UNIVERSITY OF NAIROBI

CLIMATE CHANGE ACTION TOOLKIT FOR GROUNDWATER USE IN AGRICULTURAL PRODUCTION: CASE STUDY OF LWANDA, BUNGOMA COUNTY

BY

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DECLARATION

I declare that this thesis is my original work and has not been submitted elsewhere for examination, award of degree or publication. Where other people's work or my own work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi's requirements.

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DEDICATION

I dedicate this work to my devoted parents Papa Shem and Mama Anne who imparted in me the value of education; unfailing support from my immediate family championed by my beloved husband Charles, our loving children Emmanuel, Caleb, Jael, Joshua, Patience , my dear brothers, extended family and friends who stood by my side throughout the entire study period. I am forever grateful to God for great favour and grace upon me to complete my academic work successfully in good health.

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ABSTRACT

Groundwater is an alternative fresh water source for domestic, industrial and agricultural production. Groundwater use can sustain agricultural production through irrigation during prolonged dry season to increase crop production and vegetation cover that form carbon sink. The overall objective of the study was to develop a Climate Change Action Toolkit (CCAT) for groundwater use in agricultural production to minimize climate change impacts of prolonged dry season experienced in Bungoma County. The research study was conducted in Lwanda village with field experimentation on thirty shallow wells. Depth Aquifer Recharge and Transmissivity (DART) index quantitative method and United Nations Development Programme Policy Framework (APF) methodologies were applied concurrently as a Trans-Disciplinary Approach to develop a Climate Change Action Toolkit involving various stakeholders. This is because smallholder farmers have their unique capabilities and Climate Change effects on livelihoods are not uniform. The results revealed that rainfall was directly related with DART index, Groundwater volume, Water Rest Level, Storativity, Transmissivity and Rainfall recharge. Rainfall was indirectly related with change in water depth and groundwater use. There was no relationship between the age of shallow wells and rainfall. A monthly positive DART index was observed in the month of April, May, June, September and October indicating the possibility of enhanced groundwater harvesting for agricultural production. The negative DART index was experienced in the months of January, February, March, July, August, November and December. DART indices ranged between -8.40 and 2.50 with higher values representing more resilience to the Climate Change impacts and vice versa. There were two DART Index Thresholds of -8.40 and -4.80 respectively that coincided with the onset of long and short rainfall seasons. The Mann-Kendall trend analysis values indicated an upward trend for rainfall, groundwater recharge, storativity, volume, transmissivity, groundwater use and number of shallow wells drying up but a decreasing trend for groundwater DART index and a monotonic trend in Water Rest Level. The increasing trend of shallow wells drying up indicates the vulnerability of groundwater to support agricultural production. There was a significant difference in DART index, depth of shallow wells, potential groundwater uses and Storativity but there was no significant difference in rainfall and other groundwater variables. Shallow wells were dug manually with depth of between 6.95 and 13.05 metres. The shallow wells that dried up during prolonged dry season between of four months accounted for 53 percent. A single shallow well served between 1 and 12 households with one hundred and sixty-seven households benefiting from 30 shallow wells. The low farmers' adaptive capacity was due to lack of structured farmer training and water user's association, poverty, weak institution linkages and inadequate legislations. The advanced age of farmers, remain a hindrance that cause them not to trust various information sources for transfer of superior technologies. Non-Governmental Organizations and radio were the most popular sources of agricultural and weather information respectively. There was no formal platform for Indigenous Knowledge integration to climate change adaptation. Implementing an appropriate action plan that incorporates broad perspectives of the vulnerability features identified by stakeholders improves ownership by groundwater users and adaptation to Climate change. The adoption of a CCAT-DART is capable of reducing GHG emissions by 18 % of soil carbon and 8810 tons of CO_2 per acre per farmer annually. Piloting of groundwater use technologies and strategies suggested is necessary to improve information dissemination to enhance adoption and adaptive capacity. The DART Index Thresholds are risk management indicators against negative climate change impacts for issuance of agricultural finance insurance cover. There is need for further research study on soil erosion and rainfall recharge to improve knowledge on ground water recharge and sedimentation.

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LIST OF ABBREVIATIONS/ACRONYMS AND SYMBOLS

ACT	Act Change Transform
APF	The UNDP Adaptation Policy Framework
ASAL	Arid and Semi-Arid lands
CCAT	Climate Change Action Toolkit
CHAEMP	Community Health Agriculture Education and Marketing Partnership
CWR	Crop Water Requirement
DART	**D**epth of water level change, **A**quifer storability type, **R**echarge and **T**ransmissivity
DIT	DART Index Threshold
FAO	Food Agricultural Organization
FBCIDP	First Bungoma County Integrated Development Plan
FGD	Focus Group Discussion
GCNF	Global Child Nutrition Foundation
GDP	Gross Domestic Product
GHG	Green House Gas
GIS	Geographical Information System
GOK	Government of Kenya
HDI	Human Development Index
HH	Household
HHH	Household Head
ILRR	International Land and Resource Registry
IPCC	Inter-Governmental Panel of Climate Change
IWR	Irrigation Water Requirement
KIIS	Key Informant Interviews
KNBS	Kenya National Bureau of Statistics
PCVA	Participatory Capacity and Vulnerability Analysis
TDA	Trans-Disciplinary Approach
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention for Climate Change
WRA	Water Resources Authority
WRL	Water Rest Level

DEFINITION OF TERMS

Agricultural Production is a practice concerned with cultivating land for crop production and pasture for livestock production.

APF methodology is a conceptual structure for developing and implementing strategies, policies and action plans to human development in the face of climate change.

Bachuma is the age set for male circumcised from 1960 to 1970.

Bakananachi is the age set for male circumcised from 1912-1922 and 2012 to date.

Bakhebi are the circumcisers in Bukusu community.

Bakikwamet is the age set for male circumcised from 1900 to 1910 and from 2002 to date.

Bakimba is the name given to rainmakers in Bukusu community who do not drink rainwater.

Bakinyikeu is the age set for male circumcised from 1924 and 1930.

Bakoki refers to Male belonging in same age set.

Bakolongolo is the age set for male circumcised from 1972 to1982.

Baluunda is one of Bukusu clan famous for their rain making skills.

Bamaina is the age set for male circumcised from 1948 to 1958.

Bamunaha and **Bamuki** are Bukusu clans that known to have circumcisers.

Banyange is the age set for male circumcised from 1926 and 1946.

Baraza is a public gathering at a local level presided over by a public officer like a chief.

Basawa is the age set for male circumcised from 1876 to 1898 and from 1984 to 2000 in Bukusu community.

Bilenge bisike are smoked cattle feet.

Bubwoba are natural mushroom usually harvested during the onset of long rain season in April.

Bukhwe is the dowry payment in form of twelve cows for a wife in Bukusu community.

Bukochwe are large mushrooms like an umbrella found on an anthill.

Bukusu is one of the sub tribe of the larger Luhya community.

Bukusuma are large mushrooms with a prominent navel like area on top usually found in a colony.

Chibalayo is green grams in Bukusu dialect.

Chibande are African nuts.

Chikhanu are Simsim to supplement with oils and vitamins.

Chikhungu are dried armyworms.

Chinyenyi Chinunga is green vegetables prepared in a traditional way.

Climate Change is a long-term change from one pattern of variability of naturally occurring Atmospheric and Oceanic circulations in the earth systems to another, which is considered to be outside the normal range.

Climate Change Action Toolkit is a set of specifications designed to work together for purpose of solving climate change related problems.

DART Index is a regional screening tool to identify areas that could experience possible changes in their groundwater resources because of climate change.

DART Index Threshold is the value that coincides with the start of rainfall recharge of groundwater to mark the onset of long and short rainfall.

Endelema is creeping drought resistant vegetable found in wetlands.

Enyama ya namwesinya is meat given to be paid later during drought season.

Eutrophication is an ecological process, akin to aging, in which a water body is increasingly enriched with organic matter.

GHG emission reduction cropping schedule projection is a plan that estimate the amount of carbon absorbed from the soil and atmosphere to cater for crop production in a year.

Gramineae is a scientific name for crops such as sugarcane, maize; sorghum and millet belong to this family.

Groundwater is the water found beneath the ground in the cracks and spaces in soil, sand and rock and stored in aquifers.

Household characteristics are details of a household, such as number of household members, household income household head, and gender and education levels.

Kamakhuyi are birds like Flamingoes that flew in groups.

Kamalasile is dried blood of cattle.

Kamasibili are dried edible beetle larvae.

Kimibayo, Esambo or Kimilukha are traditional ceremonies like wedding, circumcision or get together parties.

Kimiro is drought resistant traditional vegetable.

Khujale ekhafu is the practice of drawing blood from cattle using an arrow by Bukusu community.

Khukhupa Kumulasi is a traditional form of communication by elders to warn of any foreseen adversity.

Kumukhelekha is cooking vegetables using traditional lime.

Kumuranda is a smoked beef.

Lukho is a Bukusu traditional game played by two adult men with pebbles and wooden boards curved with ten small holes of five holes on each opposite side as a form of recreation during their free time.

Institutional arrangements are the policies, systems, and processes that organizations use to legislate, plan and manage their activities efficiently and effectively coordinate with others in order to fulfil their mandate.

Liponda is a traditional Bukusu cheese.

Livestock carrying capacity is the unit of livestock kept in one hectare of land.

Murere is a drought resistant traditional vegetable.

Murunde is a drought resistant traditional vegetable.

Namasaka is an indigenous vegetable in the family of nightshade.

Rainfall recharge is the amount of water percolating and entering the saturated zone reaching an aquifer over specific time.

Sabaoti is the highland Nilotic sub tribe residing around Mt Elgon and rest of Bungoma County.

Shallow well is a hole which has been dug, bored, driven or drilled into the ground for the purpose of extracting water from an aquifer and is less than 50 feet deep.

Sifuluko is a simmered traditional pudding.

Sikhubi is a leguminous vegetable that is drought tolerant.

Sikanyangaya creeping vegetable plant belonging in the wandering jew family.

Sikanyanganya is a drought resistant traditional vegetable.

Silongo are natural soil licks for livestock along wetlands.

Sitipa is a drought resistant traditional vegetable.

Smallholder farmers are farmers owning small-based plots of land of less than 50 acres on which they grow subsistence crops and one or two cash crops relying almost exclusively on family labour.

Stakeholders are persons or a group of people with common interest or concern in an organization.

Trans-Disciplinary Approach is a concept that incorporates diverse research methods, tool and experience of stakeholders to conduct research.

Transmissivity is the degree to which a medium allows something, like water to pass through it.

Vulnerability is the diminished capacity of an individual or group to anticipate, cope with, resist and recover from the impact of climate change.

Water Table is the upper surface of groundwater where the pressure of water in the soil equals the atmospheric pressure that forms a stable level of groundwater within a specific region.

CHAPTER ONE: INTRODUCTION

1.1 Background Information

1.1.1 The Concepts of Climate change, Groundwater, Groundwater use and Climate Change Action Toolkit

Climate change is any significant change in expected patterns of average temperature, rainfall and groundwater levels over long period (Schimel and Wang, 2003; IPCC, 2007; Bazaz *et al*., 2017). The most frequent climate change extreme events experienced in tropics are drought and floods (Eriksen and Lind, 2009; Esilaba *et al.*, 2015; Adiku *et al.*, 2016; Christian *et al.*, 2018). Floods can cause groundwater levels to rise while droughts cause groundwater level to fall and recede further.

Groundwater quantities are functions of depth of the aquifer, type of aquifer, recharge from rainfall and transmissivity (Jiri, 1993; Alley *et al.*, 1998; Albert *et al.*, 2011; Dennis and Dennis, 2012; Kruger and Nxumalo, 2017). Some factors that are inherent characteristics of groundwater are explained in details in following chapters. Groundwater is an alternative fresh water source besides surface water in rivers and lakes. (Alley *et al.,* 1998; Sophocleous, 2002; Grosbois, 2017).

Groundwater use involves abstraction, distribution and supply of groundwater at point of utilization for either domestic, industrial, livestock and crop production (Albert *et al.,* 2011, Kent, 2011; Allen *et al.*, 2013; Barreteau *et al.*, 2016; Bazaz *et al.*, 2017). Groundwater is abstracted by developing a shallow well or a borehole to reach water table depending on the depth. A shallow well is a hole which has been dug, bored, driven or drilled into the ground for the purpose of extracting water from an aquifer and is less than 50 feet deep (Agatha and Hughes,2001). Groundwater use for agricultural production is a strategic intervention to meet food requirements through irrigation to increase crop production and vegetation cover that form carbon sink (Giordano, 2006; Allen *et al.*, 2010). Groundwater use can sustain agricultural production during prolonged dry season to save farmer households income that could be used to purchase foodstuff especially vegetables in the absence of irrigation (Falkenmark and Rockström, 2010; Godau *et al.*, 2019) Adequate production of foodstuff on farms can reduce vulnerability to malnutrition (Giordano, 2006; Falkenmark *et al.*, 2008). Households with enough food and pasture will not encroach wetlands to graze livestock and grow vegetables during prolonged dry season (Giordano, 2006; Burke *et al.*, 2008a; Daniel and Rachel, 2016). Farmer households have options of investing saved income towards enhancing their adaptive capacity to cope with climate change impacts that are long-term as an opportunity cost (High and Pelling, 2005; Smit and Wandel 2006; Adiku *et al.*, 2016; Chen *et al.*, 2017).

A Climate Change Action Toolkit (CCAT) is a set of specifications designed to work together for purpose of solving climate change related problems. A CCAT is crucial for proper management of groundwater use for agricultural production. Groundwater is receding and scarce during drought periods when is most needed for irrigation (Beek *et al.,* 2010). Therefore, to harness the greatest benefit of groundwater application of a CCAT becomes a necessity to minimize impacts of climate change (Egeru *et al.*, 2014; Flannery and McKenzie, 2013; Field Museum, 2019). A CCAT is very essential since it encompasses broader perspectives of vulnerability features than focusing on one perspective alone to minimize maladaptation practices (Adger, 2006; Austine *et al.,* 2018). It improves chances of any intervention that addresses multiple needs of local community facing multiple sources of vulnerability (Carpenter *et al*., 2004; High and Pelling, 2005; Lakshmi *et al.,* 2016). A CCAT development is necessary to provide standards for effective use of water from shallow wells (Agatha and Hughes, 2001). In absence of CCAT, water supply and quality problems could intensify with climate change impacts coupled with poor land use practices (Kent, 2011; Omaid *et al.,* 2014).

1.1.2 Factors influencing availability of groundwater in Lwanda village

1.1.2.1 Rainfall and groundwater

The climate variability and change impact on groundwater from shallow wells varies with parent rock material, depth of shallow wells and rainfall recharge (Loaiciga, 2003; Dennis and Dennis, 2012; Behrangi *et al*., 2016; Grosbois, 2017). Rainfall is not adequate to support agricultural production along the equator even though annual rainfall is above 1800mm (Egeru *et al*., 2014) because of uneven monthly distribution of rainfall. Lwanda village is situated within mid latitude in Lake Victoria Basin where adverse climate change impacts are becoming increasingly evident (Burke *et al*., 2008a). These changes in rainfall intensity, timing and distribution affect groundwater recharge (Burke *et al.*, 2008a; Hein *et al.*, 2014).

1.1.2.2 Smallholder farmers' and socio-economic factors and groundwater

Smallholder farmers are affected most by climate change impacts caused by over reliance on rain-fed agriculture although not uniformly (Carpenter *et al*., 2004; Barnes *et al*., 2008; Berkes and Ross, 2013; Garry *et al*., 2015; Ogara *et al.,* 2018). Smallholder farmers depend on rain-fed agriculture that is now threatened by seasonal rainfall severely weakening community adaptive capacity and make households vulnerable with increasing population (Adger *et al*., 2006; IPCC, 2007; Behnassi *et al*., 2014; Behrangi *et al*., 2016). There are different attributes of adaptive capacity of groundwater use and forms of vulnerability to climate change impacts that is household specific (Boko *et al.*, 2007; Lymo *et al.,* 2010; Antle *et al.*, 2012; Adiku *et al.*, 2016). They depend on broad based sources of vulnerabilities comprising of farmer household characteristics, indigenous knowledge, institutional arrangements and access to agricultural and climate information and technologies (Burton *et al.,* 2002; Reid and Vogel, 2006; IPCC, 2007; Bovolo *et al.,* 2009; Eriksen and Lind, 2009; Austine *et al.,* 2018). Farmer households with more income, higher education levels and access to agricultural, climate information and technologies were resilient to climate change impacts and vice versa. Socio-economic vulnerabilities are external social and economic environments that affect smallholder farmers on how they utilize groundwater for agricultural production. These environments comprise of access to effective indigenous knowledge, agricultural and climate information, availability of farmer friendly institutions and policies. The smallholder farmers become disadvantaged when the socio- economic environments are limiting to hamper their adaptive capacity (Adger *et al*., 2006: Albert *et al.,* 2011; Bosire *et al*., 2015; Ogara *et al.,* 2018).

1.1.2.3 Groundwater Strategies and Technologies

Most smallholder farmers are in greatest need of adaptation strategies with least capabilities given their limited resources (Adger, 2006; Lyimo *et al.*, 2010; Berkes and Ross, 2013; Kauzeni *et al*., 2013; Ogara *et al.,* 2018). Pooling resources by communities to develop groundwater irrigation schemes is an effective strategy in comparison with individual development with limited capacity. Typical examples of such successful community groundwater schemes are Ogallala Aquifer in the United States of America (U.S.A) and Nubian Aquifer in North Africa (Baron *et al*., 2013; Bill *et al.,* 2017). The application of new knowledge and strategies improves access of groundwater for agricultural production (Brogaard, *et al.*, 2011). The recently dug shallow wells are more superior to the older ones due to new knowledge, experience and effective strategies (Agatha and Hughes, 2001; Bosire *et al*., 2015). The advanced drilling and pumping technology coupled with perception, that groundwater is a private resource caused groundwater to be intensively exploited by private sector worldwide (Albert *et al*., 2011). The landowners considered that they had absolute water rights beneath their land boundaries (Albert *et al*., 2011; Moraa *et al*., 2012; Garrido *et al.*, 2018). At local level, other technologies include casing of shallow wells, providing metal well covers, sedimentation pits, overhead storage tanks and irrigation piping (Agatha and Hughes, 2001). Access to technologies through training of farmers can improve their chances of utilizing groundwater and their accumulated years of experience of groundwater use (Bosire *et al.,* 2015; Austine *et al.,* 2018). Lack of proven strategies and technologies at farm level limits sustainable management of groundwater resource (Olago, 2018).

1.1.2.4 Adaptation Action plan

Action plan is an implementation matrix that guides how an adaptation activity can be done with available resources and timeframe. Action plan is prepared in advance to allow all actors involved to assemble needed resources for adaptation with involvement of stakeholders. Action plan also assists in estimating budget and timing for carrying out the adaptation project to minimize maladaptation. Adaptation Action Plan is also important in fundraising as it has inputs of beneficiaries and other stakeholders that encourage ownership and transparency (Government of Kenya, 2010). It also improves chances for monitoring the performance of adaptation project with responsibility of each stakeholder and performance indicators well stipulated on the plan. By adopting the adaptation action plan there is high possibility of success of solving adaptation problems to enhance adaptive capacity of local community at Lwanda village (UNFCCC, 2005; Smit and Wandel, 2006; Mukheibir, 2008).

1.2 Problem Statement

Groundwater is the main source of water for local community in Lwanda village. (FBCIDP, 2013). The fluctuations in groundwater when most of the shallow wells in Lwanda village dry up during prolonged dry seasons between January and March before onset of long rainfall season and between November and December make the community very vulnerable because of water scarcity (Mukheibir, 2010). This is because there is no recharge of groundwater (Dennis and Dennis, 2012). During prolonged dry season farmer households scramble for limited groundwater resource in a few shallow wells that did not dry up. Although Lwanda village usually receives adequate annual rainfall of above 1800mm, the assumption that this village is less vulnerable to adverse climate change impacts is not true (Smit and Wandel, 2006). Lwanda village is also prone to seasonal rainfall, experiencing flash floods in some months and little amount of rainfall in some driest months (Kerandi and Omotosho, 2008; Hein *et al*., 2014; Francis *et al*., 2014; Kimosop, 2018; Olago, 2018). These extreme rainfall events negatively affect crop and livestock production in Lwanda village where farmers practice rain-fed agriculture for subsistence farming (Allen *et al.*, 2006; Morton, 2007; Hein *et al.*, 2014; Garry *et al*., 2015; Lakshmi *et al*., 2016). Research study could assist in providing data on the interaction of rainfall and groundwater to enhance groundwater management and use for agricultural production.

Sedimentation in shallow wells also hinders water availability by reducing depth of shallow wells when water table recedes during dry season (Ahn and Merwade, 2014). Flash floods cause walls of shallow wells to collapse and increase sediments in shallow wells. Drought events experienced during dry season force termites to migrate inside the walls of shallow wells that are cooler and their activity of making anthills increase sediments (Kimosop, 2018). Most farmers incur high costs of excavation to rehabilitate such wells since knowledge on magnitude and management of sedimentation remains unknown.

Patterns of broad-based sources of vulnerabilities for groundwater use for agricultural production remain unknown in Lwanda village (Berkes and Ross, 2013). They consist of farmer household characteristics, institutional arrangements and access to agricultural and climate information (Reid and Vogel, 2006; IPCC, 2007; Barnes *et al*., 2008; Bovolo *et al.,* 2009; Eriksen and Lind, 2009; Bosire *et al.*, 2015; Austine *et al.*, 2018). The interactions of these socio-economic vulnerability factors are crucial in development of sustainable groundwater use interventions for agricultural production.

The burden to feed the increasing population of Lwanda village increased with declining harvests because of rain-fed agriculture associated with seasonal rainfall (Lyimo *et al.,* 2010, FBCIDP, 2013). The limited groundwater use strategies and non-farmer friendly policies (Omolo, 2010; Christian *et al*., 2016) are some of major impediments to farmers' capacities to effectively utilize groundwater to enhance agricultural production. Groundwater use can guarantee agricultural production throughout the year with the reality of the irrigation embargo of Nile water international treaties (Laki, 1998; Wolf, 1998; Küng, 2003; Owiro, 2004; Loulseged and Yasir, 2008; Wondwosen, 2008; Christian *et al*., 2016; Lakshmi *et al*., 2016).

During prolonged dry seasons, daily intake of vitamins and proteins was inadequate due to limited supply of fresh vegetables and milk respectively during dry prolonged season since these nutrients are never stored in the body for later use but require daily ingestion. These circumstances perpetuated incidences of opportunistic infections especially in children with low immunity to increase medication burden that makes local community vulnerable (Bartelt *et al*., 2017). In some cases, smallholder farmers also encroach on wetlands by destroying natural vegetation that served as carbon sink along riparian belt to grow vegetables and graze their livestock causing soil erosion, water pollution and contributing further to increased Green House Gas emissions Cai *et al.,* 2008). Small Scale farmers could grow vegetables in wetlands to benefit from prevailing high prices during dry season when demand is high (Bill *et al.*, 2017). On the other hand, upland farms remain fallow with limited vegetation cover that serve as a carbon sink to absorb GHG emissions and prone to erosion.

Smallholder farmers in Lwanda village suffered more as they were not accustomed to worse climatic conditions during drought events experienced in 1997, 2000, 2004, 2005 and 2010. Their survival skills are limited to cope with harsh climatic conditions with little experience in irrigated agriculture (Godau *et al.,* 2019). Effective groundwater storage strategies and technologies guarantee continuous groundwater supply for irrigation to increase vegetation cover to reduce GHG emission and improve household nutrition during dry periods. The local community has not documented most of Indigenous knowledge to refer and assist in climate change adaptation (Makhakha and Ngema, 2019).

