drivers that lead to irrigation activities, which are pressures. Based on the DPSIR conceptual framework, the process appears to be cyclical as it resumes again.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to find out the impact of irrigation the environment. The study was conducted in Chala Ward in Taita Taveta County, Kenya, while using four irrigation schemes which are Ziwani Estate Gicheha Farms, Chala Tuhire, Kithito and Njukini.

6.4 Conclusions

The findings of this research indicate that irrigation has notable negative impacts on the environment. Soils within the irrigated areas, especially the small holder irrigation schemes of Chala Tuhire, Kithito and Njukini have higher pH levels than the surrounding non-irrigated areas. This therefore means than soils in the irrigated areas are more alkaline than in the non-irrigated areas. Similarly, it was found out the diversion of water from the natural river/stream courses increases water pH and Calcium levels. This situation is further exacerbated by the high frequencies of irrigation due to the high rates of evaporation. All the farmers – 100% – in the irrigated areas were using chemical fertilizers. The use of pesticides and fungicides was also equally high since it also stood at 100% at Ziwani Estate Gicheha Farms, Chala Tuhire and Njukini while at Kithito it was 96%. These fertilizers and pesticides/fungicides have the potential to cause negative impacts to the environment.

Irrigation also has negative impacts on streams/rivers whose water has been diverted for irrigation. The amount of water diverted from the rivers/streams is quite high, and very little water is allowed to flow downstream beyond the weir. About 2 km, downstream, from the weir of River Lumi, the valley dries up completely and there is no riverine vegetation such as rushes and sedges. In fact, an invasive exotic species, *prosopis juliflora*, which usually grows in arid areas, is now growing in the river valley that once had aquatic vegetation.

6.5 Recommendations

The a high usage of chemical fertilizers, pesticides/fungicides and herbicides in the area, yet, except for Ziwani Estate Gicheha Farms, farmers seemed to have limited knowledge on the use of these chemical fertilizers, pesticides/fungicides and herbicides. The use of these chemical products could therefore be a threat not only to the environment but to human health as well. It would therefore be appropriate to provide education to the farmers on the use of the chemical products and the threats they pose to human health and the environment as well.

Within the small holder irrigation schemes of Chala Tuhire, Kithito and Njukini farmers do not carry out soil analyses. In Ziwani Estate Gicheha Farms soil analysis is done on a regular basis so that appropriate mitigations measures, including change of fertilizers, can be put in place. This couls explain why soil samples collected from Ziwani Esate Gicheha Farms showed no significance difference with the samples from the non-irrigated areas. It would be appropriate to educate the small holder farmers on the need of carrying out regular assist the way it is done at Ziwani Estate Gicheha Forms. It would also be appropriate for the government and non-governmental organizations (NGO) to volunteer to educate and finance the laboratory tests until the farmers understand the importance.

Along the river/stream course there is a serious encroachment on the riparian environment. Farming activities are taking place right into the river beds. The local administration appeared not to be keen to protect the riparian environment by banning farming in the river banks. It would be appropriate for the protection of riparian environment to be prioritized, taking into account that Chala Ward is biological hotspot assignable to the East African Coastal Biodiversity Hotspot. The impact of Water Resource Management Authority (WARMA) in Chala Ward is only felt when the body comes to remind farmers to pay their dues. However, there is no evidence to suggest that WARMA is educating the locals or ensuring the levels of water in the streams/rivers are taken care of. There is need for WARMA and other agencies like NEMA to do more to protect the riparian environment and levels of water in the downstream sections of rivers used for irrigation.

6.6 Future Studies

During this research, it was discovered that there is excessive use of chemical fertilizers, pesticides, fungicides and herbicides. There is no evidence to suggest that a research has been done in the area to ascertain the full impact of these chemical fertilizers, pesticides/fungicides and herbicides on human health. Therefore, a research could be done to find out the full impact of these chemical products on human health, both for the farmers and consumers of the products as well.

The excessive use of chemical fertilizers, pesticides/fungicides and herbicides increases the cost of irrigated agriculture. Many farms were left unattended in the irrigation schemes. At the same time, crop production has been decreasing (interview with farmers). It’s therefore not clear what the impact of irrigated agriculture on household food provision, poverty eradication and improvement of livelihood systems is. A research could be done to bring more light on this area.

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APPENDICES

Appendix 1: Soil and Water Analysis Charges

FORM No.