Most households had dug shallow wells using traditional technologies acquired and passed on from one generation to the other to abstract groundwater for household chores, livestock watering and to a limited extent for irrigation of vegetables and tree nurseries (Albert *et al.,* 2011: FBCIDP, 2013). These traditional technologies lacked scientific measurements and specifications regarding designs and dimensions (Bosire *et al.,* 2015). Most shallow wells were dug manually on trial-and-error basis if groundwater was found, causing them to dry up during prolonged dry season. Smallholder farmers also suffered exploitation from well diggers who charged them exorbitant prices. They equated this digging of graves whose costs are high and mourners communally catered for them. Contrary, well diggers also endangered their lives as they were at a greater risk when the wells curved in and buried them alive or water approached very fast to drown them before they could get out of the wells. A CCAT is one of the best tools to tackle these incidents. It is area specific and provides guidance on correct specifications of shallow wells in Lwanda village to reduce maladaptation (Adger, 2006; Global Child Nutrition Foundation, 2009).

Climate Change phenomenon is a global emerging issue that require an adaptation action plan at village level to minimize negative climate change impacts. During the establishment of an Adaptation Action Plan an opportunity is availed to local community participation in water conservation that is currently inadequate due to lack of public awareness, education and structured feedback mechanism in water sector with weak community linkages. These circumstances made Lwanda village the best choice of study location to understand how best groundwater can be utilized to promote agricultural production to meet the needs of the growing population (Akhtar *et al.*, 2011). A Climate Change Action Toolkit will ensure increased vegetation cover in farms and wetlands that serve as carbon sink to reduce GHG emissions (Andy *et al*., 2016). A Climate Change Action Toolkit will also contribute towards achievement of social and economic pillars of vision 2030 (Government of Kenya, 2012); Sustainable Development Goals (SDGs) especially goal on poverty, food security, water access and climate action (United Nations Development Programme, 2021).

1.3 Research Questions

The study aimed at addressing the overarching research question as to whether the smallholder farmers in Lwanda village had developed a climate change action toolkit specific to the area to assist them solve climate change problems of managing groundwater for agriculture production? The study attempted to answer the following specific questions.

1. To what extent is rainfall affecting groundwater use from shallow wells for agricultural production in Lwanda village?

2. How are farmer household characteristics, institutional arrangement and access to information and indigenous knowledge influencing use of groundwater from shallow wells for agricultural production?

3. What strategies and technologies are smallholder farmers using to minimize climate change impact using groundwater from shallow wells for agricultural production in Lwanda village?

4. Does Lwanda village has an Adaptation Action Plan for groundwater use for agricultural production?

1.4 Study Objectives

The main objective of the study was to develop a Climate Change Action Toolkit to minimize adverse impacts of climate change by using groundwater in agricultural production in Lwanda village in Bungoma County. To achieve the main objective, the following specific objectives were undertaken;

1. Determine the effects of rainfall on the use of groundwater from shallow wells for agricultural production using DART index in Lwanda village in Bungoma County.

2. Assess the effects of farmer household characteristics, institutional arrangements, access to information and indigenous knowledge on the development of shallow wells

to supply groundwater for agricultural production in Lwanda village in Bungoma County.

3. Identify effective technologies and strategies used by smallholder farmers for using groundwater from shallow wells in Lwanda Village in Bungoma County.

4. Establish an Adaptation Action Plan for groundwater use from shallow wells for agricultural production to minimize climate change impact in Lwanda village in Bungoma County.

1.5 Justification and Significance

1.5.1 Justification

In view of the foregoing, the study aimed to address a knowledge gap of developing a Climate Change Action Toolkit with stakeholders to tackle negative climate change impact on groundwater of shallow wells drying up. A CCAT will guide the effective use of groundwater from shallow wells that depend on rainfall to promote agricultural production to address Sustainable Development Goals especially goals on water, food security and climate action (United Nations Development Programme, 2021). The previous study carried out in Bungoma County only identify various water sources with shallow wells catering for 67% of the County population (FBCIDP, 2013).

Generally, depletion of groundwater resource resulting from increased population and seasonal rainfall informed the study. Smallholder farmers use groundwater from shallow wells for small-scale irrigation, yet it is largely quite variable because of rainfall variability (Egeru *et al*., 2014; Hein *et al.*, 2014 and Garry *et al*., 2015). In order to plan the use of the resource appropriately for sustainable irrigation and to improve food production, it is necessary to understand how the groundwater resource fluctuates with respect to changes in rainfall.

Groundwater vulnerability assessment of shallow wells is a good indicator (Kareem, 2018) of the severity of climate change impact since groundwater fluctuations depend on rainfall and land use practices. Besides, groundwater vulnerability assessments for climate change adaptation also address other secondary vulnerability traits ranging from reduction of vegetation cover in riparian belt as a carbon sink, destruction of wetland ecosystems for agricultural production in dry areas, malnutrition and health concerns locally and regionally (Garrido *et al.*, 2018). Encroachment of wetlands for agricultural production during dry periods also causes eutrophication of rivers enhancing water hyacinth invasion of Lake Victoria that have greatest environmental impact as well (Dennis *et al*., 2012).

Conflicts over groundwater use have also increased. During times of drought food shortages were experienced when malnutrition, foodstuff thefts in farms and stores was rampant with no income to purchase food (Eriksen and Lind, 2009; Omolo, 2010). Groundwater formations are complex in nature as the rainfall in another region can recharge groundwater from another region depending on slope and parent rock material (Baron *et al.,* 2013). DART Index method, TD approach and the UNDP Adaptation Policy Framework methodology (UNFCCC, 2005) highlighted some of the biophysical vulnerability traits to remove ambiguity and paucity at farm level. The study provides precise information on available groundwater in shallow wells in Lwanda village to guide on threshold for land under irrigation and livestock carrying capacity during dry season in order to increase vegetation cover and reduce destruction of wetlands.

Household characteristics, Indigenous Knowledge, institutional arrangements, access to information on development of shallow wells greatly affect supply of groundwater for agricultural production (Bosire *et al.,* 2015). Dam construction for irrigation was not feasible due to high population that could displace more people to increase their vulnerabilities instead of ameliorating it (Adger *et al*., 2006). Lack of documentation of indigenous knowledge hinders preservation of history for reference for purposes of adaptation. Inadequate access of information and training hampers agricultural extension knowledge to farmers to enhance groundwater use. Low public awareness of climate adaptations changes, low incomes, weak local community linkages to service providers, low education of smallholder farmers and weak structured feedback mechanism in the water sector reduced adaptive capacity to climate change impacts by local community.

Most smallholder farmers are not able to exploit the full potential of groundwater as they use inferior strategies and technologies (Olago, 2018). Further, manual digging of shallow wells does not generally guarantee adequate depth. Well diggers feared being buried alive due to extreme depth when such wells cave in or suffocation due to oxygen deficiency associated with ground depth (Baron *et al.,* 2013). An adaptation Action Plan is capable of identifying better options in terms of strategies and technologies that can be employed for effective use of groundwater for agricultural production to build smallholder farmers' adaptive capacity (Smit and Wandel, 2006; Bosire *et al.,* 2015).

A Climate Change Action Toolkit addresses the structured development of shallow wells: haphazard and poor workmanship in well construction can increase well rehabilitation costs (Darryn *et al.,* 2012). Limited public participation in development of shallow wells at individual level deny smallholder farmers an opportunity to trade-in with superior expert opinions from stakeholder involvement, a key feature in development of a Climate Change Action Toolkit.

1.5.2 Significance

Groundwater has inherent advantages considering its ubiquity, the speed with which it is developed, the relatively low capital cost of development, its drought resilience, and its ability to meet water needs demands at point of use (Baron *et al.,* 2013; Garrido *et al*., 2018). Water from rivers is a cheap irrigation water source but this was not the case in Lake Victoria basin because of the prevailing Nile water international treaties (Laiki, 1998; Wolf, 1998; Küng, 2003; Owiro, 2004; Loulseged and Yasir, 2008; Wondwosen, 2008). Groundwater is crucial for both rural and town water supply for domestic water, irrigation, industry and commercial uses (Albert *et al*., 2011). Groundwater can also provide solutions to complex politicized water allocation problems in comparison to surface water (Osmo, 2002; Moraa *et al.,* 2012; Olago, 2018). The effective management of groundwater makes agricultural production possible during prolonged dry season to increase vegetation cover in farms that usually lie fallow to serve as a carbon sink to reduce Green House Gases as well as increasing food production to assist people cope with impact of climate change (Bechir *et al.,* 2009).

Identification and adoption of suitable strategies and technologies to mine groundwater from shallow wells have the potential to increase crop yields through irrigation (Burke *et al*., 2008). Adequate food supply would make farmers to be in a better position to invest more in adaptation to climate change impacts thus enhancing their adaptive capacity in future. Groundwater use can adequately address conflict associated with limited food supply at local levels. The farmers will earn more income from sale of vegetables and milk at higher prices experienced during dry period dictated by market force dynamics. Increased disposable income might also mean increased investment better strategies and technologies to enhance adaptive capacity too.

A Climate Action Toolkit can guide groundwater use to keep the balance between the diminishing groundwater resources and the increasing water demands for agricultural production in Lwanda village. The research study seeks to provide scientific knowledge on groundwater availability for improving sustainable use under the prevailing climate change circumstances to build resilience of smallholder farmers.

1.6 Scope and Limitations

1.6.1 Scope

The scope of the research study involved studying water levels in thirty shallow wells in Lwanda village in Bungoma County in a period of two years between January 2017 and January 2019. The study involved collation of rainfall data for two years; conducting farmer household survey, Focus Group Discussion (FGD) and Key Informants Interviews (KIIs) to assess adaptive capacity to climate change impacts through groundwater use from shallow wells for agricultural production. The study focused on application of the **D**epth **A**quifer **R**echarge and **T**ransmissivity (DART) index method (Dennis and Dennis, 2012) and land use practices for groundwater use from shallow wells at farm-level by smallholder farmers for sustained agricultural production (Loaiciga, 2003). The study also adopted a Trans-Disciplinary Approach that involved participation of stakeholders in development of the Climate Change Action Toolkit.

1.6.2 Limitations

There was no database for farmers owning shallow wells, shallow well artisans, depth and age of shallow wells, and ground water monitoring records to establish trends and compare groundwater use from shallow wells in the village. Transmissivity and storativity data for the shallow wells were not available. The coefficients values for analogous aquifer materials derived from the study carried out in the Czech Republic (Kras'ny' and Lopez, 1989). The village had similar crystalline parent rock material found in Czech Republic. GHG emission reduction per acre under crop production was computed based on maize production as the staple food crop in Lwanda village. Most respondents were men who were the shallow well owners limiting evaluation of gender balance aspects could not be evaluated (Aamir, 2014). Some participants invited for Focus Group Discussion did not attend but sent representatives who did not have prior information. Dependence on goodwill of the well owners to avail their wells for study was not reliable as some locked the wells when they were away from their home causing some delays. Some of the shallow wells were not marked with the year when they were first developed and the researcher depended on the farmers' memory. It was not possible to take photographs because of privacy of participants. The developed Climate Change toolkit is limited for application in Lwanda village with crystalline parent rock material.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This literature review highlights rainfall and groundwater relationship; farmer household characteristics, institutions, information access, smallholder farmer' groundwater use strategies and technologies and worldwide concept application of toolkits in respect to agricultural production.

2.2 Rainfall and Groundwater use

2. 2.1 Groundwater and agriculture

Aquifers are natural groundwater storage that account for 97 percent of world freshwater supply needs of 2 billion people for domestic, industrial and irrigation purposes. Global annual precipitation is 577,000 km^3 with only 19 percent falling on land. A meagre amount of 2% (2,200 km^3) of total rainfall on the land surface is what percolates into ground storage, as the rest is lost to evaporation or surface runoff (Albert *et al.,* 2011; Garrido *et al*., 2018). Kenya has renewable groundwater resource of 3.5 Km^3 a year, constituting about 5 percent of the nation's renewable water resources (Arjen and Mekonnen, 2014). Ten years ago, 17.3 percent about 0.18Km^3 of this groundwater was the main water source by 43 percent of rural and 24 percent of urban households (KNBS, 2009). The proposed Irrigation Master Plan is supposed to enhance groundwater harvesting to increase of its use for irrigation to 0.2billion m^3 per year and to expand area under irrigation and drainage from 140,000 ha to 300,000 ha without considering the potential for depletion of groundwater resources. The potential for groundwater uses on agricultural production is an estimation of irrigation of an extra 160,000 ha (Albert *et al.,* 2011). Groundwater vulnerability assessment for agricultural production provides estimates on the likelihood of depleting the resource occasioned by changing patterns of rainfall to guide its management. Shallow wells benefit directly from rainfall and are highly sensitive to fluctuations in rainfall (Kerandi and Omotosho, 2008; Hein *et al*., 2014; Francis *et al*., 2015; Kimosop, 2018) the same area can receive flash floods and experience drought events in different months within one year.

2.2.2 Groundwater vulnerability assessment in Lwanda village

Groundwater vulnerability assessment is an analysis that determines the extent of groundwater stress due to seasonal rainfall (Bill *et al.,* 2017). Groundwater vulnerability assessment was conducted in Cape Town province of South Africa using DART index method. This method quantified estimates on the level of groundwater stress and likelihood of aquifers drying up due to seasonal rainfall without factoring adaptation element (Dennis and Dennis, 2012). The trans-disciplinary approach highlights hidden patterns of groundwater vulnerabilities. These vulnerabilities include shallow well depth, aquifer type, rainfall recharge, transmissivity, smallholder farmer household characteristics, indigenous knowledge, information access, institutional arrangements, strategies and technologies (Adger, 2006; Baron *et al*., 2009; Lyimo *et al*., 2010; Dennis and Dennis, 2012; Bosire *et al.,* 2015; Behnassi *et al*., 2014; Behrangi *et al*., 2016).

DART index is a function of **D**epth of aquifer, **A**quifer storativity, **R**ainfall Recharge and **T**ransmissivity. DART index has a maximum score of 10 indices as an indicator of groundwater resilience to Climate Change driven impacts of seasonal rainfall (Dassargues and Gogu, 2000; Dennis and Dennis, 2012; Kruger and Nxumalo, 2017). A negative change of vulnerability DART Index over a specified period indicated severe groundwater stress and a high likelihood of aquifers drying up but higher DART values represent more resilience.

DART index provides precise measurements of vulnerability assessment of groundwater as compared to the Palmer Drought Severity Index that only measures soil moisture. This is because groundwater is dynamic in nature that also benefits from rainfall from another region since the hydrological cycle is complex and never static (IPCC, 2007; Bob *et al*., 2004). There is a false assumption that large groundwater formations temporarily run low and are filled again when rainfall is plentiful as in the case of lakes, rivers and reservoirs (Bob *et al*., 2004). Groundwater recharge also depends on aquifer depth, storativity and transmissivity that do not apply to surface water reservoirs (Behrangi *et al.,* 2016; Olago, 2018).

The depth of aquifer is determined by Water Rest Level (WRL) or water table that fluctuates with rainfall and groundwater use. Deep aquifers are usually more resilient to impacts of climate change. There are two main types of aquifers. Confined aquifer and unconfined aquifer types. Confined aquifers are usually sandwiched by impermeable parent rock materials. Confined aquifer benefits more from rainfall received from other regions far away. Groundwater recharge in confined aquifers does not occur immediately after rainfall as this depends on the parent rock material (Dennis and Dennis, 2012; Kruger and Nxumalo, 2017). Unconfined aquifers are not sandwiched between two impermeable rocks and they directly benefit from rainfall in that particular region. Unconfined aquifer also acts as source of water to confined aquifer to some extent as water recedes further in the ground to feed confined aquifers. Unconfined aquifer storativity coefficient range between 0.1 and 0.3, which is another factor of groundwater vulnerability (Dennis and Dennis, 2012; Kruger and Nxumalo, 2017).

The slope and amount of rainfall received in an area usually affect the amount of groundwater recharge in shallow wells (Behrangi *et al.,* 2016). High rainfall and low slope increase amount of water infiltrated in the ground and vice versa. A country study conducted in South Africa formulated a recharge function as defined by (Dennis and Dennis, 2012) which was adopted since there has been no such studies carried out in Kenya. A constant factor of 148 was applied for an area receiving annual rainfall above 500mm with an adjustment of natural logarithm of monthly precipitation to cater for water loss during infiltration. A random variable of error for slope for computing groundwater recharge since slope may not be uniform in an undulating area (Dennis and Dennis, 2012; Kruger and Nxumalo, 2017).

Transmissivity is a measure of permeability of the parent rock material and an important hydraulic property of aquifer to make estimation of possibility of abstracting groundwater (Jiri, 1993). Low transmissivity is an indication of low water yields and vice versa (Jiri, 1993). Quaternary fluvial deposits have highest transmissivity followed by sandstone rocks and crystalline rocks in that order. There are five classes of transmissivity magnitude designated by class I, II, III, IV and V depending on the transmissivity co-efficient and groundwater supply potential of an aquifer. Class I has coefficient of transmissivity of above 1000m^2/d for aquifers of great regional importance especially transboundary aquifers with expected discharge of above 50litres of water per second. Class II has coefficient of transmissivity varying between 100 and 1000 m^2/d with expected discharge between 5 and 50 litres per second. Some sand rocks (100 - 330 m^2/d) and all Quaternary fluvial deposits (360 - 860 m^2/d) parent material belong in the class whose transmissivity magnitude is denoted as high. The intermediate transmissivity magnitude is Class III with coefficient of transmissivity ranging between 10 and 100 m^2/d with expected discharge varying from 0.5 to 5 litres per second to include most sandstone rocks. Class IV has low transmissivity magnitude with coefficient of transmissivity of between 1 and 10 m^2/d where most crystalline parent rocks belong (0.45 - 7.9 m^2/d) with discharge ranging between 0.05 and 0.5 litres per second. Class V has very low transmissivity magnitude with coefficient of transmissivity of less than 1 m^2/d with negligible discharges because the parent rock is highly impervious.

2.3 Farmer Household characteristics, Institutions and Information access factors

2.3.1 Farmer household characteristics factors and groundwater use

Farmer household characteristics also influence groundwater use largely (Austine *et al.,* 2018; Ogara *et al.,* 2018). They include household income, household size, and land size, head of household gender, education levels and farming systems (Aamir, 2014; Bilenkisi *et al*., 2015; Bosire *et al*., 2015). Smallholder farmers are affected most by climate change impacts although not uniformly (Carpenter *et al*., 2004; Barnes *et al*., 2008; Berkes and Ross, 2013; Hanjira and Qureshi, 2010; Ogara *et al*., 2018). Smallholder farmers usually depend on rain-fed subsistence agriculture for livelihood with least capabilities given their limited resource (Garry *et al*., 2015). They have greatest need of adaptation strategies and technologies (Agatha and Hughes, 2001: Daniel *et al*., 2008; Ogara *et al.,* 2018). Famers with inadequate sources of income are seldom in a better position to hire shallow well diggers to dig deeper wells that attract high costs considering other competing basic needs (Chandrasekhar and Mukhopadhya, 2010, Olsson *et al*., 2014; Daniel and Rachel, 2016). More disposable income enables farmers to invest more in advanced strategies and technologies to improve extraction of groundwater (Mukheibir, 2008; Olsson *et al*., 2014;

Bosire *et al*., 2015). Some of the strategies and technologies employed by farmers for agricultural production consisted of by increasing depth of shallow wells, construction of sedimentation barriers or casing the well, drilling and excavation equipment, erection of overhead storage tanks and installation of water pumps (Agatha and Hughes, 2001). Some common sources of incomes in the rural community included salary and wages, pension, petty trading, credit and from social networks (Adger, 2006; Olsson *et al*., 2014). Large household sizes need more food requiring and more efficient groundwater use technologies to increase agricultural production to guarantee adequate foodstuff compared with households with fewer members (Daniel and Rachel, 2016; Martin. 2019). Smaller landholdings meant for subsistence farming require irrigation to increase food production (Huang *et al*., 2010).

Households' heads with higher education levels are more likely to have better exposure to technology and information than those that are semi-illiterate and thus utilize groundwater more effectively (Bosire *et al.,* 2015; Ogara *et al.,* 2018). The household heads with higher education are more likely to earn higher income from skilled labour and invest extra income in development of groundwater for agricultural use unlike their counterpart with low education levels (Olsson *et al*., 2014; Bilenkisi *et al.,* 2015). Male-headed households are likely to have higher levels of education and higher income while enjoying good reputation based on superior cultural role perceptions (Aamir, 2014). These positive attributes may enable male-headed households to exploit groundwater easily compared to female-headed households in rural farming set ups. Male-headed households were also likely to access financial assistance and revenant information considering their involvement in outdoor activities. They normally attend public meetings and have adequate time to listen to the radio and watch television. On the other hand, female counterparts are involved with indoor activities and other household chores in the kitchen far away from the external information sources and do not own land as a collateral (Barnes *et al*., 2008; Aamir, 2014 and Bosire *et al.,* 2015).

Farming systems also affect groundwater availability. The number of livestock kept and crop surface under irrigation determine groundwater use (Majule and Mary, 2009; Huang *et al*., 2010; Ogara *et al.,* 2018). Crop water requirement (CWR) is the minimum water threshold needed for crop production in a week (Kerandi and Omotosho, 2008). It is about

30% of total amount of water required by a particular crop (Brogaard *et al*., 2012). Daily livestock water requirements depend on the kind of livestock kept with chicken using least amount of water. Households practicing mixed farming may need more water for livestock and crop production as well (Omaid *et al.,* 2018). Irrigation of pastures, crops and tree nurseries during dry period to increase vegetation cover to serve as a carbon sinks to absorb more GHG emissions to improve the microclimate of an area (Carpenter *et al.,* 2004; Cai *et al*., 2008; Omaid *et al.,* 2018). Availability of pasture on farms is likely to increase milk production that in turn could also stabilize market milk prices because of steady supply (Ogara *et al*., 2018). Incidents of livestock grazing on wetlands could also reduce thus allowing wetland vegetation to regenerate that serve as an important carbon sink and control soil erosion (Beverly, 2014). Irrigation of crops especially vegetables could increase daily vegetable intake to reduce malnutrition associated with vitamin deficiency to reduce opportunistic infections and medication burden implications. A well-fed and healthy population is more likely to give priority to implement climate change recommendation than a hungrier and unwell community whose priorities are different and counterproductive (Food and Agriculture Organization, 2011; Kauzeni *et al*., 2013). Income saved from opportunity costs such as not purchasing milk, vegetables and medication and instead invested in climate change adaptation to enhance communities' adaptive capacity to build their resilience against climate change impacts (Smit and Wandel, 2006; Bovolo *et al*., 2009; Berkes and Ross, 2013). Farmers could also save time from looking for pasture and water for livestock in wetlands far away to do other useful engagements to assist community to cope well with climate changes (Lakshmi *et al.,* 2018). Groundwater has the greatest potential to counter negative effects of climate change when used for irrigation of crops and pasture during dry season (Giordano, 2006; Brogaard *et al*., 2012).

2.3.2 Implication of Indigenous knowledge on groundwater use for agricultural production

Evaluation of indigenous knowledge helps to understand local community norms observed regarding groundwater management. Women usually do not own land among most African communities that may be synonymous to owning wells (Food and Agriculture Organization (2011; Aamir, 2014). The *Bukusu* sub tribe of the larger Luhya community as the majority and *Sabaoti* as the minority clan in the main local community have common norms regarding gender roles where women are the ones charged with responsibility of fetching water. Lwanda village has Quaker church, Seventh Day Adventist Catholics and Pentecostal churches. The knowledge of worship days is important in deciding on the meeting days with local community. These local communities practise male circumcision in August after two years with one age set comprising of 10 years of circumcision ceremonies. The circumcisers are called *Bakhebi* are circumcisers in local dialect. A few clans like *Bamunaha* and *Bamuki* usually carry out this practice. Composing of circumcision songs with climate change verses can assist to communicate and create awareness to local community at grassroots levels. There are eight age sets; *Basawa, Bakikowamet Bakananachi, Bakinyikeu, Banyange, Bamaina, Bachuma, Bakolongolo* and people belonging in same age set are called *bakoki* (Makhakha and Nafuna, 2019). These age-sets could assist in matching chorological events of climate change impacts and their shared unity is an asset to organizing groundwater user's association for climate change adaptation. The senior age sets also enjoy respect in the community are useful goodwill ambassadors to communicate climate adaptation in formation. Lwanda village community is a patriarchal society where men are automatic household heads and pay dowry (*Bukhwe)* for their wives. Females have the responsibility of fetching water, firewood and cooking while males look after livestock, and ensure family security and community wellbeing (Aamir, 2014). Sports especially football and athletics are what many youths engage in during holidays that could be useful forums for climate change adaptation awareness creation. Buteyo Miti Park is a botanical garden that serve as a source of herbal medicine for local community that can serve as a good example of carbon sink with indigenous trees that take long period to mature and are resistant to climate change impacts. Most youth attend tertiary education at Sangálo Institute of Science and Agriculture and Lwanda Youth Polytechnic as day-scholars who can engage in climate change adaptation during weekends and holiday as interpreters of local dialect. *Baluunda* clan *(bakimba)* known for being rainmakers never drink rainwater harvested from roof tops but use groundwater. Circumcisers and rainmakers are traditionally respected role players who can create public awareness on climate change adaptations.

2.3.2 Information access and groundwater use

Access to information and technology through training of farmers improves the chances of utilizing groundwater for agricultural production (Burke *et al.,* 2008a; Brogaard *et al*., 2011; Bosire *et al.,* 2015). Some known sources of information are farmer- to- farmer, training, and mass media communication channels like television, radio, web-based communication and newspapers.

2.3.3 Institutional arrangements and groundwater use

Institutional arrangements are about legislation instruments and access to training on groundwater management. The widespread notion that groundwater is an inexhaustible and a private resource with which landowners have an absolute right has affected its management since it contradicts the position of the laws (Albert *et al*., 2011; Garrido *et al.*, 2018). Lack of knowledge of a complex common pool resource perception and unique insuperable management challenges cause uncertainty over the future of intensive groundwater use (Garrido *et al.*, 2018). The unfriendly farmer legislations especially the Nile treaty that inhibits surface water use for irrigation can promote use of groundwater as an alternative in Lake Victoria basin with expanding population (Laki, 1998; Küng, 2003; Owiro, 2014; Loulseged and Yasir, 2008; Christian *et al.,* 2016). In Kenya, there are five significant trans-boundary aquifer clusters consisting of the Rift Valley aquifers, the Elgon aquifer, the Merti aquifer, the Kilimanjaro aquifer and the Coastal sedimentary aquifers (Albert *et al.,* 2011; Garrido *et al.*, 2018).

Institutional capacity arrangements remain weak to finance research studies for groundwater vulnerability analysis to inform implementation of shared groundwater resource although the National Water Policy acknowledges that Kenya has shared water resources (Albert *et al*., 2011). Frameworks in Kenya deal broadly with the management of water resources and they are not dedicated specifically to groundwater management. Groundwater management decision making is overly centralized and sector-based carried out overall *ad hoc* without considering management of land and other land-based resources (Albert *et al.*, 2011; Moraa *et al.,* 2012). It overlooks the implications of management decisions on physical planning, land use planning and agricultural activities (Olago, 2018).

Generally, there is low public awareness about the specific characteristics of groundwater and the connectivity between surface water, groundwater and climate change because of limited training and access to appropriate information by smallholder farmers (Sophocleous, 2002; Brogaard *et al*., 2012; Bosire *et al.,* 2015; Ogara *et al.*, 2018).

2.4 Smallholder farmers' Strategies and Technologies for groundwater use

The advanced technical developments in drilling and pumping technologies by India, the United States and China has led to abstraction of over 50 percent of global groundwater estimated at 442 km^3 per annum of an estimated 840 km^3 annually to address climate change impacts (Albert et al.*,* 2011; Garrido *et al.*, 2018). Private water users and not governments took the initiative of developing groundwater on this scale, particularly for agricultural purposes. Government funding of groundwater resources management has remained low compared to its benefits and equivalent funding for surface water development (Llamas and Martinez-Santos, 2005; Garrido *et al.*, 2018). Some of technologies applied by smallholder farmers include casing of shallow wells, providing metal well covers, sedimentation pits, hand water pumps, Jumia water pumps, moneymaker pedal pump, Maji water pumps, electric and solar pumps, overhead storage tanks, and irrigation piping excreta (Agatha and Hughes*,* 2001). Lwanda village has electricity making it easier to use drilling and pumping technology (FBCIDP, 2013).

There are three perspectives of groundwater strategies and technologies used by farmers for agricultural production expressed in terms of development, storage and supply (Cynthia and Tubiello, 2007; Antle *et al.*, 2012; Lakshmi *et al.*, 2016). Farmers dug wells manually or used drilling machines. Manually dug wells are usually limited in depth and took a long time depending on the parent rock material, effort and performance of well digger. Drilling equipment bored the wells very fast but it is relatively expensive to hire the equipment (Llamas and Martinez-Santos, 2005; Albert *et al.*, 2011; Baron *et al.,* 2013). Drawing water manually usually takes a long time with greater effort to fetch adequate water for agricultural production depending on the depth of water table compared to pumping the water (Llamas and Martinez-Santos, 2005). Groundwater can be stored in earth dams, water pans and overhead tanks for agricultural purposes later during dry season (Mukheibir, 2008; Ogara *et al.,* 2018). The canals, pipes, sprinklers or drips can supply groundwater for distribution for crop production. Water supply through drips is most efficient although expensive. Most strategies used addressed trade-offs or exploited new opportunities offered by superior developed technologies to improve groundwater management (Majule and Mary, 2009; Bosire *et al.,* 2015; Lemma and Wondimagegn, 2016).

2.5 An Adaptation Action Plan

In establishing, an Adaptation Action Plan a complete project cycle stages process is followed that includes coping, aggregation of diagnostic information, needs assessment, action planning, monitoring and evaluation (Global Child Nutrition Foundation, 2009). Scoping involves identification of objectives to tackle as terms of reference. Aggregation of diagnostic information is gathering of existing information that establishes the current trends. Needs assessment involves carrying out of field experimentations to determine relationships of the variables in the set objectives and the threshold levels (Antle *et al.,* 2012). Action planning is the choice of adaptation interventions and assigning of period of implementation of various tasks by different players. Monitoring and evaluation are after identification of performance indicators and timings for indicators to determine the success of any adaptation plan (Kjell and Pervez, 2006; Barnes *et al.,* 2008; Alpha *et al.,* 2009).

The United Nation Development Programme (UNDP) Adaptation Policy Framework (APF) methodology (UNFCCC, 2005; Daniel *et al.,* 2008) is one of Trans-Disciplinary (TD) approach. It analyses groundwater vulnerability and socio-economic vulnerability contexts to cater for adaptation (Boko *et al*., 2008; Brogaard *et al.*, 2012). APF involves participation of various categories of stakeholders, research tools and expert experiences in developing of an Adaptation Action Plan (Osmo, 2002; Antle *et al.,* 2012).

2.6 Application of a Climate Change Action Toolkit (CCAT)

Application of a Climate Change Action Toolkit is most effective when it incorporates broad perspectives of vulnerability features described above (Adger, 2006; Berkes and Ross, 2013; Austine *et al.,* 2018). By understanding the interactions of climatic conditions, groundwater, smallholder farmer household characteristics, Indigenous Knowledge, information access, institutional arrangements, strategies and technologies. It becomes possible for stakeholders to develop an appropriate Climate Change Action Toolkit at farm level (Darryn *et al.*, 2012). The United States of America and Australia use CCATs to provide solutions to climate change impacts (Flannery and McKenzie, 2013). Typical examples are the British Columbia and Chicago in USA (Field Museum, 2019) and Melbourne in Australia (Darryn *et al.,* 2012) that have used community Climate Action Change Toolkits.

Participation of stakeholders is possible through surveys, interviews and focus group discussions to obtain their opinions that improve success of adaption with high degree of ownership of the recommendations (Osmo, 2002; Darryn *et al.,* 2012). Participation of stakeholders is also a form of public participation that is an integral requirement of the Constitution of Kenya (Government of Kenya, 2010). Application of various research tools to include both qualitative and quantitative research tools assist in relating people perceptions to scientific findings (Antle *et al*., 2012). A scientific finding either concurs with traditional knowledge or invalidates it since this provides a platform for paradigm shift amicably when need arises to reduce divergent opinions that affect adaptations (Martin, 2019).

Expert experience is equally important especially in areas where scientific data is inadequate considering that climate change impact on groundwater is an emerging event that is gaining importance. It also helps in creating public awareness about climate change adaptations to other participants in the study especially smallholder farmers during various stages of development of CCAT (Ogara *et al.,* 2018). Application of a CCAT as a planning tool improves precision in choice of suitable adaptation interventions of using groundwater from shallow wells to minimize adaptation costs that ranges between 5% and 10% of national Gross Domestic Product (GDP) (Alpha *et al*., 2009; Falkenmark and Rockström, 2010).

2.7 Conceptual Framework for Groundwater use in Lwanda village

This conceptual framework explains the relationship between different variables and groundwater use for agricultural production in Lwanda village in Figure 2.1.

The rainfall as an independent variable that usually affects the dependent variables. These dependent variables are groundwater use. Rainfall amount affects groundwater recharge and transmissivity that contribute to groundwater quantities. The vulnerability traits are other independent variables that affect groundwater use. These vulnerability traits are household characteristics, institutional arrangements, Indigenous Knowledge, information, and technology.

The exploitation of groundwater from shallow wells for agricultural production has potential to increase crop and pasture production and tree nursery establishment during prolonged dry season. There is increased food produced and vegetation cover through irrigation. The increased food and pasture production reduce malnutrition and tendencies by local communities to graze livestock in wetlands. The increased vegetation cover enhances carbon sink by absorption of carbon dioxide gas through the process of photosynthesis to convert it to carbohydrates. The increased vegetation cover also increases evapo-transpiration rate through stomata that will increase water vapour that condenses to form cloud cover in the atmosphere. When the c cloud formed will increase relief rainfall to recharge groundwater. The savings made from reduced medication burden due to increased food production can be invested in adaptations to enhance community adaptive capacity. Groundwater use ensures increased vegetation cover that reduces Greenhouse Gas emissions (Bob *et al*., 2004 and Garrido *et al.,* 2018).

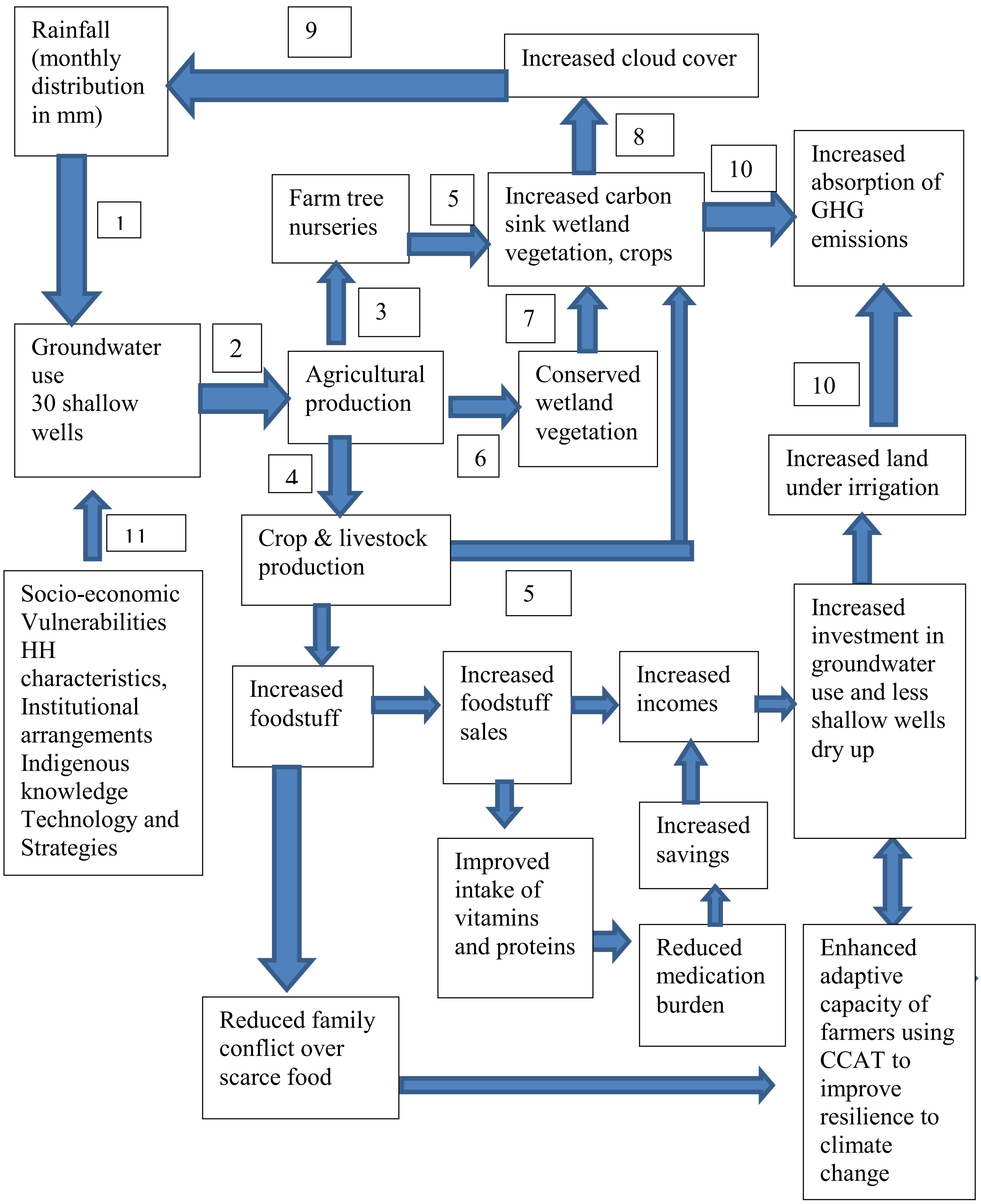


Figure 2.1: Conceptual framework for Climate Change Action Toolkit for groundwater use for agricultural production in Lwanda village, Bungoma County

Keys for Figure 2.1

1. Precipitation

2. Irrigation

Keys for Figure 2.1

3. Irrigation of tree nurseries
4. Irrigation of crops and drinking water for livestock
5. Conservation of wetlands
6. Photosynthesis process
7. Photosynthesis process
8. Evapo-Transpiration process
9. Condensation process
10. Storage of carbon in plant tissues
11. Abstraction of groundwater

CHAPTER THREE: STUDY AREA, MATERIAL AND METHODS

3.1 Introduction

This section highlights the study area location and physical features of Lwanda village, material used and the various methods applied during the study.

3.2 Study Area

3.2.1 Location and Description

Bungoma County covers an area of 3032.4 Km^2 bordering the Republic of Uganda to the North West, Trans-Nzoia County to the North-East, Kaka mega County to the East and South-East and Busia County to the West and South West (Hein *et al*., 2014). Lwanda village in Bungoma County is situated within a sub-humid region lying at 1370 metres above sea level along a latitude of 34º37'5''E and 0º33'0''N of the equator. Lwanda village is marked in red colour in Figure 3.1 and Figure 3.2.

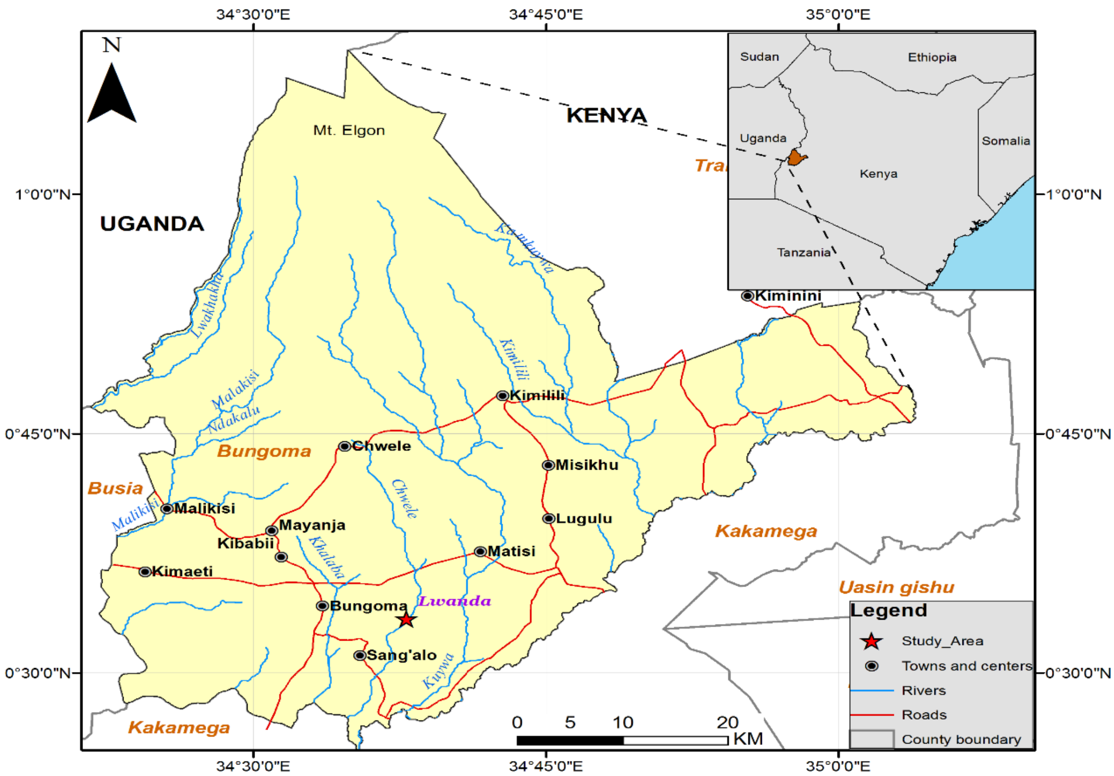


Fig 3.1: Map of Bungoma County within L. Victoria basin

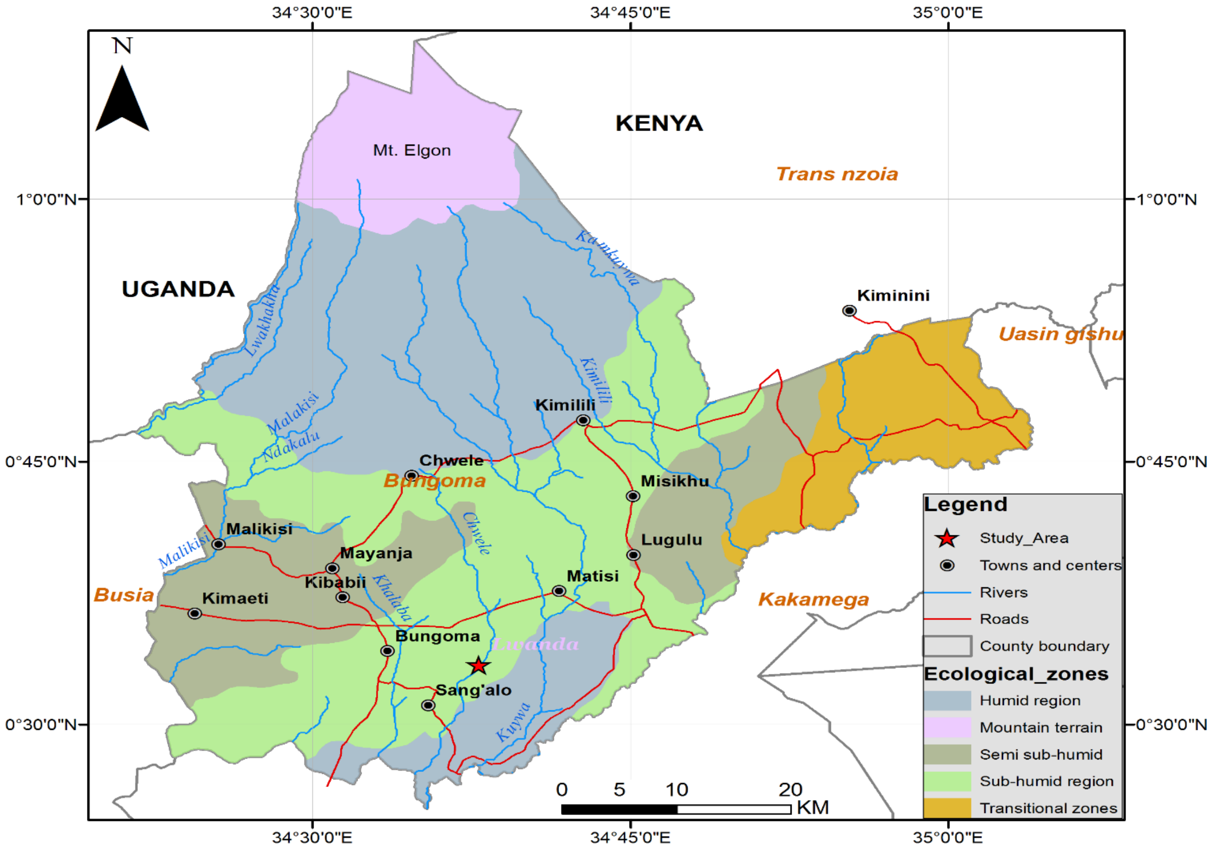


Fig 3.2: Map of village location within Bungoma County and its ecological zones

3.2.2 Biophysical setting of Lwanda village

The biophysical setup comprised of topography, climate, soils, vegetation, land uses, resources physical drainage and local groundwater availability.

3.2.2.1 Topography of Lwanda village

Topography of land in Bungoma generally slopes from the foot of Mt. Elgon to the North to the low-lying South and South West but Lwanda village had gentle undulating slopes of about 5% within sub-humid lower midlands (LM2) Agro ecological zone (Hein *et al.*, 2014). The slope encouraged surface runoff infiltration to recharge groundwater (Sophocleous, 2002). Lwanda area has Matumbufu rock outcrops on the northern side, Bayobo rocks and cave on the southern side and Sang'alo hill on the Southeastern side. This scenery makes it appear as a depression.

3.2.2.2 Climate, soils and vegetation of Lwanda village

Lwanda village is within Lake Victoria basin, which usually experiences both convectional and convergent rainfall (Francis *et al*., 2015). The convectional rainfall occurs during the long rainy season between March and May with amount of rainfall between 580 and 720 mm (Hein *et al*., 2014). A convergence of the daily Lake Victoria winds and the Trade winds from the East causes the short rains from October to December with amount of rainfall ranging between 380 and 450 mm, an inadequate amount to support agricultural production (Kerandi and Omotosho, 2008). The total annual rainfall averaged 1970.2mm in 2018.The mean maximum temperature ranges between 26.3ºC and 33.1ºC and mean minimum temperature between 12.5ºC and 14.9ºC. The evapo-transpiration ranges between 1400 mm to 1800 mm per year and the average wind speed is 6.1 km/hr. (Egeru *et al.,* 2014). Soils are sandy loams that are shallow to deep, permeable and allow surface runoff to percolate to recharge groundwater (Hein *et al*., 2014). Soils are suitable for growing *Gramineae*, fruit trees, legumes and root crops (FBCIDP, 2013). The vegetation is of savannah grassland type (Hein *et al*., 2014).

3.2.2.3 Land uses and resources of Lwanda Village

Lwanda village has about 4km^2 of arable land with 95% (380ha) under crop and livestock production. Five per cent was estimated land for one primary school, two secondary schools, one polytechnic, churches and shops (FBCIDIP, 2013). Land uses were agriculture, farm forestry, construction of human settlements, business ventures, social and public amenities. Land is also as credit collateral.

3.2.2.4 Physiography and drainage of Lwanda village

There are two permanent rivers sandwiching Lwanda village. River Chwele flows on Eastern side about 2 Km away while river Khalaba flows on western side at about 4 Km away (Hein *et al.,* 2014). Both rivers flow from Mt Elgon towards the south to Lake Victoria.