Revision No.2
Effective date: 1/10/2010

UNIVERSITY OF NAIROBI
COLLEGE OF AGRICULTURE AND VETERINARY SCIENCES
DEPARTMENT OF LAND RESOURCE MANAGEMENT AND AGRICULTURAL TECHNOLOGY
SOIL SCIENCE SECTION REVISED SOIL ANALYSIS CHARGES

Name:……………………………………………………………………Date…………………

Address:……………………………………… ……………………………………Date…………………

Analysis to be done	No of Samples	Charge Rate (KShs.)	Total Amount
pH		60	
EC		40	
Organic carbon		250	
Total nitrogen		300	
Nitrate nitrogen		200	
Ammonium nitrogen		200	
Sulphate sulphur		200	
Phosphorus		250	
CEC		300	
K and Na		200	
Texture (hydrometer method)		150	
Bulk density		100	
Hydraulic conductivity		150	
Complete moisture characteristic (PF)		500	
1/3 bar + 15 bar atmospheres		200	
Soil moisture determination (gravimetric)		100	
Quantitative analysis of irrigation water quality		600	
AAS, **Ca** ,& **Mg** per sample/element		100	
AAS. **Mn, Zn, Fe, Cu** per sample/element		200	
Extraction for trace elements AAS		100	
AAS reading only **Ca& Mg** per sample each		100	
AAS reading **Mn, Zn Fe, Cu** per sample each		200	
Microbiological analysis (each microbiological species)		400	
Grand Total			

Analyzed by……………………………………………………………………………**Date**……………
Senior Technologist

Approved by ……………………………………………………………………………**Date**……………
Section Head, Soil Section
Credit Vote No. : 400-635-035 **Receipt No**…………

DEPARTMENT OF
LAND RESOURCE MGT. & AGRIC. TECH.
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Appendix 2: Survey Questionnaire on Farming practices within the irrigation schemes

University of Nairobi

College of humanities and social sciences

Department of Geography and Environmental Studies

Dear respondent,

This survey questionnaire is planned to assess the impact of irrigation in drylands on the environment, and is using Chala ward as a case study. The study focuses on the frequency of application of water on the irrigated fields as well as the use of fertilizers, pesticides and herbicides, all of which can have various impacts on the environment. The overall goal is to understand how these elements could be impacting on water quality and quantity, soil and the downstream sections of rivers/streams used for irrigation, mainly the flora and fauna. The environment provides crucial services that are vital for development. It is critical that a balance be found between development and environment, since the environment provides crucial services necessary for development. A balance is therefore essential so that today's development does not adversely affect the environment and starting eating back into the achieved realized so far.

Your acceptance to respond to this questionnaire is therefore a noble undertaking as it will be crucial in realizing the objectives of this study. I therefore request for your active cooperation in responding to the questionnaires, and for your responses to be truthful to the best of your understanding so that the results could accurately reflect the reality on the ground. These questionnaires are fully for academic research purpose ONLY. Additionally, any information you provide will be kept confidential.

Name of irrigation scheme ……………………………………………………………

1. Name of respondent ……………………………………………………………
2. How long have you been farming/working in this irrigation scheme?

   ....

3. Land ownership a) Own…………………………………………………
   b) Rented………………………………………………
   c) Employed………………………………………….
4. Do you apply the following in your farm?
   a) Fertilizer……………………………………………………………………………
   b) Pesticide…………………………………………………………………………..
   c) Herbicide………..…………………………………………………………………
5. If you answered 'Yes' to any of 4 above, please fill the attached table at the back of this questionnaire.
6. How did you acquire knowledge about **irrigation?**

   ………………………………………………………………………………………………
   ………………………………………………………………………………………………
   ………………………………………………………………………………………………
7. How did you acquire knowledge about the use of fertilizers?

   ………………………………………………………………………………………………
   ………………………………………………………………………………………………
   ………………………………………………………………………………………………
   ………………………………………………………………………………………………
   ………………………………………………………………………………………………
8. How did you acquire knowledge about the use of pesticides and herbicides?

   ………………………………………………………………………………………………
   ………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

9. Has any soil analysis been done in your farm?
    a) Yes……………………..
    b) No……………………….
    c) Don't know……………….

10. If answer to 9 above is **'yes',** what were the findings?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

………………………………………………………………………………………………..

11. Has any water analysis been done in your irrigated portion?
    a) Yes………………………..
    b) No………………………….
    c) Don't know…………………

12. If answer to 11 above is **'yes',** what were the findings?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

………………………………………………………………………………………………..