3.2.2.5 Local groundwater availability of Lwanda village

Lwanda shallow aquifer lies within the Kenyan Lake Victoria basin water catchment area of 18,374 km^2 and 3.2% of the total area of Kenya (Water Resources Authority, 2019). This basin normally experiences 149mm, 1.1672 x $10^{10}m^3$and 1.16x $10^8m^3$of runoff, surface and groundwater per annum (Beverly, 2014). Groundwater provides 61.4 per cent of water supply in Bungoma County, to meet 166, 40 $1m^3$ of annual water requirements (FBCIDP, 2013). This is because investment in shallow wells is relatively inexpensive engineering that guarantee water supply close to points of use and does not require water permit in Water Act of 2016 (Government of Kenya, 2016b).

3.2.3 Biophysical vulnerabilities of Lwanda village

The gently undulating land towards the north against the general regional topography that usually slopes southwards from Mt Elgon might hamper groundwater formation. The crystalline rock outcrops surrounding the area are evidence of rocky surface beneath limiting well depth during excavation and groundwater abstraction (Jiri, 1993). The rainfall was not evenly distributed to support agricultural production (Kerandi and Omotosho, 2008). The high temperatures and wind speed cause evaporation of surface runoff and soil moisture to reduce groundwater recharge. Farm forestry of eucalyptus trees with deep roots and high transpiration rates also reduce groundwater. Farmers over dependence on rain-fed agriculture will reduce yield by 50% in 2020, and with increasing drought events interval of 7 years, can contribute to increased malnutrition cases (Burke *et al*., 2008; Garry *et al*., 2015). Presence of anthills indicated presence of termites that could increase sedimentation in shallow wells.

3.2.4 Socio-economic setting of Lwanda village

Bungoma County has nine Sub-Counties, 45 Wards, 81 locations and 179 sub-locations. The sub counties are Kanduyi, Bumula, Kimilili, Webuye East, Webuye West, Sirisia, Kabuchai, Mt Elgon and Tongaren, respectively (FBCIDP, 2013). Lwanda area belongs to Lwanda sub location within East Bukusu Location in West Sang'alo Ward of Kanduyi Sub County. Sugarcane is the main cash crop and maize is a staple food. Eight per cent of jobs are from operating businesses and working in three public schools while two per cent of the population work in towns and the rest are farmers. Human Development Index (HDI) and Gender inequality index is 0.265 and 0.457, respectively, below the national average of 0.5817 and 0.651 respectively (FBCIDP, 2013). The new Water Act 2016 that governs water resources seeks to improve communication and enhance citizens' participation to remove ambiguity in roles of different actors coordinated by Water Resources Authority (WRA) (Osmo, 2002; Moraa *et al.,* 2012: Government of Kenya, 2016b).

3.2.5. Socio-economic vulnerabilities

During the 2009 census, West Sang'alo Ward had 42,286 persons with 3.1 % annual population growth rate within an area of 59.2 km^2. The increasing population has led to land fragmentation and encroachment on wetlands and riparian belts for food production purposes, f causing deterioration of quality and quantity of water resources (FBCIDP, 2013; Chen *et al*., 2017). The current pressure on groundwater use might deplete the resource with dependence of over sixty per cent of groundwater supply due to lack of tap water. Ninety per cent of the population depends on agricultural production and remains highly vulnerable to any slight shock in climatic conditions that depresses livelihoods (Garry *et al.,* 2011). Malnutrition is one of the major causes of morbidity and mortality. Irrigation to increase food production can reverse this trend (Food and Agriculture Organization, 2011; FBCIDP, 2013). Nile water international treaties (Laki, 1998; Owiro, 2004; Wondwosen, 2008, Christian *et al*., 2016) hampered the benefits of irrigation. Government investment in groundwater development remained low with limited budgets allocations (Albert *et al.,* 2011; Moraa *et al.,* 2012). Depressed economic conditions of sugarcane farming due to non-payment of cane delivered by Nzoia Sugar Company have incapacitated farmers' financial position to invest in groundwater development (Chandrasekhar and Mukhopadhya, 2010). The malnourished households usually opt to purchase food and medicine as their basic needs instead of investing in development of groundwater that is only a secondary need.

3.3 Methods

3.3.1 Introduction of data collection methods

This study adopted Trans-Disciplinary Approach comprising of UNDP Adaptation Policy Framework methodology (UNFCCC, 2005) and DART index method to develop a Climate Change Action Toolkit. TDA is the method is preferred since it allows use of various tools in collection of multiple data sources and aggregation into a database for analysis and interpretation respectively. It encourages interaction of local community and expert opinions to produce well-synthesised and balanced conclusions (EFSA, 2013). A Typical example is the combination of qualitative and quantitative research methods is a Trans-Disciplinary Approach (Antle *et al*., 2012). APF methodology involved application of a combination of various tools for data collection processing involving different stakeholders (Osmo, 2002; Darryn *et al*., 2012). The primary and secondary data was obtained and analysed using Microsoft excel and descriptive statistics. Trans Disciplinary Approach also assisted in bringing together different actors with different experiences to enrich research knowledge from both scientific and society perspectives.

The sampling techniques for choice of target farmers depended on experience of the farmers, willingness to participate in the study, good memories of the past and ability to self-expression. A standard universal sample size of thirty was chosen for large population in this study (Kjell and Pervez, 2006). Review of relevant literatures enabled the development and designing of data collection instruments for Trans-Disciplinary Approach.

3.3.2 Data collection methods for effects of rainfall on groundwater use in agricultural production

There were several methods employed for data collection and analysing the effects of climatic conditions on groundwater parameters and agricultural production. These methods are highlighted in the following sections.

3.3.2.1 Secondary data collection method for rainfall and temperature

Monthly rainfall, minimum and maximum temperatures between January and December of 2017 and 2018 was obtained from Sang'alo weather station. This data was captured and analysed using Microsoft excel worksheets to determine mean and standard deviation of the rainfall experienced in village for a period of 24 months to establish relationships between groundwater parameters and rainfall.

3.3.2.2 Field survey studies

Field studies were conducted to collect primary data. The field studies involved Field visit, Pre-testing and piloting of research tools, DART index experimental method, farmer household survey, one Focus Group Discussion and involvement of three Key information informants.

a) Field visits

There were field visits made to Lwanda village between 2017 and 2019 to familiarize with the location and biophysical features of the local community in relation to groundwater. The field visits assisted in establishing the location of shallow wells and coding them accordingly with unique numbers to avoid data mix up. The field visits also assisted in creating a relationship with the local community to allow free communication and exchange of Indigenous Knowledge information. The field visits' purpose was to introduce the research study and prepare the local community in advance to understand the purpose of study and to reduce suspicion in absence of adequate information as well as obtain consent from shallow well owners for data collection. During the field visits, the farmer household survey itinerary was prepared together with the village elder who assisted to trace the farmers' homes in Lwanda village.

b) Farmer Household Survey

Farmer household survey questionnaires were developed and administered to thirty farmers owning shallow wells to collect primary data. A sample of farmer household questionnaire in Appendix 1. This primary data collection tool was pre-tested before the actual research study begun to minimize errors due to misinterpretation of the contents to enhance accuracy of the results. The researcher also benefited from piloting of Transdisciplinary Approach research tools carried out in Kisumu and Homa Bay counties during group fieldwork studies conducted by University of Nairobi for postgraduate students of the Institute of Climate Change and Adaptation in January 2017. The farmer survey was conducted to collect data on year of shallow well development, type of livestock kept and crops grown to estimate groundwater use for agricultural production between 5th January and 20th January 2019.

c) Focus Group Discussion

A Focus Group Discussion checklist schedule was developed to collect group primary data to assist in triangulating collected data from various sources. A Focus Group Discussion held involved participants from Ministry of Agriculture, Livestock and Irrigation, farmers, Assistant Chief, representatives from CBOs and private sector on 30th January 2019 at Ekitale Chief Centre. A sample of Focus Group discussion schedule in Appendix 2. A Focus Group discussion was held within two weeks after the farmer household survey studies when farmers 'memories were still fresh on groundwater and climate change subjects that had been introduced to them.

d) Interviews with Key Information Informants

A Key Information informants' checklist schedule was prepared that was used to guide interview of Key information informants in both Bungoma County and National government to provide information on groundwater use for agricultural production. The appointments with three key information informants were made after availing them with the checklist schedule and an introduction letter that explained the purpose of the research study before the material interview day. This was done to allow them adequate time reorganize the relevant information in their custody for the study. The key information informants' interviews were conducted on 5th April 2019 in Bungoma County, 7th November 2019 at Ministry of Water and Irrigation headquarters at Maji House and on 9th November 2019 at Ministry of Agriculture and Livestock at Kilimo House Nairobi. A sample of key information informant's checklist schedule in Appendix 3.

e) ***DART Index field experimental method***

DART index experimental method was adopted to collect data on shallow well dimensions, water level and rainfall data for a period of twelve months between January and December 2018. A sample size of thirty shallow wells was studied to derive the DART index.

i) Apparatus and materials

The following were the apparatus and materials used in this field experiment.

1. A steel tape of 20 meters
2. A metal disc plate with a diameter of 300mm and 10mm thick
3. A 200 mm long bright coloured string
4. Data collection forms
5. A 10-meter tape measure
6. A pen
7. A marker-pen

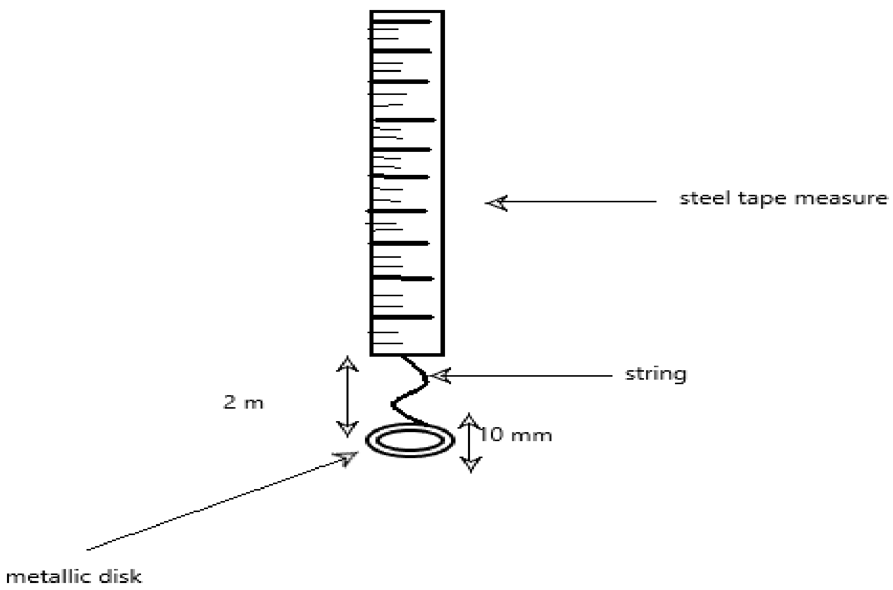


Fig 3.3: Dipping apparatus for DART index experimentation

ii) Procedures

DART field experimentation procedures for observation of a sample size of thirty shallow wells were implemented as below;

1. The list of farmers owning shallow wells was prepared from Lwanda village where thirty shallow wells were picked randomly. These shallow wells were then coded respectively designated by SWL1 to SWL 30. The SWL was an abbreviation of shallow wells of Lwanda village, which were numbered between 1 and 30. These thirty shallow wells were observed for a period of twelve months.

2. The farmers whose wells were randomly picked for study were informed and requested to give consent to participate in the field experiment before it commenced.

3. The shallow wells picked randomly were then assigned a special code number.

4. A dipping apparatus was locally made of 20 meters long steel tape with calibrations attached to 200 mm long bright yellow coloured string tied at the middle of a metallic disc plate with a diameter of 300mm and 10mm to a to make it balance when suspended. This dipping apparatus measured 22.10 meters long. Metallic disc and string prevented steel tape from floating and twisting respectively.

5. A record of diameter r of shallow wells was measured from the entrance.

6. A dipping apparatus was directed inside the well until the metallic disc touched the bottom to measure the current height of each of the thirty wells once at the beginning of the study.

7. The same procedure as in (6.) was repeated for measuring Water Rest Levels monthly for twelve months and water level fluctuations were recorded accordingly.

3.3.3 Data analysis methods for determining effects of rainfall on groundwater use in agricultural production

Different data analysis methods were applied to analyse the results as elaborated below.

3.3.3.1 Correlation Analysis method

The correlation values for different groundwater parameters and rainfall were established using equation (3.1). Correlation analysis assists in establishing the relationship between rainfall and different groundwater variables under the study.

$$\textbf{Correlation } (\boldsymbol{r}) = \frac{\Sigma(\frac{(x-\mu x)}{\sigma x} \times \frac{(y-\mu y)}{\sigma y})}{\boldsymbol{N}} \qquad \textbf{Equation (3.1)}$$

Where;

r is correlation value

X is rainfall variable on x-axis

μ_x is monthly mean rainfall

σ_x is standard deviation of rainfall

Y is groundwater variable on y-axis

μ_y is monthly mean groundwater variable

σ_x is standard deviation of groundwater variable

N is number of months in the year

The correlation values usually range between -1 and +1. The relationship between rainfall and groundwater variables was determined using correlation value denoted by r (Rumsey, 2016). Correlation value ‘r’ indicates the strength of the relationship between variables as well as determining whether the relationship is negative of positive. The positive value indicates that the two variables are both increasing or reducing appropriately. The negative value indicates that when one variable is increasing while the other variable is decreasing. Correlation value of zero indicates that there is no relationship between the two variables in question. The correlation analysis establishes the relationship between variables to inform further analysis such as regression analysis. A significant correlation determines whether it is worthwhile to proceed with developing a regression analysis or not. In the case, there is no relationship between variables then further analysis is not performed to the unrelated variables.

3.3.3.2 Trend analysis for groundwater variables and rainfall

There were two methodologies adopted for trend analysis. They were DART Index Vulnerability analysis and Mann-Kendall Trend Analysis.

a) DART Index Vulnerability Trend analysis

Monthly data of groundwater DART index variables were collected and calculated from January to December 2018.

The DART Vulnerability index was determined using Equation (3.2) (Dennis and Dennis, 2012).

$$\boldsymbol{DART\ Index} = \boldsymbol{D} \times \boldsymbol{ƨA} \times \boldsymbol{R}\breve{e} \times \check{T} \quad \text{.................................} \textbf{Equation (3.2)}$$

Where;

D is Water Rest Level of shallow well

$ƨA$ Is the aquifer storativity

$R\breve{e}$ is Rainfall recharge

$\check{T}$ is Transmissivity

b) Mann-Kendall Trend Test Analysis

The Mann-Kendall test was used to determine whether a time series has a monotonic upward or downward trend within 12 months for groundwater variables and rainfall. The Mann-Kendall Trend Test analyses difference in signs between earlier and later data points. The positive sign shows upward trend and negative sign indicates downward trends. Each successive value is compared to a preceding value in the time series, which gives a total of n (n – 1) / 2 pairs of data, where "n" is the number of observations in the set (Kamal and Pachauri, 2018). S denotes the difference between two values to determine the trend as to whether is downwards or upward trend. S value ranges between +1 and -1. When a successive value is greater than preceding value then the S value is +1 indicating upward trend (S>0). In the case of the downward trend the successive value is smaller than the preceding value with S value being -1 (S<0). When the successive value and preceding value are equal, then there is no trend and (S=0). Mann-Kendall (MK statistic) trend value is the sum of the S values in a dataset within specific time series following Equation (3.3), Equation (3.4), Equation (3.5), Equation (3.6) and Equation (3.7).

$$S= \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(xj - xk)= \begin{pmatrix} +1, \\ 0 \\ -1 \end{pmatrix} \begin{pmatrix} if\ Xk-Xj\ is>0 \\ if\ Xk-Xj\ is=0 \\ if\ Xk-Xj\ is<0 \end{pmatrix}$$ ......**Equation (3.3)**

Where;

S is difference of successive value and preceding value that is either -1, or 0 or +1.

k is the successive value.

j is the preceding value

n is the number of values in a data set

MK=$\sum_{nk}^{nj} s > 0 \sum_{nk}^{nj} s < 0$..**Equation (3.4)**

Where;

MK is the sum of S values in a dataset and Mann-Kendall trend value that is positive or negative to indicate upward or downward trends respectively.

Variance= n (n – 1) / 2 pair .... **Equation (3.5)**

Where;

n is number of observations, for example, there were 12 observations, then variance will be 12 (12 – 1) / 2 = 12(11)/2 = 132/2 = 66.

Z_{MK}Value=$\frac{MKvalue-1\ if\ s>0}{\sqrt{Variance}}$ indicating increasing trend............ **Equation (3.6)**

Z_{MK}Value=$\frac{MKvalue+1\ if\ s<0}{\sqrt{Variance}}$ indicating decreasing trend.......... **Equation (3.7)**

3.3.3.3 Regression analysis method

Regression analysis is a quantitative expression used to establish the nature of relationship between dependent and independent variables after establishing that the two variables are correlated after performing correlation analysis explained above. A single regression model was adopted and model was represented graphically. Climate change and variability shock of seasonal rainfall was independent variable. The groundwater parameters are dependent variables since they depended on rainfall because shallow wells directly benefit from rainfall. Regression analysis determines whether the relationship that exists is linear, logarithmic or exponential. In Equation (3.8) Regression assists in determining the effects of rainfall on groundwater for agricultural production.
Rainfall was on X-axis while water level and volume on Y-axis.

$$\textbf{Regression}\ (\boldsymbol{\gamma_i}) = \boldsymbol{\beta_0} + \boldsymbol{\beta_1 x_i} + \boldsymbol{\varepsilon_i} \qquad \textbf{Equation(3.8)}$$

Where;

Yi is regression that represents the curve function that represents groundwater variable

$\boldsymbol{\beta_0}$ is the intercept of groundwater variable on the y axis

$\boldsymbol{\beta_1}$ is the slope of the function

$\mathbf{X_i}$ **i**s the rainfall variable on the x-axis

ε is a random error

3.3.3.3 Level of Significance analysis

Significance levels are important elements to measure difference among values of a given sample in research. These tests determine whether the evidence found in any sample is strong enough to suggest that the outcome of the results exists in whole zone (Kenney and Keeping, 1962). Level of significance tests were determined for rainfall, groundwater volume, number of shallow wells drying up, water depth, storativity, groundwater recharge, transmissivity, DART index and groundwater use. The variance and standard deviation of the samples were determined using group data of root mean square method (Hoehn and Niven (1985).

a) T-test for Level of Significance

Levels of significance of the variables were tested against t- value of ± 1.363 at 95% confidence interval. There was no significant difference when the calculated t value fell within the set boundaries of ± 1.363 at 95% confidence interval and 11 degree of freedom for 12 number of sample size (Webster,1992; Grimvall and Libiseller, 2002). When the calculated t value was beyond this range then there were significant differences in the values of the sample that reflect in the entire population. The t-test was subjected to rainfall and groundwater variables observed for 12 months in Lwanda village following Equation (3.9).

Calculated t- $_{\text{test}} = \frac{\delta}{\sqrt{n-1}}$................................ **Equation (3.9)**

Where;

δ is group standard deviation

n is number of samples observed which were twelve months

b) Z-test for Level of Significance

Levels of significance of the variables were tested against Z value of ± 1.96 at 95% confidence interval (Webster, 1992). There was no significant difference when the calculated Z value fell within the set boundaries of ± 1.96 Z at 95% confidence interval (Cuo *et al*., 2011). When the calculated Z value was beyond this range then there were significant differences in the values of the sample that reflect in the entire population. The Z test was subjected to shallow well parameters consisting of age and depth of shallow wells for 30 farmers in Lwanda village. Equation (3.10) was applied to calculate Z –value of age, original depth, current depth, diameter and change in depth of thirty shallow wells.

Calculated Z $_{\text{test}} = \frac{\delta}{\sqrt{n}}$................................ **Equation (3.10)**

Where;

δ is group standard deviation

n is number of samples observed which were thirty shallow wells

3.3.4 Data acquisition and analysis methods for assessment of farmer household characteristics, institutional arrangements, access to information and Indigenous Knowledge

There were both primary and secondary data collection and analysis tools employed for the second research objective that is highlighted below.

3.3.4 .1 Secondary data acquisition method

Most of secondary data was acquired online for different government ministries and agency portals. Secondary information was in form of literature reviews of credible government documents. They were the Crops Act of 2013, First Bungoma County Integrated Development Plan of 2013 Water Act of 2016, National Climate Change framework policy of 2016 and Irrigation Act of 2017 that covered institutional arrangement assessment (FBCIDP, 2013; Government of Kenya, 2013; Government of Kenya, 2016a; Government of Kenya, 2016b and Government of Kenya, 2017).

3.3.4.2 Primary data collection methods

Primary data was collected from field studies conducted through farmer household survey, Focus group Discussion and interview with key information informants.

a) Farmer Household survey

A farmer household survey was conducted and data collected from thirty farmers on the type of livestock kept and crops grown to assess groundwater use for agricultural production between 5th January and 20th January 2019 in company of a village elder. Individual farmers were trained and explained in details the objectives of the study on material day. A semi-structured questionnaire was administered to farmer households who owned shallow wells to collect data on various aspects of households. Appendix 1 is a sample of household survey questionnaire.

b) Group Focused Group Discussions (FGDs)

The participants of Focused group discussions were contacted. They were then invited to attend a Focused group discussion meeting on 30th January 2019. This was two weeks after conducting the farmer household survey. The Focus group discussion was planned at this particular time immediately after the farmer household survey had been concluded when farmers' minds were still fresh to recall and capture their ideas. A Focus Group Discussion was held to triangulate collected data from various sources. A Focus Group Discussion involved participants from Ministry of Agriculture, Livestock and Irrigation, farmers, Assistant Chief, representatives from CBOs and private sector on 30th January 2019 at Ekitale Chief Centre. Appendix 2 is a sample of Focused Group discussion schedule.

c) Key information informants' interviews

There were interviews held for Key information informants (KIIs) in both county and National governments to provide information on institutional arrangements provisions on groundwater development for agricultural production. The researcher made appointments with Ministry of agriculture and Ministry of Water to make prior arrangements to carry out the interviews. This prepared the officials in advance to understand the subject matter to enable them provide precise information during the interview time that was guided by the Key information informants interview schedule in appendix 3. The interview was conducted in three days on 5th April 2019 in Bungoma County, 7th November 2019 at Ministry of Water and Irrigation headquarters at Maji House and on 9th November 2019 at Ministry of Agriculture and Livestock at Kilimo House Nairobi.

d) Documentation of story-telling episodes

There were story-telling episodes by local community where indigenous knowledge concerning adaptive capacity during drought was documented accordingly. The best time was in late afternoons when old men met at Ekitale centre to play *Lukho* where they shared freely some traditional indigenous information about cultural norms and practices of local community as they played in turns. There used to be about four to ten persons who met in the afternoons as part of their leisure time.

3.3.4.3 Data analysis for Indigenous knowledge and institutional arrangements

There were various methods applied to analyse descriptive data from farmer household survey questionnaires, Focus Group Discussions, Key information informants and storytelling episodes. These data analysis methods were coding and analysing descriptive data method, document analysis and profile of indigenous knowledge obtained as explained below.

a) Document analysis for institutional arrangements and access to information and Indigenous Knowledge for groundwater development

Secondary data collected from credible documents were reviewed and analysed in tabular form. Secondary data involved review of existing legislations and institutions that govern the management of groundwater for agricultural production. The institutions involved with management of groundwater for agricultural production were profiled that included Agriculture Forest and Fisheries Authority, Bungoma County government irrigation development unit, Water Resource Management Authority, Ministry of Environment and Natural Resources and National Irrigation Development Authority. The Legislations and policy documents that were reviewed were Crops Act, 2013; National climate change framework policy, 2016; Water Act, 2016 and Irrigation Act, 2017 (FBCIDP, 2013; Government of Kenya,2013; Government of Kenya, 2016; GOK Government of Kenya, 2016b; and Government of Kenya, 2017). Their role in governance and management of groundwater was assessed respectively.

b) Profiling access to information and indigenous knowledge for groundwater development

The story telling episodes for Indigenous Knowledge were organised and profiled following alphabetical order of the traditional practices. The local names were expressed in italics in tabular form. The indigenous names given to these practices in local language were included in definitions to assist in interpretation of these terms.

3.3.5 Identification of groundwater technologies and strategies used by smallholder farmers

The groundwater strategies and technologies practised by smallholder farmers were identified through primary and secondary data collection methods described in the 3.3.2, 3.3.3.3 and 3.3.4 above. In addition, personal observations in the field during 24 months of research study were also applied in identifying groundwater strategies and technologies that farmers were using.

Descriptive data obtained from primary source was coded accordingly and analysed using Microsoft Excel worksheet expressed in percentages to describe adoption of groundwater technologies and strategies by smallholder farmers. Descriptive data was profiled and tabulated to illustrate the outcome of the results

3.3.6 Establishment of an Adaptation Action Plan for groundwater use

The primary and secondary data discussed above in sections 3.3.2, 3.3.3, 3. 3. 4 and 3.3.5 described above were all combined to develop an adaptation action plan applicable to Lwanda village community.
Data analysed in 3.3.2 to 3.3.5 above was consolidated and categorized in six strategic interventions during a Focus Group Discussion session held. These interventions were based on shallow well design, licensing of well artisans, groundwater harvesting, control of termite activity, capacity building and training of farmers, stakeholder communication system, and groundwater infrastructure and quality. The information was aggregated and compiled accordingly to develop an Adaptation Action Plan in a tabular format.

3.3.6.1 Schematic illustration of the steps for establishment of an Adaptation Action Plan

An Adaptation Action Plan undergoes four stages of development. During the study there were four steps followed for establishment of an Adaptation Action Plan. The first step was setting up of the objectives that is also known as scoping. The second step involved undertaking assessment of groundwater biophysical and socio-economic vulnerabilities by gathering and analysing diagnostic information. The third step was identification and consolidation of effective interventions and action implementation timelines. The fourth step is that one of listing of main activities and action implementation timelines with responsibility centres, budgets and assigning each activity with outcome or output indicators respectively and creation of awareness of the complete Adaptation Action Plan in Figure 3.4.

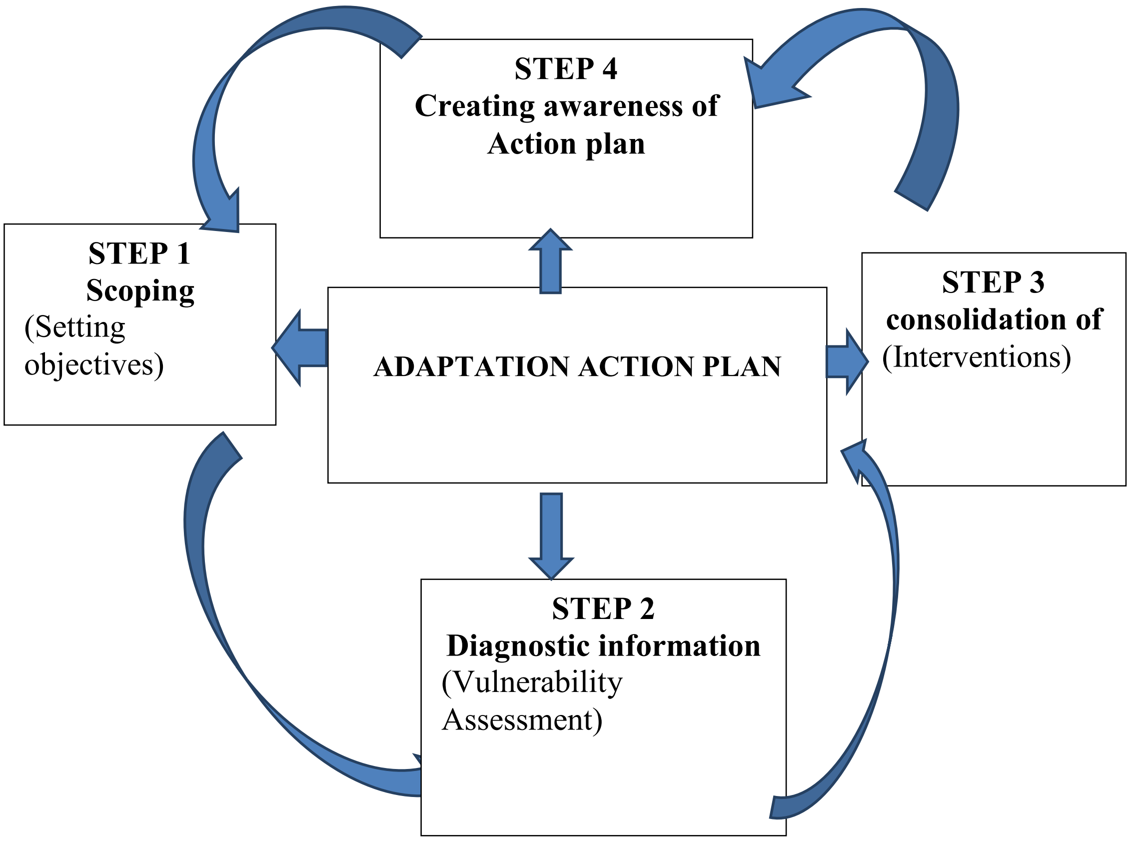


Fig 3.4: Steps for establishing Adaptation Action Plan for groundwater use in agricultural production

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents and discusses the results obtained when various methods outlined were applied to achieve the overall and specific objectives of the study. The results of effects of rainfall on the use of groundwater from shallow wells for agricultural production using DART index are presented and discussed first followed the other three outlined specific objectives.

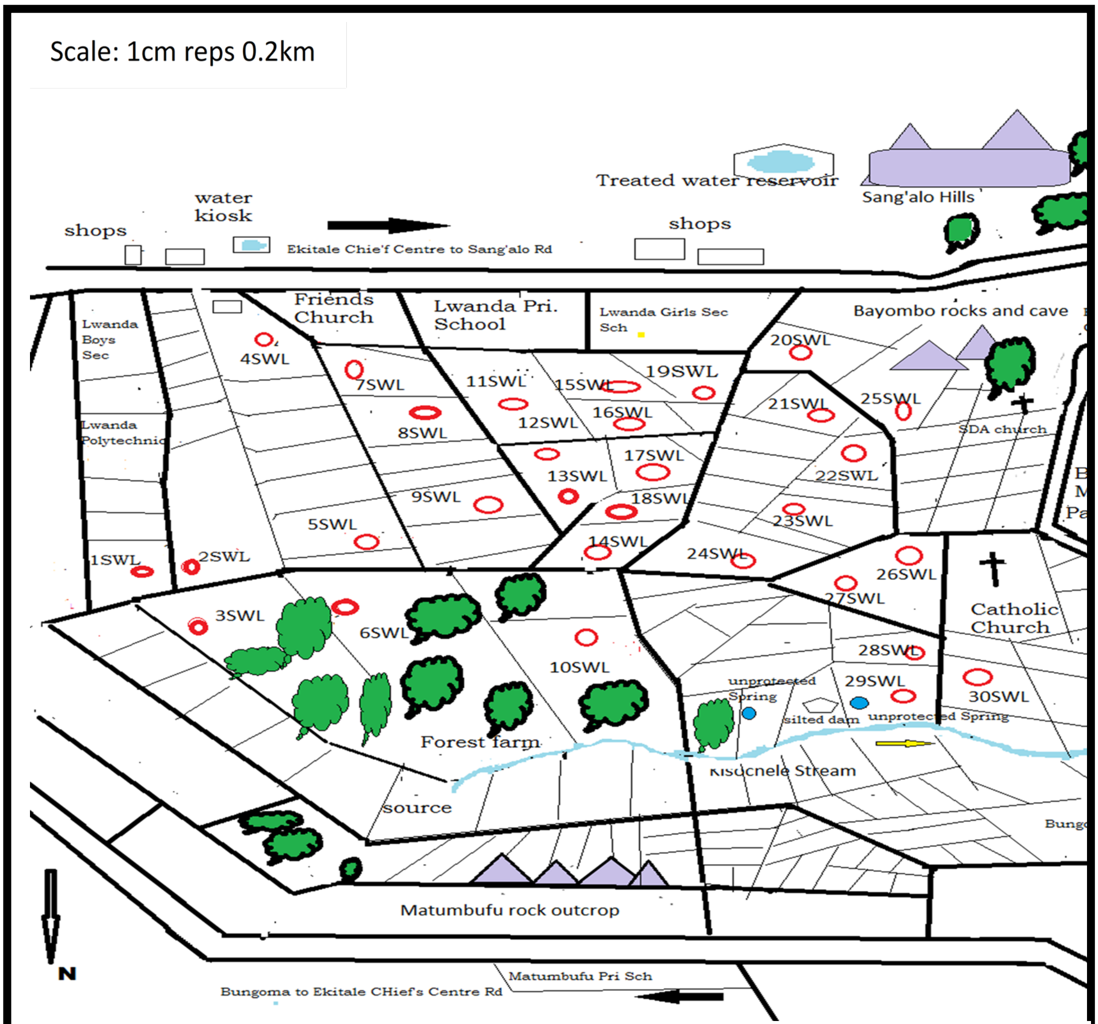
4.2 The effects of rainfall on groundwater use in shallow wells with application of DART Index for agricultural production

4.2.1 Groundwater and Agriculture

This result highlights the current agricultural production situation in the village and the location of thirty shallow wells observed during the study period in relation of other physical features in village.

4.2.1.1 Distribution and particulars of shallow wells in Lwanda village

The relative position of the thirty shallow wells studied in Lwanda village between January 2017 and December 2018 is indicated in Figure 4.1. Shallow wells are an artificial form of unconfined aquifers that are not sandwiched between two impermeable rocks. The crystalline rock outcrops surrounding Lwanda village is evidence of rocky surface beneath limiting shallow well depth between 6.93 to 13.03 metres during excavation to affect groundwater abstraction in Table 4.2 (Jiri, 1993). Shallow wells benefit directly from rainfall and are source of water to confined aquifer to some extent. The particulars of shallow wells included age; original and current depths, change in depth and the diameter of shallow wells in Lwanda village are illustrated in Tables 4.1, 4.2, 4.3, 4.4 and 4.5.



Symbol	Meaning
	Land boundaries
	Foot paths
	Murram roads
L	Shallow wells of Lwanda
	Forests and trees
	Caves, hills and rock outcrops
	Unprotected springs

Fig 4.1: Sketch map of Lwanda village and thirty shallow wells

a) Age of shallow wells in Lwanda Village

The age of shallow wells ranged between 1 year and 40 years when the respective households first dug them in Table 4.1. Majority age of shallow wells was less than eleven years.

Table 4.1 Age of shallow wells in Lwanda village

Age of wells in years	No of wells	Cumulative Frequency	Percentage
1 – 10	19	30	63
11 – 20	6	11	20
21 – 30	3	5	10
31 - 40	2	2	7
Total	**30**		**100**

b) Depths of shallow wells in Lwanda village

The original and current depth of shallow wells in Lwanda village range between 6.1 metres to 14 metres deep in Table 4.2 and Table 4.3. The depth of most shallow wells in Lwanda village was reducing due to sedimentation with only 13% of shallow wells showing increase in current depth (Table 4.4).

Table 4.2 Original depth of wells in Lwanda village

Original Depth of wells in metres	No of wells	Cumulative Frequency	Percentage
6.1-8.0	4	30	13
8.1-10.0	12	26	40
10.1-12.0	8	20	27
12.1-14.0	6	6	20
Total	30		**100**

Table 4.3 Current Depth of wells in Lwanda village

Current Depth of wells in metres	No of wells	Cumulative Frequency	Percentage
6.1-8.0	7	30	23
8.1-10.0	16	23	53
10.1-12.0	5	7	17
12.1-14.0	2	2	7
Total	30		100

Table 4. 4 Difference in depth of current and original depth of shallow wells in Lwanda village

Depth difference ranges in m	Number	Percentage
(-4.51- -5.5)	1	3
(3.51 - -4.5)	2	7
(-2.51- -3.5)	3	10
(-1.51- -2.5)	6	20
(-0.51- -1.5)	12	40
(-0.5- 0.49)	2	7
0.5- 1.5	1	3
1.51-2.5	2	7
(4.51- 5.5)	1	3
Total	30	100

c) Diameter of shallow wells in Lwanda village

Diameter of shallow wells is the dimension to measure the size of the shallow wells from the entrance. Diameter was the measurement that was used to determine the volume of water in each well. The diameter of shallow wells ranged from 0.4 metres to 1m wide at the entrance of the shallow wells. The diameter of shallowest wells fell between 0.6 to 0.79 metres Table 4.5.

Table 4.5 Diameter of shallow wells in Lwanda village

Range of diameter in metres	No of wells	Percentage
0.4-.0.59	8	27
0.6-0.79	11	36
0.8-0.99	8	27
1.0-1.19	3	10
Total	30	**100**

4.2.1.2 Crops and livestock production in Lwanda village

The results in Table 4.6 illustrates types of crops grown by farmer households. The smallholder farmers in Lwanda village grew variety of crops with all households growing maize crop as the staple food and majority of households growing bananas and sugarcane as cash crops. A few farmers grew other crops to include cassava, arrowroots, finger millet, commercial sorghum, coffee and tomatoes. Farmers were also growing commercial trees and Napier grass as pasture for dairy cattle production. The farmers with different varieties of crops that are drought resistant were likely to cope well with adverse climate change impacts of seasonal rainfall.

Table 4.6 Types of crops grown in Lwanda village

Types of Crops	Percentage of farmers
Maize	100.0
Bananas	73.3
Sugarcane	60.0
Beans	50.0
Vegetables	45.7
Commercial Trees	43.3
Napier grass	26.7
Groundnuts	16.7
Fruit trees (Mangoes, Pawpaw & Avocadoes)	16.7
Sweet Potatoes	13.3
Cassava	6.7
Arrow roots	3.3
Commercial Sorghum	3.3
Finger millet	3.3
Tomatoes	3.3
Coffee	3.3

N=30

The results in Table 4.7 illustrates types of livestock kept by farmer households. Majority of households kept indigenous chicken and local cattle breeds but only very few households were engaged in fish farming. The farmers with different kinds of livestock are likely to cope with adverse climate change impacts of seasonal rainfall as they have different water requirements.

Table 4.7 Livestock production in Lwanda village

Type of livestock	Percentage of households
Indigenous chicken	93.3
Local cattle breeds	53.3
Dairy cattle	26.7
Sheep and goats (shoats)	16.7
Fish farming	3.3

N=30; N is number of households surveyed

4.2.1.3 Trend analysis of rainfall in Lwanda village in 2018

The climatic condition of Lwanda village is for the year 2017 and 2018. Monthly rainfall and temperature data collected from Nzoia Sugar Company at Sang'alo weather station and tabulated in Table 4.8. Rainfall amounts were higher in 2018 than that received in 2017 by 332.2 mm. The Month of May was the wettest month in both years while December and February months were the driest months in 2017 and 2018 respectively. The lowest amount of rainfall was experienced in February with 16.6 mm in 2018 compared to the lowest amount of 47.4 mm of rainfall experienced December in 2017. The highest amount of rainfall was 280. 9mm and 486.6mm received in May of 2017 and 2018 respectively. The highest maximum temperatures were experienced in January of 2017 at 32.3^0C and in February of 2018 at 33.1^0C. The lowest minimum temperatures were experienced in December of 2017 at 12.8^0C and in January of 2018 at 12.5^0C. The hottest months with coldest nights also corresponded driest months in the both years. The total annual rainfall was 1638mm and 1970mm in 2017 and 2018 respectively. The mean monthly rainfall was 136.5mm in 2017 and 164.5 mm in 2018.

Mann-Kendall trend analysis indicated an S value of +2 showing an increasing trend of rainfall amount experienced in 2018 in Table 4.9.

Table 4.8 Climatic conditions of Lwanda village in 2017 and 2018

Months	**Rainfall(mm)**		**Maximum Temperatures in° C**		**Minimum Temperatures in °C**	
	2017	**2018**	**2017**	**2018**	**2017**	**2018**
January	67.0	25.0	32.3	29.7	13.8	12.5
February	136.1	16.6	30.8	33.1	13.9	13.8
March	92.0	163.7	29.7	27.2	13.6	13.8
April	204.1	458.4	29.4	26.3	14.0	14.1
May	280.9	486.6	27.4	26.7	14.3	14.7
June	147.4	146.4	27.7	26.5	13.1	14.9
July	73.1	131.3	26.8	26.3	13.1	14.2
August	142.7	117.4	27.0	26.8	13.0	14.5
September	159.0	167.0	27.1	28.5	13.0	13.9
October	169.9	169.5	28.2	28.1	13.5	14.4
November	118.4	55.5	28.0	28.1	13.2	14.4
December	47.4	32.8	30.2	29.4	12.8	14.5
Total	1638.0	1970.2				
Average	136.5	164.2				

Source: Nzoia Sugar Company Limited

Table 4.9 Mann-Kendall trend analysis for rainfall in Lwanda village

Month	Rainfall in mm	S- Values (+1, 0 or -1)												Total
		25	17	164	458	487	146	131	117	167	170	56	33	
Jan	25													
Feb	17	+1												
Mar	164	-1	-1											
Apr	458	-1	-1	-1										
May	487	-1	-1	-1	-1									
Jun	146	-1	-1	+1	+1	+1								
Jul	131	-1	-1	+1	+1	+1	+1							
Aug	117	-1	-1	+1	+1	+1	+1	+1						
Sept	167	-1	-1	-1	+1	+1	-1	-1	-1					
Oct	170	-1	-1	-1	+1	+1	-1	-1	-1	-1				
Nov	56	-1	-1	+1	+1	+1	+1	+1	+1	+1	+1			
Dec	33	-1	-1	+1	+1	+1	+1	+1	+1	+1	+1	+1		
S<0 (-1)		10	10	4	1	0	2	2	2	1	0	0		-32
S=0		0	0	0	0	0	0	0	0	0	0	0		0
S>0(+1)		1	0	5	7	7	4	3	2	2	2	1		+34
MK value														+2
Variance= (n(n-1)/2=66														66
Z $_{MK}$-Value= $\frac{MKvalue-1\ if\ s>0}{\sqrt{Variance}}$ =+2-1/√66=1/8.124														0.25

There was an increasing trend of +0.25 for rainfall in Lwanda village

4.2.2 Result on groundwater vulnerability assessment results

Monthly trend analysis of groundwater DART index variables was done for between January and December 2018 illustrated in Table 4.10. The Ground water DART index variables considered were depth of groundwater in shallow wells, unconfined aquifer storativity, groundwater recharge and transmissivity. Monthly data was collected and computed accordingly for water volume and groundwater use potential. Random factor of 148 was adopted since the village received more than 500 mm annual rainfall. Depth of groundwater ranged between 1.20 and 9.30 metres. Storativity ranged between 0.005 and 0.020. Groundwater recharge ranged between -725 mm and 880 mm. Transmissivity was between 5.20 m^2/d and 38.90 m^2/d. Groundwater volume was between 0.6m^3 and 4.0 m^3. Groundwater use potential per well was maximum at 13,700 m^3 with water shortage of 3,150 m^3 in the driest month. The number of shallow wells that dried up in a month ranged between 2 and 18 out of the thirty shallow wells under the study because of prolonged dry season. These groundwater parameters are what constituted groundwater vulnerability factors. DART index appears positive during April-May-June and September-October when ground water recharge is occurring during long and short rainfall periods respectively.

Table 4.10 DART index and groundwater use in Lwanda village

Month	**Water Volume inm^3**	**Water Rest level or Depth in m**	**No. of dried -up wells**	Storativity	Transm-issivity amount in m^2/day	Rainfall Recharge in mm	DART index	Potential Groundwater use in m^3 per well
Jan	5.70×10^{-1}	1.35	7	4.95×10^{-3}	5.65	-7.20×10^{2}	-7.75	-1.50. $\times10^{2}$
Feb	5.40×10^{-1}	1.25	16	7.75×10^{-3}	5.20	-7.25×10^{2}	-8.40	4.90. $\times10^{3}$
Mar	7.40×10^{-1}	1.95	18	1.25×10^{-2}	8.15	-1.00×10^{2}	-6.65	1.45×10^{3}
Apr	3.50	8.25	0	2.30×10^{-2}	3.45×10^{1}	8.60×10^{2}	1.90	1.25×10^{4}
May	3.70	9.30	0	2.45×10^{-2}	3.90×10^{1}	8.80×10^{2}	2.60	1.40×10^{4}
June	1.90	4.50	0	$1.2.70\times10^{-2}$	1.90×10^{1}	4.25×10^{2}	1.50	6.60×10^{3}
July	1.30	3.10	0	8.80×10^{-3}	1.30×10^{1}	-5.15×10^{2}	-6.05	5. 40x10^{2}
Aug	1.20	2.80	0	7.80×10^{-3}	120×10^{1}	-5.65×10^{2}	-4.80	-3.10×10^{3}
Sept	1.20	2.90	0	8.10×10^{-3}	1.20×10^{1}	1.50×10^{2}	1.40	2. 4010^{2}
Oct	1.30	2.90	0	8.40×10^{-3}	1.20×10^{1}	2.45×10^{2}	2.45	4.10×10^{3}
Nov	8.50×10^{-1}	1.90	2	6.10×10^{-3}	8.00	-6.90×10^{2}	-2.10	-1.50×10^{3}
Dec	6.45×10^{-1}	1.50	4	4.95×10^{-3}	6.10	-7.10×10^{2}	-1.05	-2.10×10^{3}

N=30; Storativity coefficient=0.2; Transmissivity coefficient=4.175M^2/d; Slope 2%; Precipitation coefficient < 500mm=148

4.2.2.1 Trend analysis for groundwater variables in Lwanda village

The Man-Kendall trend analysis values calculated for various groundwater variables were tabulated in Table 4.11, 4.12, 4.13, 4.14, 4.15 and 4.16 established an upward trend except in Table 4.13 and Table 4.14 that indicated a monotonic trend and a decreasing trend respectively.

Table 4.11 Mann-Kendall trend analysis for groundwater volume in Lwanda village

Month	Ground-water volume	S- Values (+1, 0 or -1)											Total
		0.6	0.5	0.7	3.5	3.7	1.9	1.3	1.15	1.2	1.25	0.85	
Jan	0.60												
Feb	0.50	+1											
Mar	0.70	-1	-1										
Apr	3.50	-1	-1	-1									
May	3.70	-1	-1	-1	-1								
Jun	1.90	-1	-1	-1	+1	+1							
Jul	1.30	-1	-1	-1	+1	+1	+1						
Aug	1.15	-1	-1	-1	+1	+1	+1	+1					
Sept	1.20	-1	-1	-1	+1	+1	+1	+1	-1				
Oct	1.25	-1	-1	-1	+1	+1	+1	+1	-1	-1			
Nov	0.85	-1	-1	-1	+1	+1	+1	+1	+1	+1	+1		
Dec	0.60	-1	-1	+1	+1	+1	+1	+1	+1	+1	+1	+1	
S<0 (-1)		10	10	8	1	0	0	0	2	1	0	0	-32
S=0		0	0	0	0	0	0	0	0	0	0	0	0
S>0(+1)		1	0	1	7	7	6	5	2	2	2	1	+34
MK value													+2
Variance= (n(n-1)/2=66													66
Z MK-Value=$\frac{MKvalue-1\ if\ s>0}{\sqrt{Variance}}$ =+2-1/√66=1/8.124													0.25

There was an increasing trend of 0.25 in groundwater volume in Lwanda village.