13. What measures do you take as **individual** to protect soil in your irrigated portion?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

14. What **collective** measures do you take to protect soil in your irrigated portions?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

Application of water, fertilizer, pesticides and herbicides

Type of crop	No. of time irrigated before harvest	No. of harvests per year	Fertilizer used	No. of times fertilizer applied	Pesticides used	No. of times used	Herbicides used	No. of times used

Appendix 3: Questionnaire on state of environment since commencement of irrigation

University of Nairobi

College of humanities and social sciences

Department of Geography and Environmental Studies

Dear respondent,

This survey questionnaire is planned to assess the impact of irrigation in drylands on the environment, and is using Chala ward as a case study. The study focuses on the frequency of application of water on the irrigated fields as well as the use of fertilizers, pesticides and herbicides, all of which can have various impacts on the environment. The overall goal is to understand how these elements could impact on water quality and quantity, soil and the downstream sections of rivers/streams that provide water for irrigation, mainly the flora and fauna. The environment provides crucial services that are vital for development. It is critical that a balance be found between development and environment, since the environment provides crucial services necessary for development. A balance is therefore essential so that today's development does not adversely affect the environment and starting eating back into the achieved realized so far.

Your acceptance to respond to this questionnaire is therefore a noble undertaking as it will be crucial in realizing the objectives of this study. I therefore request for your active cooperation in responding to the questionnaires, and for your responses to be truthful to the best of your understanding so that the results could accurately reflect the reality on the ground. These questionnaires are fully for academic research purpose ONLY. Additionally, any information you provide will be kept confidential.

Name of irrigation scheme ………………………………………………………………

1. Name of respondent ………………………………………………………………………………
2. When did you start farming in this irrigation scheme? ....
3. Did you witness the opening of this irrigation scheme? ……………………………………………..
4. Which year did you start farming in this irrigation scheme? ....
5. Compared to today, has the level of water
   a) Increased……………………………………………………………………………………….
   b) Reduced………………………………………………………………………………………
   c) Remained constant………………………………………………………………………..
6. In the early days of irrigation, were you using chemical fertilizers? ....
7. Do you use fertilizers today? ....
8. If answer to 7 above is 'Yes'. Why did you start using chemical fertilizers?

   ……………………………………………………………………………………………………

   ……………………………………………………………………………………………………

   ……………………………………………………………………………………………………

   ……………………………………………………………………………………………………

   ……………………………………………………………………………………
9. Were there same animals: mammals, reptiles, insects, etc that live in and were present in the main river/stream that you use for irrigation today? ....
10. If the answer to 9 above is 'Yes', what are some of these animals?

    ……………………………………………………………………………………………………

    ……………………………………………………………………………………………………

    ……………………………………………………………………………………………………

    ……………………………………………………………………………………………………

    ………………………………………………………………………………………

11. Are these animal/fish etc still there? ……………………………………………………………………

12. If the answer to 11 above is No, what happened to these animals?

…………..

....

....

....

13. Are there some plants that grew in water that you can remember? ....

14. If the answer to 13 above is **'Yes'**, what are some of these plants?

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

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15. Are these plants still there today? ....

16. What happened to the plants?

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Appendix4: Agricultural practices in Non-Irrigated areas

Questionnaire No………………..

University of Nairobi

College of humanities and social sciences

Department of Geography and Environmental Studies

Dear respondent,

My name is Justus M Muli from Mahandakini Sub-Location. I am currently doing a Masters of Arts Degree in Environmental Planning and Management at the Department of Geography and Environmental Studies, University of Nairobi. I am carrying out a research on the impacts of irrigation in dry lands on the environment by using Chala Ward as a case study.

The study focuses on the frequency of application of water on the irrigated fields as well as the use of fertilizers, pesticides and herbicides, all of which can have various impacts on the environment. The overall goal is to understand how these elements could impact on water quality and quantity, soil and the downstream sections of rivers/streams that provide water for irrigation, mainly the flora and fauna. The environment provides crucial services that are vital for socio-economic development, and it is crucial to know how it can be affected by human activities, where this research has chosen to focus on irrigation. The specific objective of this questionnaire is to make a comparison between irrigated and non-irrigated fields within Chala Ward. This questionnaire is therefore being administered to farmers within Chala Ward who practice rain fed agriculture outside the irrigated fields.

Your acceptance to respond to this questionnaire is therefore a noble undertaking as it will be crucial in realizing the objectives of this study. I therefore request for your active cooperation in responding to the questionnaires, and for your responses to be truthful to the best of your understanding so that the results could accurately reflect the reality on the ground. These questionnaires are fully for academic research purpose ONLY and any information you provide will be kept confidential.

1. Name of respondent ……………………………………………………………………

2. How long have you been farming in this area? ....

3. Do you apply the following in your farm?

    d) Fertilizer………………………………………………………………………………

    e) Pesticide………………………………………………………………………………..

    f) Herbicide………..……………………………………………………………………

4. If you answered 'Yes' to any of 3 above, please fill the attached table at the back of this questionnaire.