Table 4.12 Mann-Kendall trend analysis for rainfall recharge in Lwanda village

Month	Rainfall recharg e in m	S- Values (+1, 0 or -1)											Total
		-0.7	-0.7	-0.1	0.85	0.9	0.4	-0.5	-0.55	0.15	0.25	-0.7	
Jan	-0.70												
Feb	-0.70	0											
Mar	-0.10	-1	-1										
Apr	0.85	-1	-1	-1									
May	0.90	-1	-1	-1	-1								
Jun	0.40	-1	-1	-1	+1	+1							
Jul	-0.50	-1	-1	+1	+1	+1	+1						
Aug	-0.55	-1	-1	+1	+1	+1	+1	+1					
Sept	0.15	-1	-1	-1	+1	+1	+1	-1	-1				
Oct	0.25	-1	-1	-1	+1	+1	+1	-1	-1	-1			
Nov	-0.70	-0	0	+1	+1	+1	+1	+1	+1	+1	+1		
Dec	-0.70	0	0	+1	+1	+1	+1	+1	+1	+1	+1	0	
S<0 (-1)		8	8	5	1	0	0	2	2	1	0	0	-27
S=0		3	2	0	0	0	0	0	0	0	0	1	6
S>0(+1)		0	0	4	7	7	6	3	2	2	2	0	+33
MK value													+6
Variance= (n(n-1)/2=66													66
Z_{MK}-Value= $\frac{MKvalue-1\ if\ s>0}{\sqrt{Variance}}$ =+6-1/√66=5/8.124													0.62

There was an increasing trend of +0.62 in rainfall recharge of groundwater in Lwanda village

Table 4.13 Mann-Kendall trend analysis Water Rest Level in Lwanda village

Month	Water Rest Level in metres	S- Values (+1, 0 or -1)											Total
		1.35	1.2	1.9	8.2	9.3	4.5	3.1	2.8	2.9	2.9	1.9	
Jan	1.35												
Feb	1.20	+1											
Mar	1.90	-1	-1										
Apr	8.20	-1	-1	-1									
May	9.30	-1	-1	-1	-1								
Jun	4.50	-1	-1	-1	+1	+1							
Jul	3.10	-1	-1	-1	+1	+1	+1						
Aug	2.80	-1	-1	-1	+1	+1	+1	+1					
Sept	2.90	-1	-1	-1	+1	+1	+1	-1	-1				
Oct	2.90	-1	-1	-1	+1	+1	+1	-1	-1	0			
Nov	1.90	-1	-1	0	+1	+1	+1	+1	+1	+1	+1		
Dec	1.50	-1	-1	+1	+1	+1	+1	+1	+1	+1	+1	+1	
S<0 (-1)		10	10	7	1	0	0	2	2	0	0	0	-32
S=0		0	0	1	0	0	0	0	0	1	0	0	2
S>0(+1)		1	0	1	7	7	6	3	2	2	2	1	+30
MK value													0

There was a monotonic trend in Water Rest Level in Lwanda village.

Table 4.14 Mann-Kendall trend analysis for groundwater DART index in Lwanda village

Month	DART index	S- Values (+1, 0 or -1)											Total
		-7.7	-8.4	-6.65	1.9	2.6	1.5	-6.0	-4.8	1.4	2.4	-2.1	
Jan	-7.70												
Feb	-8.40	+1											
Mar	-6.65	-1	-1										
Apr	1.90	-1	-1	-1									
May	2.60	-1	-1	-1	-1								
Jun	1.50	-1	-1	-1	+1	+1							
Jul	-6.0	-1	-1	-1	+1	+1	+1						
Aug	-4.80	-1	-1	-1	+1	+1	+1	+1					
Sept	1.40	-1	-1	-1	+1	+1	+1	-1	-1				
Oct	2.40	-1	-1	-1	-1	+1	-1	-1	-1	-1			
Nov	-2.10	-1	-1	-1	+1	+1	+1	+1	-1	+1	+1		
Dec	-1.05	-1	-1	-1	+1	+1	+1	+1	-1	+1	+1	-1	
S<0 (-1)		10	10	9	2	0	1	2	4	1	0	1	-40
S=0		0	0	0	0	0	0	0	0	0	0	0	0
S>0(+1)		1	0	0	6	7	5	3	0	2	2	0	+26
MK value													-14
Variance= (n(n-1)/2=66													66
Z MK-Value= $\frac{MKvalue+1\ if\ s<0}{\sqrt{Variance}}$ =-14+1/√66=-13/8.124													-1.60

There was a decreasing trend of -1.60 for groundwater DART index in Lwanda village.

Table 4.15 Mann-Kendall trend analysis for number of shallow wells drying up in Lwanda village

Month	No of dried up of wells	S- Values (+1, 0 or -1)											Total
		7	16	18	0	0	0	0	0	0	0	2	
Jan	7												
Feb	16	-1											
Mar	18	-1	-1										
Apr	0	+1	+1	+1									
May	0	+1	+1	+1	0								
Jun	0	+1	+1	+1	0	0							
Jul	0	+1	+1	+1	0	0	0						
Aug	0	+1	+1	+1	0	0	0	0					
Sept	0	+1	+1	+1	0	0	0	0	0				
Oct	0	+1	+1	+1	0	0	0	0	0	0			
Nov	2	+1	+1	+1	-1	-1	-1	-1	-1	-1	-1		
Dec	4	+1	+1	+1	-1	-1	-1	-1	-1	-1	-1	-1	
S<0 (-1)		2	1	0	2	2	2	2	2	2	2	1	-18
S=0		0	0	0	6	5	4	3	2	1	0	0	21
S>0(+1)		9	9	8	0	0	0	0	0	0	0	0	+26
MK value													+8
Variance= (n(n-1)/2=66													66
Z MK-Value= $\frac{MKvalue-1\ if\ s>0}{\sqrt{Variance}}$ =+8-1/√66=7/8.124													+0.86

There was an increasing trend of +0.860 for shallow wells drying up in Lwanda village.

Table 4.16 Mann-Kendall trend analysis for storativity in Lwanda village

Month	Storativity	S- Values (+1, 0 or -1) in N X 10^{-3} where N is value in Table										Total
		5	7	12	23	24	13	9	8	8	8	
Jan	0.005											
Feb	0.007	-1										
Mar	0.012	-1	-1									
Apr	0.023	-1	-1	-1								
May	0.024	-1	-1	-1	-1							
Jun	0.013	-1	-1	-1	+1	+1						
Jul	0.009	-1	-1	+1	+1	+1	+1					
Aug	0.008	-1	-1	+1	+1	+1	+1	+1				
Sept	0.008	-1	-1	+1	+1	+1	+1	+1	0			
Oct	0.008	-1	-1	+1	+1	+1	+1	+1	0	0		
Nov	0.006	0	+1	+1	+1	+1	+1	+1	+1	+1	+1	
Dec	0.005	0	+1	+1	+1	+1	+1	+1	+1	+1	+1	
S<0 (-1)		9	8	3	1	0	0	0	0	0	0	-21
S=0		2	0	0	0	0	0	0	2	1	0	3
S>0(+1)		0	2	6	7	7	6	5	2	2	2	+40
MK value												+19
Variance= (n(n-1)/2=66												
$Z_{\text{MK Value}}=\frac{MKvalue-1\ if\ s>0}{\sqrt{Variance}}$ =+19-1/√66=18/8.124												+2.22

There was an increasing trend of +2.22 for storativity of groundwater in Lwanda village

Table 4.17 Mann-Kendall trend analysis for Transmissivity in Lwanda village

Month	Transmissivity in m^2/day	S- Values (+1, 0 or -1)											Total
		5.65	5.15	8.1	34	39	19	13	11.6	12	12.2	8	
Jan	5.65												
Feb	5.15	+1											
Mar	8.10	-1	-1										
Apr	34.0	-1	-1	-1									
May	39.0	-1	-1	-1	-1								
Jun	19.0	-1	-1	-1	+1	+1							
Jul	13.0	-1	-1	-1	+1	+1	+1						
Aug	11.60	-1	-1	-1	+1	+1	+1	+1					
Sept	12.0	-1	-1	-1	+1	+1	+1	+1	-1				
Oct	12.20	-1	-1	-1	+1	+1	+1	+1	-1	-1			
Nov	8.0	-1	-1	+1	+1	+1	+1	+1	+1	+1	+1		
Dec	6.10	-1	-1	+1	+1	+1	+1	+1	+1	+1	+1	+1	
S<0 (-1)		10	10	7	1	0	0	0	2	1	0	0	-31
S=0		0	0	0	0	0	0	0	0	0	0	0	0
S>0(+1)		1	0	2	7	7	6	5	2	2	2	1	+35
MK value													+4
Variance= (n(n-1)/2=66													66
$Z_{\text{MK-Value}}=\frac{MKvalue-1\ if\ s>0}{\sqrt{Variance}}$ =+4-1/√66=3/8.124													0.37

There was an increasing trend of +0.37 for transmissivity of groundwater in Lwanda village

Table 4.18 Mann-Kendall trend analysis for groundwater use in Lwanda village

Month	Ground-water use in million litres	S- Values (+1, 0 or -1)											Total
		-1.5	4.9	1.4	12.5	13.7	6.6	0.5	-0.3	4.15	0.25	-1.5	
Jan	-1.50												
Feb	4.90	-1											
Mar	1.40	-1	+1										
Apr	12.50	-1	-1	-1									
May	13.70	-1	-1	-1	-1								
Jun	6.60	-1	-1	-1	+1	+1							
Jul	0.50	-1	+1	+1	+1	+1	+1						
Aug	-0.30	-1	+1	+1	+1	+1	+1	+1					
Sept	4.15	-1	+1	-1	+1	+1	+1	-1	-1				
Oct	0.25	-1	+1	+1	+1	+1	+1	+1	-1	+1			
Nov	-1.50	0	+1	+1	+1	+1	+1	+1	+1	+1	+1		
Dec	-2.10	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	
S<0 (-1)		9	3	4	1	0	0	1	2	0	0	0	-20
S=0		1	0	0	0	0	0	0	0	0	0	0	1
S>0(+1)		1	7	5	7	7	6	4	2	3	2	1	+45
MK value													+25
1.Variance= (n(n-1)/2=66													66
Z $_{MK}$-Value= $\frac{MKvalue-1\ if\ s>0}{\sqrt{Variance}}$ =+25-1/√66=24/8.124													2.95

There was an increasing trend of +2.95 for groundwater use in Lwanda village

4.2.2.2 Relationship between rainfall and groundwater variables

The correlation value calculated for various groundwater variables were tabulated in Table 4.19. There was a positive correlation between rainfall and groundwater variables except number of shallow wells drying up which depicted a negative correlation coefficient.

The negative relationship is depicted by the downward trend while the positive relationship is depicted by uphill trend on the scatter graphs indicated in Figures 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8 and 4.9 respectively. Negative relationship meant that when rainfall was increasing the other variable was decreasing instead. On the other hand, a positive relationship meant that when rainfall was increasing the other variable was also increasing proportionately.

Table 4.19 Correlation value for groundwater variables and rainfall in Lwanda village

Groundwater and shallow well variables	Correlation value (r)
DART index	0.53
Groundwater use	0.84
Groundwater recharge	0.90
Storativity	0.95
Groundwater volume	0.96
Water Rest Level	0.96
Transmissivity	0.97
No. of dried-up shallow well	-0.58
Age of shallow wells	0

N=30

N is number of shallow wells observed

a) Rainfall and groundwater volume

There was a positive exponential relationship between rainfall and groundwater volume in shallow wells indicated in Figure 4.2. Initially there was slow increase in groundwater volume but increased rapidly with increase in rainfall (Allen *et al*., 2006; Kerandi and Omotosho, 2008; Egeru *et al*., 2014; Hein *et al*., 2014; Francis *et al*., 2014; Behrangi *et al*., 2016).

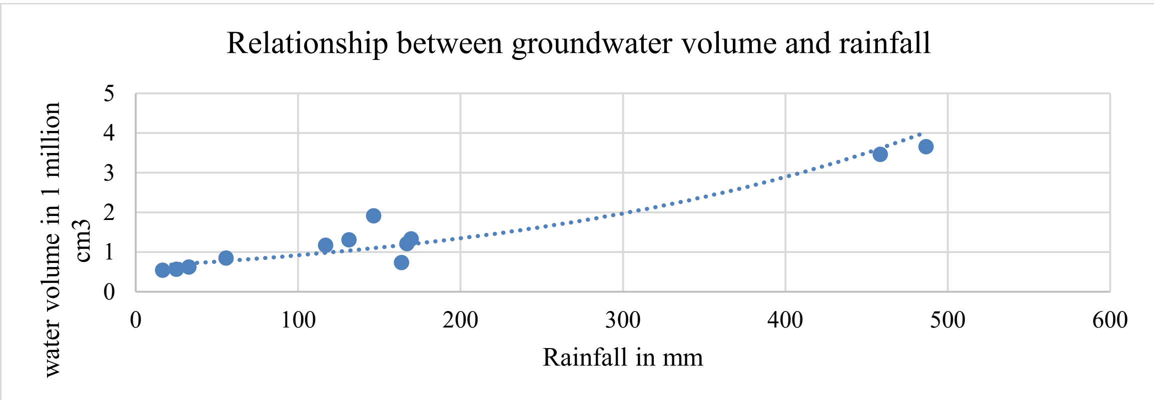


Fig 4.2: A positive exponential relationship between rainfall and water volume in shallow wells

b) Rainfall and Water Rest Level

There was a positive exponential relationship between rainfall and Water Rest Level in shallow wells indicated in Figure 4.3. Initially there was slow increase in Water Rest Level but it increased rapidly with increase in rainfall.

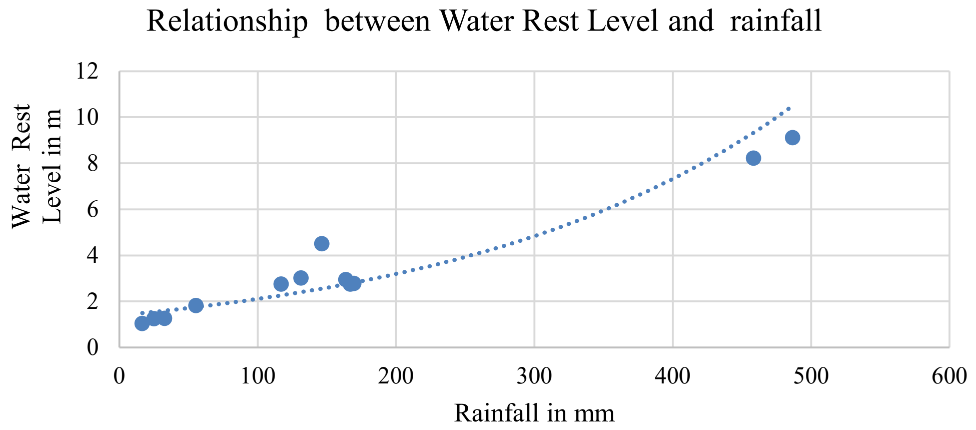


Fig 4.3: A positive exponential relationship between Water Rest Level and rainfall

c) Groundwater Recharge and Rainfall

The groundwater recharge was on the y-axis that depended on the amount of rainfall on the x-axis. The increase in groundwater recharge is logarithmic with the tip of the curve levelling off indicating that groundwater recharge has a saturation point and it could not increase further even when rainfall increased in Figure 4.4.

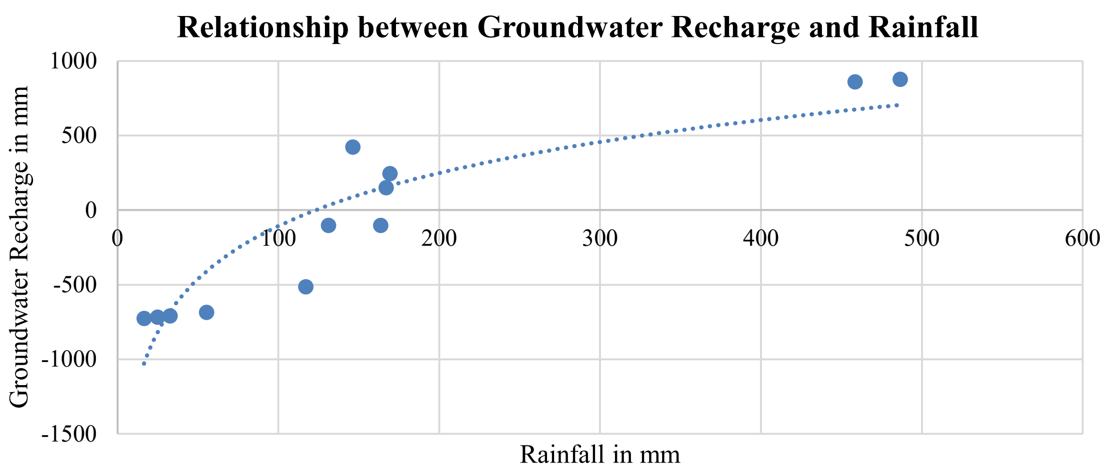


Fig 4.4: A Logarithmic positive relationship between groundwater recharge and rainfall

d) Rainfall and Transmissivity

The transmissivity was on the Y-axis as it depended on the amount of rainfall that was on the X-axis. The transmissivity increased linearly with increase for rainfall. There was a strong positive relationship between rainfall and transmissivity that is depicted by the uphill trend on the scatter graph indicated in Figure 4.5. The tip of the transmissivity curve was increasing linearly indicating transmissivity has capacity to increase further with increased amount of rainfall. This is close to a perfect positive linear relationship.

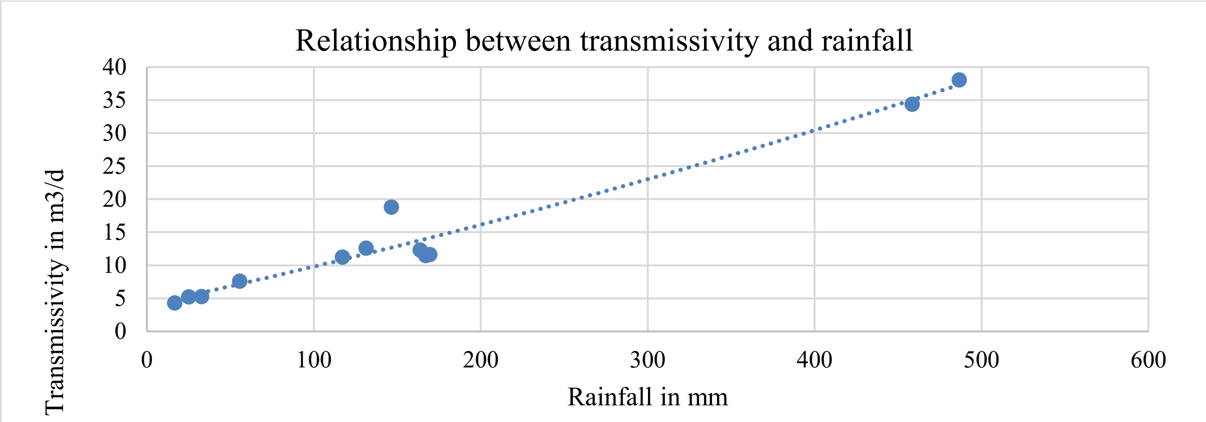


Fig 4.5: A positive linear relationship between transmissivity and rainfall

e) Rainfall and Storativity

The Storativity was on the Y-axis as it depended on the amount of rainfall that was on the X-axis. The Storativity increased with increase for rainfall. This relationship is depicted by the uphill trend on the scatter graph indicated in Figure 4.6. The tip of the storativity curve was increasing linearly but slowly indicating the capacity of storativity was approaching its maximum when further increase cannot be achieved even though rainfall amounts increased because of inherent unconfined aquifer property characteristics.

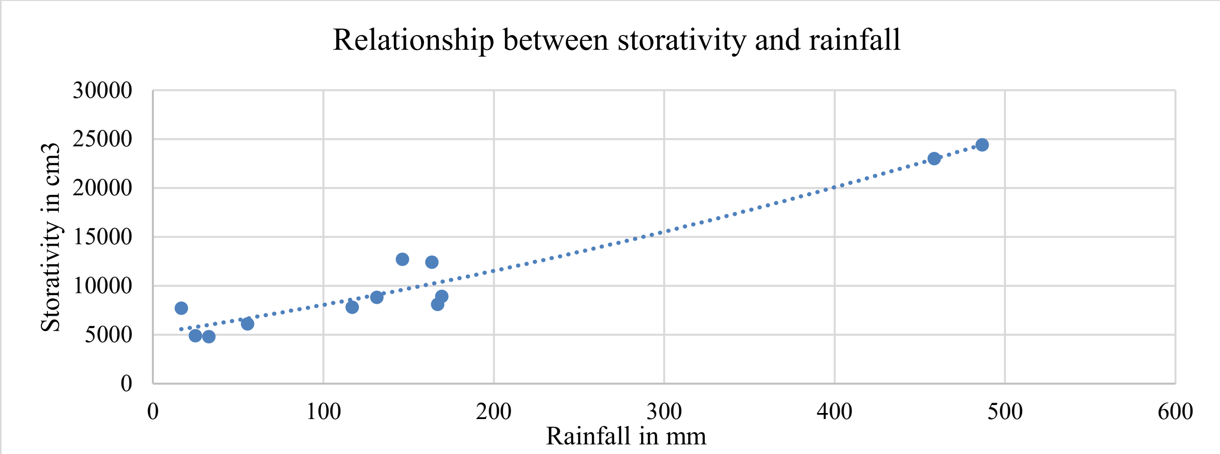


Fig 4.6: A positive linear relationship between rainfall and storativity

f) Rainfall and DART index

The DART index was on the Y-axis as it depended on the amount of rainfall that was on the X-axis. The DART index values increased with increase for rainfall that is depicted by the upward trend on the scatter graph indicated in Figure 4.7. The increase in DART index was gradual with low amount of rainfall but it increased logarithmically when rainfall was at the peak. The tip of the curve was levelling off indicating that DART Index has a saturation point and it could not increase further even when rainfall increased due to limiting factors of recharge and storativity mentioned above.

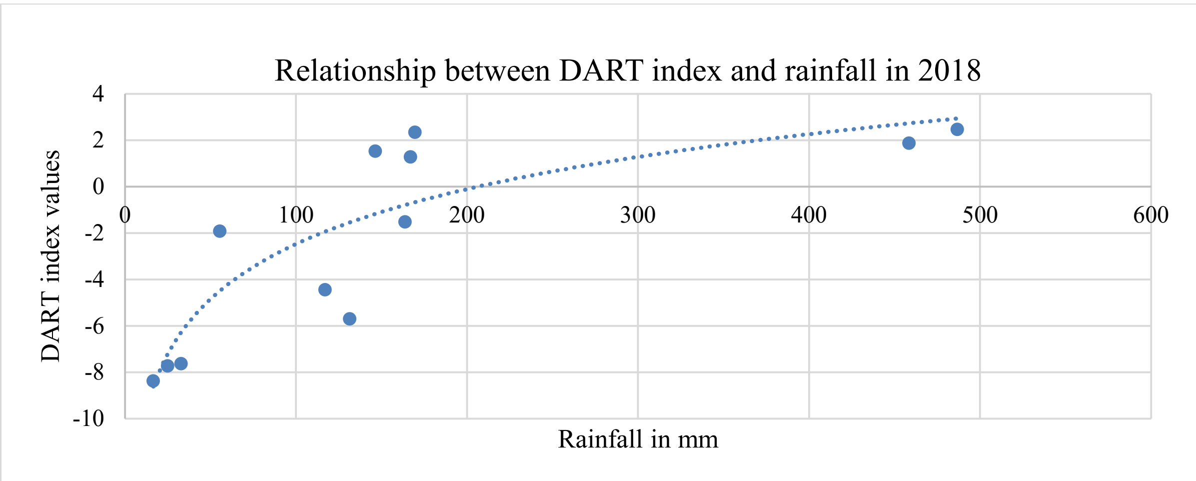


Fig 4.7: A positive logarithmic relationship between rainfall and DART-Index

g) Rainfall and groundwater use

The groundwater use parameter was on the Y-axis as it depended on the amount of rainfall that was on the X-axis. The potential groundwater for agricultural use increased with increase in rainfall when water was readily available. There was a positive linear relationship between rainfall and potential groundwater use that is depicted by the upward trend on the scatter graph indicated in Figure 4.8.

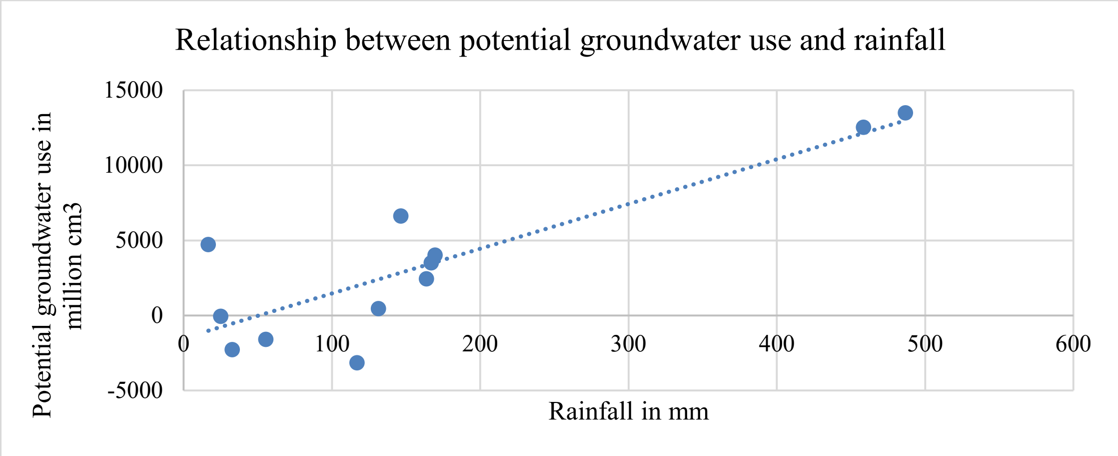


Fig 4.8: A positive linear relationship between groundwater use and rainfall

h) Rainfall and drying up of shallow wells

Number of shallow wells drying up was on the Y-axis as it depended on the amount of rainfall that was on the X-axis. The number of shallow wells increased with decrease for rainfall in Figure 4.9. This implies that more than a half of the shallow wells risk drying up annually due to fluctuation in rainfall in the village.

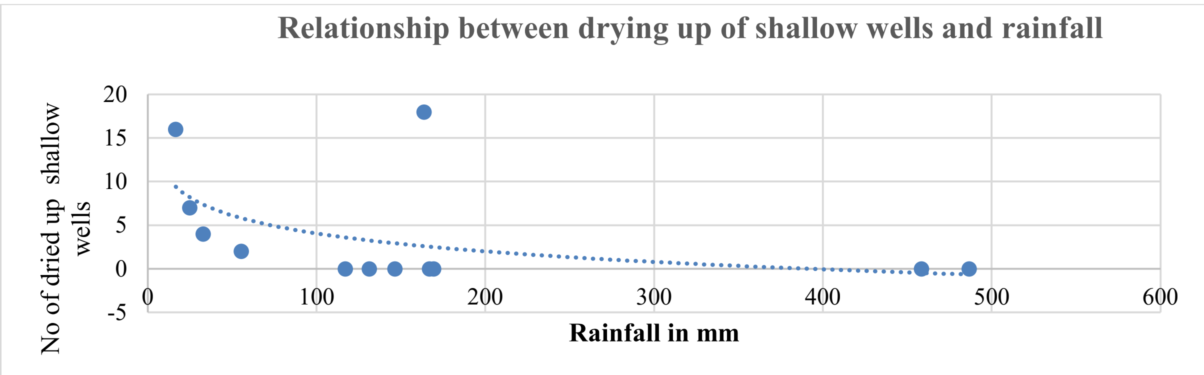


Fig 4.9: A negative logarithmic relationship between drying up of shallow wells and rainfall

4.2.2.3 Testing for level of significance for rainfall and groundwater variables

a) Testing of level of significance using t-test

The Mann-Kendall trends for rainfall and groundwater variables were subjected to t- testing for level of significance at 95% confidence interval with 12 months representing the degree of freedom (n-1). When the MK-value for the trend falls outside the range of t- value of ±1.363 at 95% confidence interval at 11 degree of freedom then the value is significant and is marked with one star (*). When MK-value was within the range of t-value ±1.363 (-1.363 ≤ t ≥ 1.363 at 95% confidence interval of 11 degree of freedom then the MK value for the trend was Non- Significant (^{NS}). Table 4.20 has indicated the level of significance for rainfall and groundwater variables. The results in Table 4.20 show that the trends of most groundwater variables were Non-Significant except for Groundwater DART Index, Groundwater use and Storativity had significant difference. Groundwater DART index was the only variable with a significant downward trend and Groundwater use and Storativity had significant upward trend.

Table 4.20 T-Test for level of significance for groundwater variables and rainfall in Lwanda village

Experimental variables	MK-Value	Trend Type	The level of Significance at 0.05 at 11 degree of freedom (n-1)		MK value after t-test
Groundwater DART index	-1.60	Downward	±1.363	Significant trend	-1.60^{*}
Potential groundwater use	+2.95	Upward	±1.363	Significant trend	2.95*
Groundwater volume	+0.25	Upward	±1.363	Non-Significant trend	0.25^{NS}
Number of dried-up wells	+0.86	Upward	±1.363	Non-Significant trend	0.86^{NS}
Rainfall amount	+0.25	Upward	±1.363	Non-Significant trend	0.25^{NS}
Rainfall recharge	+0.62	Upward	±1.363	Non-Significant trend	0.62^{NS}
Storativity	+2.22	Upward	±1.363	Significant trend	2.22*
Transmissivity	+0.37	Upward	±1.363	Non-Significant trend	0.37^{NS}

c) Testing level of significance using Z-test of group data for shallow well particulars

The shallow well particulars comprising of age, depths and diameter were tested using Z-test at 95% confidence interval in Table 4.21, 4.22, 4.23 and 4.24. There was no significant difference in diameter, original and current depth and diameter of the shallow wells but there was significant difference in change in original depth due to sedimentation. Sedimentation affects availability of water in shallow wells.

Table 4.21 Statistical values of Original Depth of shallow wells

Class Range	Mid – point (x)	Frequency (f)	fx	D=(x-μ)	f(x-μ)	$f(x-\mu)^2$
6.1-8.0	7.05	4	28.2	-3.34	-13.36	178.50
8.1-10.0	9.05	12	126.7	-1.34	-16.08	258.60
10.1-12.0	11.05	8	88.4	0.66	5.28	27.90
12.1-14.0	13.05	6	78.3	2.66	15.96	254.70
Total		30				**719.70**
Mean (μ)						**10.40**
Variance (s^2)						**67.50**
Standard deviation (δ)						**8.20**
$Z_{test} = \frac{\delta}{\sqrt{n}}$						**1.50^{NS}**

Table 4.22 Statistical values of current depth of shallow wells in Lwanda village

Class Range	Mid –point (x)	Frequency (f)	fx	D=(x-μ)	f(x-μ)
6.1-8.0	7.05	7	-2.21	-15.47	239.30
8.1-10.0	9.05	16	-0.21	-3.36	11.30
10.1-12.0	11.05	5	1.79	8.95	80.10
12.1-14.0	13.05	2	3.79	7.58	57.45
Total		**30**			**388.20**
Mean (μ)					9.25
Variance (s^2)					41.90
Standard deviation (δ)					6.45
$Z_{test} = \frac{\delta}{\sqrt{n}}$					1.18^{NS}

Table 4.23 Statistical values of difference in depth of between current and original depth of shallow wells

Class Range	Mid –point (x)	Frequency (f)	F(x)	D=(x-μ)	f(x-μ)
(-4.51- -5.5)	-5.01	1	-3.82	-3.82	14.60
(3.51 - -4.5)	-4.01	2	-2.82	-5.64	31.80
(-2.51- -3.5)	-3.01	3	-1.82	-5.46	29.80
(-1.51- -2.5)	-2.01	6	-0.82	-4.92	24.20
(-0.51- -1.5)	-1.01	11	0.18	1.98	3.90
(-0.5- 0.49)	0.01	4	1.2	4.8	23.00
0.5- 1.5	1.01	1	2.2	2.2	4.80
1.51-2.5	2.01	2	3.2	6.4	40.95
Total		30			173.20
Mean (μ)					-1.20
Variance (s^2)					-150
Standard deviation (δ)					12.10
$Z_{test} = \frac{\delta}{\sqrt{n}}$					2.2*

*Indicates significant difference.

Table 4.24 Statistical values of diameter of Shallow wells in Lwanda village

Class Range in m	Mid – point (x)	Frequency (f)	fx	D=(x-μ)	f(x-μ)	$f(x-\mu)^2$
0.4-.0.59	0.495	8	3.96	-0.215	-1.72	2.9580
0.6-0.79	0.695	10	6.95	-0.015	-0.15	0.0225
0.8-0.99	0.895	9	8.055	0.185	1.665	2.7720
1.0-1.19	1.095	3	3.285	0.385	1.155	1.3340
Total		30				7.0870
Mean (μ)						**0.710**
Variance (s^2)						**9.980**
Standard deviation (δ)						**3.15**
$Z_{test} = \frac{\delta}{\sqrt{n}}$						**0.105**^{NS}

4.3 Results on effects of farmer household characteristics, institutional arrangements, access to information and Indigenous Knowledge on development of shallow wells for groundwater supply for agricultural production

The results on social vulnerability traits are those factors that are people driven that affect development and management of groundwater to promote agricultural production at household level. These traits are farmer household characteristics, Institutional arrangements, indigenous knowledge and access to agricultural and weather information that are covered in subsection 4.3.1 to 4.3.4.

4.3.1 Results on effects of farmer household characteristics on development of shallow wells for water supply for agricultural development

The results of farmer household characteristics comprised of Age of Head of Households, Education level, income, shallow wells water user's household and land size described in the following Tables 4.25, 4.26, 4.27, 4.28, 4.29 and 4.28.

4.3.1.1 Age and gender of Head of Households of Lwanda village

Farmer household survey conducted revealed that fifty three percent of heads of farmer households were above 56 years old with very few youthful heads of households between 18 and 35years accounting for 7%. Eighty seven percent of farmer households were male headed. Women and widowed headed households were the minority and more vulnerable stipulated in Table 4.25.

Table 4.25 Age and gender of Head of Households

Description of attributes	**Household Head characteristics**							
Age and marital status	18-35 years	36-45 years	46-55 years	Above 56 years	Female	Male	Single	Married
Percentage	7	17	23	53	86.7	13.3	16	84

N=30

4.3.1. 2 Education levels of Head of Households in Lwanda village

Ninety seven percent of farmer household heads have attended formal education that enhanced their capacity to be trained as indicated in Table 4.26.

Table 4.26 Education levels of Head of Households in Lwanda village

Description of Household Head Education levels	**Education level of Head of Household**					**Total**
	Basic Education	**Primary Education**	**Secondary Education**	**Tertiary Education**	**University Education**	
Percentage	3	23	17	47	10	100

N=30

4.3.1.3 Farmer household size in Lwanda village

Fifty four percent of households had a household size of between 5 and 8 members being the majority but three percent of households comprised of more than12 members as illustrated in Table 4.27.

Table 4.27 Farmer household size in Lwanda village

Farmer Household size category	**Percentage (%)**
1 and 4 members	10
Between 5 and 8 Members	54
Between 9 and 12 members	33
Above 12 members	3
Total	100

N=30

4.3.1.4 Farmer household income in Lwanda village

Majority of households were living below poverty level of one dollar per day with a total annual income of less than Ksh160, 000 for a household of eight members with various income sources as illustrated in Table 4.28. Most households had multiple sources of income except for 26.7% of households with only one source of income making these households vulnerable. Farming was the main source of income for the local community comprising of 48%.

Table 4.28 Farmer household income in Lwanda village

Farmer Household income descriptions		**Percentage**
1. Income sources	Preaching	2
	Well digging	2
	Casual jobs	2
	Donations	6
	Pensions	6
	Teaching	8
	Trading	8
	Permanent employment	18
	Farming	48
Total		100
2. Number of income sources		
	Single income source	26.7
	Two sources of income	60
	Multiple income sources	13.3
Total		100
3. Household annual income	Less than Kshs 40,000	20
	Between Kshs 40,001 and 80,000	6.7
	Between Kshs 80,001 and120,000	26.7
	Between Ksh120,001 and 160,000	13.3
	Above Kshs160,000	33.3
Total		100

4.3.1.5 Farmer household land size in Lwanda village

Eighty eight percent of farmer household land sizes were below 10 acres and only 12 % of farmers could be categorized as large-scale farmers described in Table 4.29.

Table 4.29 Average Farmer Household land size in Lwanda village

Farmer Household land size category	Below 2.5 acres	Between 2.6 and 5 acres	Between 5.1 and 7.5 acres	Between 7.6 and 10 acres	Above 10 acres	Total Percent
Percentage (%)	53	19	3	13	12	100

N=30

4.3.1.6 Shallow well water users in Lwanda village

There were households sharing groundwater from a single shallow well apart from the owners. Majority of households using water from a single well were less than five households indicated in Table 4.30.

Table 4.30 Average number of households using water from one well in Lwanda village

Household well water users	**Percentage (%)**
Between 1 and 4 households	67
Between 5 and 8 households	20
Between 9 and 12 households	10
Above 12 households	3
Total	100

N=30

4.3.2 Results on effects of Institutional arrangements on development of shallow wells for groundwater supply for agricultural development

The institutional arrangements were the relevant legislations in respect to governance of groundwater development and management reviewed in terms of when they were enacted, the responsible institutions charged with their implementation and the purpose of these public statutes. All of the legislations reviewed after promulgation of the new Constitution of Kenya in 2010. There were five legislations, policy documents reviewed that guide development, and management of groundwater summarised in Table 4.31.

Table 4.31 Institutional arrangements for groundwater use for agricultural production

Name of legislation	Year of enactment	Institution established	Purpose
1.Crops Act	2013	Agriculture Forest and Fisheries Authority	It provided a framework for formation and registration of farmer groups to improve access to agricultural information and extension services.
2.FBCIDP	2013	County government irrigation development unit	For development and execution of county irrigation strategy at county level
3.Water Act	2016	Water Resource Management Authority	It provided for acquisition and regulation of rights to use water for effective management of water supply
4.National climate change framework policy	2016	Ministry of Environment and Natural Resources	For mainstreaming of climate change adaptation and mitigation initiatives for management of GHG emission inventory.
5.Irrigation Act	2017	National Irrigation Development Authority	It promotes and regulates the development and management, financing and providing support services of irrigation sub sector.

4.3.3 Results on effects of Indigenous knowledge and development of shallow wells for groundwater supply for agricultural production

The Indigenous Knowledge gathered included indigenous interventions and cultural practices that were applied by *Bukusu* people as the majority of the local community to improve food security during drought season to cope with negative impact of climate change. Traditional practices described in Table 4.32 below consisted of various foodstuffs preserved like cheese, beef, mushrooms, insects and dried vegetables. The practice of growing various drought resistant indigenous vegetables, meat sharing norms, traditional early warning and information systems and other festivities were important aspects of climate change adaptation by local community.

Table 4.32 Indigenous interventions to cope with Climate Change impacts

1.Boiled and dried animal blood mixed with bile *(kamalasile*)
2. Composing songs with climate change adaptation messages to be sang during festivals (*kimibayo*)
3.Drawing fresh blood from cattle *(khujala chikhafu*) to mix with vegetables to improve nutrition of children
4.Dried insects especially white ants (*chiswa*), larva (*chikhunngu* and *kamasibili*) for fat and proteins
5.Dried mushrooms (*bubwoba)* especially *bukusuma* and *bukochwe* (giant variety of mushrooms)
6.Dried traditional vegetables especially (*chinyenyi, chinunga*), simsim (*chikhanu*), green grams (*chibalayo*) and nuts (*chibande*) to make a pudding *(sifuluko*)
7.Early warning of climate change impacts (*kukhupakumulasi*)
8.Making traditional cheese (*libonda)* to provide proteins and vitamins from milk
9.Planting drought resistant vegetables *like kimiro, sikanyanganya, murunde, sitipa, murere, endelema and namasaka*
10.Preserving mineral rich soils (*silongo)* to serve as salt licks for livestock during dry season
11. Slaughtering cattle and sharing meat *(enyamaya nemwesinya)* among local community for the members to payback in kind when they harvest their crop.
12.Smoked beef (*kumuranda*) and cattle feet *(bilenge)* to be used to supply proteins to children during dry season
13. *Kamakhalange* was drying of local brew to cater for later use during the dry season when there were no cereals for fermentation
14.Smoking of large birds (*kamakhunyi*) which used to come to the village in hundreds before rains

4.3.4 Results on effects of access to agricultural and weather information on development of shallow wells for groundwater supply for agricultural production

Results revealed that majority of smallholder farmers accessed agricultural and weather information that constituted 67% and 60% respectively in Table 4.33 and Table 4.34. Most of farmers were putting in practise the agricultural information accessed with only twenty percent not applying it. On the other hand, very few farmers constituting 17% were using the weather information they accessed due to complexity of the information received. Non-Governmental Organizations were the most popular sources of agricultural information to farmers with 33% followed by private sectors at 27%, the government at 23% and fellow farmers at 17% as indicated in Table 4.33. Radio was the most common source of weather information with 27% respondents followed by newspapers at 17% and Television with 16%.

4.3.4.1 Farmers access to agricultural information in Lwanda village

Table 4.33 Agricultural information sources, access and application for farmers in Lwanda village

Description of agricultural information sources, access and application		Percentage
1. Sources of agricultural information	Fellow farmers	17
	Ministry of Agriculture and Livestock	23
	Non -Governmental Organizations	33
	Private sector	27
Total		100
2. Access to agricultural information	Farmers who have accessed agricultural information	67
	Farmers who have **never** accessed agricultural information	33
Total		100
3. Application of agricultural information	Farmers who applied agricultural information accessed	80
Total	Farmers who did **Not** apply agricultural information accessed	20
4. TOTAL		100

N=30

4.3.4.2 Source of Weather information

There are various sources of weather information as illustrated in Table 4.34.

Table 4.34 Sources of Weather information for farmers of Lwanda village

Weather information sources, access and application descriptions		Percentage
1. Sources of Agricultural information	From Chief's Baraza and public forums like funerals	33
	Farmers accessing weather information from radio	27
	Farmers accessing weather information from newspapers	17
	Farmers accessing weather information from Television	16
	Informal and unverified sources (fellow farmers, pupils and students, village hearsays and gossip)	7
Total		100
2. Access to formal weather information	Farmers who have accessed weather information	60
	Farmers who have accessed weather information from unverified sources	40
Total		100
3. Application of weather information	Farmers who applied weather information accessed	17
Total	Farmers who did **Not** apply weather information accessed	83
Total		100

4.3.4.3 Level of public awareness on Climate change concept

The results revealed that the Lwanda local community were general aware about climate change based on their perception about the causes of drying up of the shallow wells. There was a difference in respondents during individual farmer survey and at Focus Group Discussion. Majority of farmers in both farmer household survey and Focus Group Discussion indicated that Climate Change was the cause of drying up of shallow wells during prolonged dry season with 40% and 34% respectively. The other causes of drying up of shallow wells perceived by farmers were sedimentation, termite activities, lack of financing to drill wells, poor workmanship and a shift in groundwater pathway indicated in Table 4.35.

Table 4.35 Peoples' perception on causes of drying up of shallow wells in Lwanda village

Peoples' Perception on causes of drying up of shallow wells	Climate change impacts	sedimentation	Ant hill construction by termites	Shift in groundwater pathway	Lack of financing to drill wells	Poor workmanship
Percentage in survey	40	30	23	7	N/A	N/A
Percentage in FGD	34	23	N/A	N/A	31	12

Farmer survey N=30   FGD N=35

4.4 Results for identification of climate change adaptation strategies and technologies for groundwater use for agricultural production

The results highlighted various strategies and technologies that farmers have employed to abstract groundwater. Strategies and technologies employed are either groundwater development and supply technologies. Groundwater development strategies and technologies are all those that are geared towards drilling of shallow wells, abstraction and storage of groundwater. Groundwater supply strategies and technologies are employed to distribute and utilization of groundwater for both crop and livestock production. The results also underlined some strategies to improve groundwater management to address capacity building, enhance groundwater benefits while solving challenges.

4.4.1 Result on groundwater strategies and technologies

The results described in Table 4.36 revealed that all shallow wells were developed manually with majority of farmers comprising of 94% drawing water using bucket and rope. A few of farmer consisting of 6% were using water pumps and external overhead storage tanks. Ninety-three and forty-three percent of farmers were using portable drinking troughs to water livestock and irrigate tree and vegetable nurseries. Farmers did not have a standard irrigation regime but they employed different irrigation regimes with 33% and 10% irrigating daily and after 2 days respectively. Farmers also had different irrigation timing with 40% irrigating crops in the morning and afternoon but very few farmers consisting of 3% irrigated crops once in the morning only.

Table 4.36 Groundwater strategies and technologies used in Lwanda village

Activity description	Groundwater strategies and technologies	Percentage
1. Manner of groundwater development	Mechanical drilling of shallow wells	0
	Manual excavation of shallow wells	100
Total		100
2. Ways of drawing water from shallow wells	Bucket and rope	94
	Claw bar	0
	winch	0
	Hand pump	3
	Electric pump	3
Total		100
3. Livestock water facilities	Stationery drinking troughs	7
	Portable drinking troughs	93
Total		100
4. Irrigation of crops and tree nurseries	Farmers irrigating tree and vegetable nurseries	43
	Farmers not carrying out irrigation	57
Total		100
5. Irrigation facilities	Irrigation using water buckets	23
	Irrigation using watering cans	13
	Sprinkle irrigation	7
	No irrigation	57
Total		100
6. Irrigation regime	Farmers irrigating crops daily	33
	Farmer irrigating crops after 2 days	10
	Farmers irrigating crops in the morning and afternoon	40
	Farmers irrigating crops in the morning only	3
Total		100
7. Groundwater storage facilities	Farmers with overhead storage tanks	6
	Farmers without storage tanks	94
Total		100

4.4.2 Identification of capacity building areas for groundwater strategies and technologies

A focus group discussion held to identified capacity-building areas after pointing out groundwater benefits and challenges. This was done to improve groundwater management to cope with climate change impacts.

4.4.2.1 Groundwater benefits of Lwanda village

The participants stated benefits of groundwater with most of them consisting of 34% identifying near to point of source and use followed by easy accessibility in remote areas with 31%. The other benefits cited were below 20% as indicated in Table 4.37 comprising of relatively cheap source of water with low investment, operation & maintenance, eco-friendly and good quality water source and requiring less quantum of users for development with 16%, 10% and 9% respectively.

Table 4.37 Benefits of groundwater use for agricultural production in Lwanda village

Description of groundwater benefits	Percentage
Near point of source and use	34
Easily accessed by local community residing in remote areas	31
Relatively cheap source of water with low investment, operation & maintenance	16
Eco-friendly and good quality water source	10
Require less quantum of users for development	9

N=35 FGD

4.4.2.2 Challenges of groundwater use for agricultural production

Twenty seven percent of the FGD participants indicated low water volume at peak water demand during prolonged dry season was the major challenge in development of groundwater followed by exorbitant labour charges and poor workmanship with 24%; anticipated prohibitive legislation to implement high water bills was cited by 21% participants. The other challenges that limited groundwater development were high risk of not finding water by untrained artisans and poor water quality resulting from pollution of water source that is localized with 14% each in Table 4.38.

Table 4.38 Challenges of groundwater extraction from shallow wells

Description of challenges of groundwater extraction from shallow wells	Percentage
Exorbitant labour charges and poor workmanship	24
Anticipated prohibitive legislation to implement high water bills	21
Low water volume at peak water demand during prolonged dry season	27
High risk of not finding water by untrained artisans	14
Poor water quality resulting from pollution of water source that is localized	14

N=35 FGD

4.4.2.3 Improvement of groundwater strategies and technologies

The Focus group discussion cited improvements of strategies and technologies to enhance groundwater management to address challenges and strengthen the realisation of benefits indicated in Table 4.39. 21.7 % of FGD participants preferred improvement in external water storage facilities followed by 19.2% who identified training and licensing of groundwater artisans. Other improvements that participants of FGD suggested were creation of public awareness for registration of groundwater user's association, reduction of sedimentation, standard well designs and well excavation charges.

Table 4.39 Capacity-building areas of groundwater Strategies and Technologies

Description of capacity building areas	Percentage
Improvement in standard well designs	14.3
Improvements to reduce sedimentation in shallow wells	15.1
Improvement in external water storage facilities	21.7
Improvement in standardization of well excavation charges	13.4
Improvement in training and licensing of artisans	19.2
Improvement in creation of awareness to register groundwater user's association	16.3
Total	100

N=35

4.4.3 Results of DART index thresholds for establishing an Adaptation Action Plan

The DART index threshold coincides with the beginning of groundwater recharge after a dry season and is determined when undertaking groundwater vulnerability assessment during the second step. There were two DART index thresholds. The First DART threshold was -8.4 that occurred in the month of February while the second one of -4.4 occurred in the month of August. These two DART thresholds are important indicators that mark the period when groundwater recharge commenced preceding a long and short dry spell respectively in Fig 4.10.

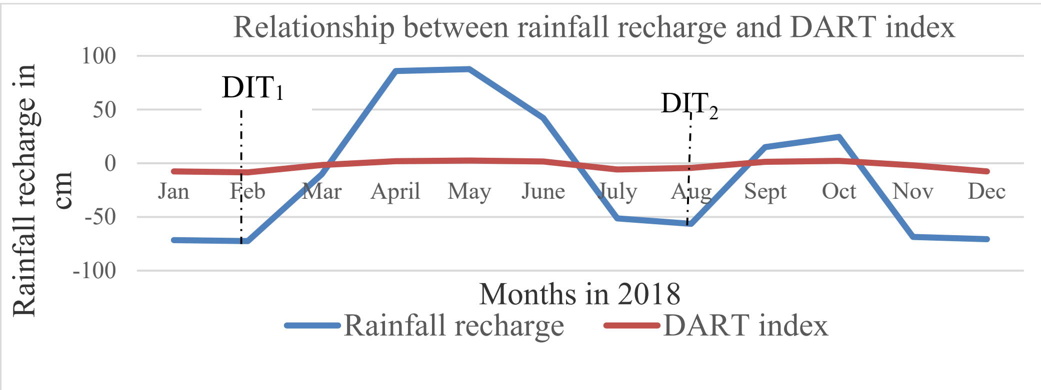


Fig 4.10: DART Index Thresholds for CCAT development

4.4.3.1.1 Application of an Adaptation Action Plan

Application of an Adaptation Action Plan as a planning tool improves precision in choice of suitable adaptation interventions as indicated in Table 4.36. An Adaptation Action Plan has a title citing the purpose and the area, with precise statements that give the description of the water source, reference year, annual rainfall, sedimentation load, DART index Thresholds, highest WRL and geographical position with a detailed implementation matrix.

4.4.3.2 Components of an Adaptation Action Plan

An Adaptation Action Plan has two major components. The first section is a brief that provides information about the area in summary. The second section in the implementation matrix that highlights the groundwater vulnerabilities experienced in the area and alternative adaptation activities with budget, timelines and indicators.

a) An Adaptation Action Plan brief

This is an introduction to provide direction and a summary of the area in question in summary. An Adaptation Action Plan brief has included groundwater source, groundwater use, year of reference, highest WRL, sedimentation depth, rainfall peak months, low rainfall months, highest DART index, Highest water volume, First and second DART index thresh hold and area spatial information reference in Table 4.40.

Table 4.40 An Adaptation Action Plan brief for Lwanda village

Description of groundwater parameter	**Particular details**
Ground water supply source	Shallow wells
Groundwater use:	Agricultural production
Reference Year	2018
Annual Rainfall	1970.2 mm
Highest Water Rest Level:	9.3 meters
Sedimentation depth	1.34 metres
Rainfall peak months:	April May, September & October
Low rainfall months:	January, February, July, November & December
Highest DART index: value and month	2.47; May
Highest water volume and month	$3.66m^{3;}$ May
First DART Index Threshold: & month	-8.4: February
Second DART Index Threshold and Month	-4.4: August
Lwanda Village reference	34^{0}37’5’’E and 0^{0}33’0’’N

b) Groundwater Implementation Matrix section

Groundwater Implementation Matrix section of Adaption Action Plan has six columns stipulating the strategic intervention, the action, the person responsible of taking the action, the budget, the frequency of undertaking the action and the monitoring indicators. A sample of an Adaption Action Plan Implementation Matrix for groundwater from shallow wells is shown in Table 4.41.

Groundwater Implementation Matrix has seven colours that represent different universal thematic areas as well as breaking monotony (Smith *et al.,* 1990; Birren, 2006). The seven colours used are gold, yellow, green, purple, grey, blue and brown. Gold colour represent the golden rule of structure of implementation matrix with six columns and six rows as a 6 x 6 matrix or [6:6]. Yellow colour represents creativity and innovations in development of shallow wells. Green colour represents legislation and authorization of artisans to ensure environmental safety and adhering to standards. Purple colour represents transformation of groundwater management for agricultural production through capacity building. Blue colour represents availability of groundwater resources by adoption of appropriate groundwater harvesting strategies and technologies. Grey colour represents creating a balance in decision making by encouraging stakeholder engagements. Brown colour represents colour of soil in form of sedimentation caused by termite activity.

Table 4.41 Groundwater implementation Matrix for Adaptation Action Plan for Lwanda Village

Ground water Strategic Intervention	Climate change action Measures	Responsibility	Budget	Frequency	Monitoring Indicator
1.Standardize well design and dimension to reduce sedimentation and prevent drying up of shallow wells	Adherence to standard well dimensions while developing of shallow wells	National and County government; Farmers, artisans and donors	Excavation and casing costs	Once	Standard well dimension of 1.65 diameter and 19.8m deep
	Manual excavation of standard shallow wells to widen diameter to 1.65m		Casing and plastering costs	Once	5 meters from top and 10 meters from bottom
	Manual excavation of standard shallow wells to deepen wells to 19.8 m		Excavation and casing costs for extra depth	Once	19.8meters deep
	Mechanical drilling/ boring of shallow wells to standard depth and diameter	National and County government; Farmers and donors	Excavation and casing costs	Once	Not more than 0.4 meters wide and 19.8 m
2.Licensing of water artisans	Engagement or registration of licensed artisans appearing in public register	National and County Governments and artisans	License fee and insurance costs	Annually	Reduced maladaptation of annual excavation
	Timing of excavation of shallow wells	County governments Farmers and artisans	Excavation and casing costs	Once	Permit to be issued only during low rainfall months Mid-December to Mid-February
3.Control of termite activity in shallow wells	Casing and plastering of walls of shallow wells	National and County government; Farmers and donors	Casing and plastering costs	Once	10 meters from the base and 5 meters from the top to cover sub soil layer

	Killing termite in ant hills near shallow well during dry season to avoid water contamination	National and County government; Farmers and donors	Purchase of ant killer and labour	Annually	Absence of ant hill 50 metres away Zero anti hills inside shallow wells.
Ground water Strategic Intervention	**Climate change action Measures**	**Responsibility**	**Budget**	**Frequency**	**Monitoring Indicator**
4.Enhancing groundwater harvesting	Installation of overhead storage tanks to store water in April, May, June, July, September and October when DART index was positive	National and County government; Farmers, donors, business community	Cost of procuring 15 ,000 litre tank per household	Continuous	Installed 15,000 litres tanks
	Installation of standard shallow well base manhole cover to temporarily prohibit water from receding by transmission during low rainfall when recharge is limited	National and County government; Farmer, artisan donors, business community	Cost of base manhole covers	During low rainfall periods	Limited receding of Water Rest Level due to transmission
	Installation of a water pump to pump water in overhead water storage pumps to enable gravity irrigation	National and County government; Farmers, donors, business community	Cost of water pump and piping	One off	Between 3 litres and 10 litres per hour
	Digging of crescent ditches at 10- 50 m away from shallow well to improve rainfall recharge of ground water	Farmers	Cost of digging crescent ditches	Continuous	Crescent ditches of at least five meters deep
	Maintenance and repair of water	Farmers	Cost of maintaining		

	pump and water tanks to ensure continuous supply of irrigation water		water pumps and tanks	Continuous as need arise	Functioning water pumps and tanks
	Installation of sprinkler irrigation or drip irrigation system to cover one acre to ensure crop production throughout the year to reduce CO_2 concentration in the atmosphere	National and County government; Farmers, donors, business community	Sprinkler and drip irrigation system initial costs	One off	1 acre under irrigation for every farmer throughout the year
	Preparation of irrigation regime calendar to be done in the evening to reduce evapotranspiration to conserve more water and twice a week	Farmers, county government	Cost of irrigation and monitoring	Twice a week	Irrigation regime calendar in place
5. Capacity building and training of farmers and artisans to enhance technology transfer to improve groundwater infrastructure and water quality	Acquisition of skills to utilize groundwater and climate change awareness creation to build local community resilience to improve management of irrigation system and water storage tanks	National and County government; Farmers, artisan donors, business community	Cost of training farmers and artisans	Annually	No of farmers and artisans trained
Ground water Strategic Intervention	**Climate change action Measures**	**Responsibility**	**Budget**	**Frequency**	**Monitoring Indicator**
5. Capacity building and training of farmers and artisans to enhance technology	Maintenance irrigation system to ensure continuous supply of irrigation water	Farmers/ County government	Cost of monitoring and evaluation of performance of mini-	Continuous	No of mini-irrigation systems functioning

transfer to improve groundwater infrastructure and water quality			irrigation schemes		
	Calibration of irrigation system to ensure continuous supply of irrigation water	National and County government;	Cost of calibration and automated calibration installation	Annually	No of mini-irrigation systems calibrated
	Public private partnership arrangements to finance installation of storage tanks, pumps, piping and irrigation system to improve local community resilience to climate change impacts	National and County government and business partners	Cost of partnership agreement meeting costs	Continuous	Viable public private partnerships
	Registration of groundwater user's association to organize farmer networks to access training finance to develop shallow wells	National and County government	Cost of registration and administration of water user's association	Continuous	Registered groundwater user's association in place
	Administration of groundwater by Assigning reference number of shallow wells for effective management of groundwater inventory	County/ National government	Cost of maintaining database	Once	Database of groundwater users of shallow wells
	Monitoring shallow well design and dimension and water use to reduce	County/ National government	Cost of field visits and issuance of certificate of compliance	Monthly	Before the shallow well is put in use

	maladaptation by adherence to standards				
	CDF, Women Fund, Youth Fund and Devolved Fund quarter allocation	County/ National government	Cost of disbursing	Annually	Amount of funds allocation to develop shallow wells.
	Draining of water from storage tanks to prevent contamination of water	Farmers	nil	Once	One month after onset of long rain season
	Providing top lid to prevent contamination of groundwater	Farmers	Cost of top cover	Once	Presence of lockable top lid.
	Testing of water quality o monitor water quality	County/ National government	Cost of testing water samples	Regularly	During long rainfall period and during dry season
Ground water Strategic Intervention	**Climate change action Measures**	**Responsibility**	**Budget**	**Frequency**	**Monitoring Indicator**
6.Improve stakeholder communication on climate change GHG emissions reduction and groundwater use	Public participation in Groundwater use to involve governments	County/ National government	Cost of public forums	One off	Public participation minutes and submissions
	Decommissioning of shallow wells for wells dug that do not meet the standards to reduce maladaptation due to non-compliance	County/ National government	Cost of backfilling of shallow wells	Quarterly	Decommission notice and no of accidents reported
	Carbon dioxide sequencing per farmer per year	Farmers	Cost of production of 1 acre of	Continuous	1 acre of land per farmer under irrigated

	to quantify amount of GHG emission reduced for GHG inventory reporting		land throughout the year		agriculture (167 acres)
	Groundwater Use GHG inventory Amount of GHG emission absorbed by the crops equivalent to CO_2	National and County government; stakeholders	Cost of data collection and maintenance of GHG emission inventory	Annually	741.48 tons of CO2 per acre by adoption of GHG emission reduction cropping schedule
	Reduction of GHG emissions from soil (Amount of soil carbon reduced from soil being 109 tons/ha without any vegetation)	Farmers	Cost of data collection and maintenance of GHG emission inventory by individual farmers	Annually	18% reduction of soil carbon . adoption of GHG emission reduction cropping schedule

In adopting of an Adaption Action Plan in Table 4.36 and Table 4.37, they demonstrate the possible amounts of GHG emissions that can be reduced depending on the choice of growing season of maize crop in a year. For example, adopting three maize growing seasons has the potential to reduce GHG emissions more compared to two seasons or one season. The Table 4.42 is a theoretical consideration.

Table 4.42 Groundwater Adaptation Action Plan application of GHG emission reduction for maize production using groundwater

Land surface under production	Amount of GHG emission reduced of Atmospheric CO_2 in tons			Amount of GHG emission reduced of soil carbon in tons		
	One growing season	Two growing seasons	Three growing seasons	One growing season	Two growing seasons	Three growing seasons
1	2.70	5.50	8.20	2.60	5.30	7.85
5	12.65	27.30	40.90	13.10	10	214.00
10	27.30	54.60	81.90	26.15	52.30	78.40
15	40.90	81.90	122.80	39.20	78.40	117.60
20	54.60	109.20	163.80	52.30	104.55	156.80
25	68.20	136.50	204.70	65.30	130.70	196.00
30	81.90	163.80	245.65	78.40	156.80	235.20
35	95.50	191.10	286.60	91.50	182.95	274.40
40	109.20	218.40	327.50	104.50	209.10	313.60
45	122.80	245.70	368.50	117.60	235.20	352.80
50	136.45	272.95	409.40	130.65	261.35	392.00

4.5 Discussion

This section highlights the implications of the results of the four stated objectives of this research study carried out between January and December 2019 in Lwanda Village of Bungoma County.

4.5.1 Discussion for the determination of the effects of rainfall on groundwater use in shallow wells with application of DART index for agricultural production

This discussion assists to provide explanation of the results in objective one that includes status of agricultural production, climatic conditions and groundwater vulnerability assessment in each of the following paragraphs.

The Lwanda village farmers practice mixed farming by producing both crops and livestock under rain-fed agriculture making them highly vulnerable to slight changes in weather patterns (Barnes *et al*., 2008; Burke *et al*., 2008 and Garry *et al*., 2015). Maize being a staple foodstuff for local community has high water requirements of between 500 and 800mm during the entire growing season and highly sensitive to seasonal rainfall (Kerandi and Omotosho, 2008; Brogaard *et al.,*2011; (Egeru *et al*., 2014). Groundwater use for irrigation can increase crop yields during low rainfall periods to supplement crop water requirements (Burke *et al.,* 20008; Albert *et al.,* 2011). Majority of households kept indigenous chicken and local cattle breeds that require less water to assist farmers cope well with impacts of seasonal rainfall. Therefore, more groundwater will be required for irrigation of maize than for use in production of chicken and local breeds in Lwanda village. Farmers with both crops and livestock cope better with climate change impact as compared to those depending on either crops or livestock production alone.

The hottest months with coldest nights also corresponded with driest months with little amount of groundwater. The highest temperatures increased evapo-transpiration during the day and drastic fall in temperatures at night affect maize production as it impairs leaf growth and fertilization process (Barongo *et al.,* 2009; Laura *et al*., 2011). High temperatures shorten the length of growth period necessary for optimum plant and grain size thus affecting overall yields of crops. The heat and water stress are twin impacts that can affect crop production during drought periods.

The slope of the area affects groundwater recharge and movement with low elevations encouraging high groundwater recharge and low speed of groundwater movement (Sophocleous, 2002; Barongo *et al.,* 2009). Therefore, shallow wells on high elevations are likely to have less water than those in low elevations. Shallow wells on the northern side are likely to dry up as compared to those situated on the southern side. The depth of shallow wells that are near to *Bayobo* rock outcrops is likely to be less since it is limited by hard surface beneath considering that the wells are excavated manually (Jiri, 1993). Shallow wells with low depth are more likely to dry up than those that are deeper during prolonged dry period (Asheem, 2019).

There were fluctuations in groundwater variables with rainfall. It is evident that positive correlation exists between rainfall and groundwater variables such as groundwater recharge, storativity, volume, Water Rest Level, transmissivity, groundwater uses and DART index. However, there was a negative moderate correlation between rainfall and number of shallow wells drying up. There was no relationship between rainfall and age of shallow wells. A positive correlation value indicated that the change in one variable directly affected the other variable proportionately. As rainfall increased these seven groundwater parameters also increased and decreased when rainfall declined. Transmissivity increased with rainfall since hydraulic pressure is usually high during rainfall seasons but declined with decrease in rainfall. Transmissivity increased exponentially with a tipping curve at the end implying that it was still increasing with increase in rainfall. Groundwater volume increased in shallow wells as rainfall increased since shallow wells directly benefited from rainfall recharge. Groundwater volume reduced when rainfall decreased because of seepage, increased groundwater uses and low ground recharge (Allen *et al*., 2006; Kerandi and Omotosho, 2008; Barongo *et al.,* 2009; Egeru *et al*., 2014; Hein *et al*., 2014; Francis *et al*., 2014; Behrangi *et al*., 2016). The change in Water Rest Level increased when rainfall increased and vice versa when rainfall decreased. The decrease in Water Rest Level during low rainfall was due to seepage and increased groundwater use coupled with low groundwater recharge. The increase in Water Rest Level with increased rainfall was because of limited use of groundwater, groundwater recharge and saturation. Irrigation need is low during rainfall season leading to less ground water abstraction that causes WRL to remain stable (Allen *et al.,* 2013). Storativity increased with increase in rainfall to a limited extent. The inherent unconfined aquifer property characteristics have a certain maximum level. Storativity increases exponentially without curving at the tip. This is evidence that it can increase further with increase in rainfall (Kra'sn'y and Lopez, 1989; Kruger and Nxumalo, 2017). Rainfall recharge increased with increase in rainfall. Groundwater recharge increased proportionately with rainfall with a dipping curve at the peak. This is an indication of groundwater recharge saturation point (Bob *et al*., 2004; Dennis and Dennis, 2012). The potential of groundwater use increased with rainfall indicating the optimal timing of groundwater harvesting for storage to be used for irrigation during dry season when irrigation needs are highest (Smit and Wandel, 2006).

Drying of shallow during dry season hinders groundwater use (EFSA, 2013; Alex *et al.,* 2018; Kimosop*,* 2018). DART index increased with rainfall due to rainfall recharge but it also declined due to low rainfall with minimal recharge when shallow wells dried up (Dennis and Dennis, 2012). A negative correlation value indicated that the change in one variable inversely affected the other variable. A decline in rainfall increased the number of shallow wells drying up respectively.

The Mann-Kendall trend analysis values indicated an upward trend for rainfall, groundwater recharge, storativity, volume, transmissivity, groundwater use and number of shallow wells drying up in 2018. The increasing trend in groundwater recharge, storativity, volume, transmissivity and groundwater use were influenced by rainfall because of positive correlation existing between these groundwater variables and rainfall. On the other hand, the increasing trend in number of shallow wells drying up spells doom because of other exogenous factors other than rainfall since they are negatively correlated. Some of exogenous factors affecting number of shallow wells drying up are sedimentation and shallow depth due to hard ground surface.

There was a decreasing trend in DART index which indicates the likelihood of shallow wells drying up depicting vulnerability of groundwater use for agricultural production (Smit and Wandel, 2006; Dennis and Dennis, 2012). There was a monotonic trend in Water Rest Level indicating that there is limited change in Water Rest level because of self-regulating mechanism in which excess water drain naturally beneath to feed confined aquifer (Sophocleous, 2002; Bob *et al.*, 2004; Dennis and Dennis, 2012).

The level of significance testing performed on rainfall and groundwater variables indicated that there were significant differences in monthly data for groundwater DART index, groundwater uses and storativity. However, there was no significant difference level, rainfall, groundwater recharge, volume, transmissivity, groundwater uses and number of shallow wells drying up in 2018 even though there were increasing trends. Groundwater DART index has a negative level of significant differences indicating the severity of groundwater drying up and unable to support agricultural production (Dennis and Dennis, 2012).

4.5.2 Discussion on effects of farmer household characteristics, institutional arrangements, access to information and Indigenous Knowledge on groundwater development for agricultural production.

This discussion of second objective explains the implication of the results of social vulnerability traits such as farm household characteristics, institutional arrangements and access to Indigenous Knowledge, agricultural and weather information in respect to development of groundwater for agricultural production against negative impacts of climate change.

The farmer aging population hinders technology adoption. The old farmers normally take a long time to accept new ideas and innovations (Daniel *et al*., 2008). Ninety seven percent of farmer household heads attended formal education. This enhanced their capacity to be trained to transfer new technology of groundwater use without facing many difficulties in communication (Bosire *et al.,* 2015; Bilenkisi *et al.,* 2015; Ogara *et al.,* 2018). Women and widowed headed households were the minority and more vulnerable. They lacked partners that denied them the benefits of combined efforts from their spouses (Barnes *et al*., 2008; Aamir, 2014; Allen *et al.*, 2013). Large household size required more groundwater for agricultural production. Their high food demand exerted pressure on groundwater use (Daniel and Rachel, 2016). Majority of households in Lwanda village had diversified their income sources that made them less vulnerable. Multiple sources of income reduce risks when one income source was disrupted (Adger, 2006; Chandrasekhar and Mukhopadhya, 2010; Daniel and Rachel, 2016). Farming was the major income source in Lwanda village with forty-eight percent followed by salaries and wages with thirty-two percent from teaching, preaching, shallow well digging, preaching causal jobs and other employment, income from business doing business, donations and pension. Therefore, farmer households were highly vulnerable to climate change impacts. They depended on rain-fed agriculture as their main source of income (Beek *et al.*, 2010; Behnassi *et al.,* 2014). The income disparity reduced budget for expensive technologies for shallow water development even though farmers were well educated and informed (Olsson *et al.*, 2014; Bosire *et al.*, 2015; Daniel and Rachel, 2016). The farmer households with small land sizes were in dire need of more intensive and superior technologies to increase food production to meet food requirements as a basic need since they were at risk of starvation (Olsson *et al.*, 2014; Bosire *et al.,* 2015). There were households sharing groundwater from a single shallow well apart from the owners that can enhance formation of groundwater user's association to assist them pool resources to adopt superior technologies for improving groundwater use for agricultural production (Adger *et al.*, 2006; Bill *et al.*, 2017).

The five relevant frameworks reviewed in this study exposed that there is no specific legislation dedicated to groundwater management but are broad based management of water resources. Groundwater management decision making is overly centralized and sector-based carried out overall *ad hoc* without considering management of land and other land-based resources (Albert *et al.,* 2011; Moraa *et al*., 2012. It overlooks the implications of management decisions on physical planning, land use planning and agricultural activities (Olago, 2018). Generally, there is low public awareness about the specific characteristics of groundwater and the connectivity between groundwater and climate change because of limited training and access to appropriate information by smallholder farmers (Bosire *et al.,* 2015).

There were inadequate linkages between different public institutions. There were gaps existing in the present legislations have designated groundwater staff to take data of boreholes but not shallow wells since they are regarded less important. The Irrigation Act of 2017 (Government of Kenya, 2017) did not provide a direct definition of groundwater use from shallow wells. There was no monitoring and evaluation system for groundwater use from shallow wells. However, the Irrigation Act gives a provision for a system of measuring, reporting and interpreting the quantity and quality of water provided, actions implemented, immediate outcomes achieved and impacts realized.

Neither the National Irrigation Development Authority facilitated the formation nor strengthening of irrigation water users' associations at farm level nor conducted periodic technical and management audits. The Authority also did not gather information and maintain database on irrigation water supplies, demands, irrigated areas, potential for expansion and human resources for groundwater users from shallow wells for irrigation development and management. The Crops Act of 2013 allows the Agriculture Forest and Fisheries Authority to register farmer groups (Government of Kenya, 2013). The National Climate Change Framework policy was concerned with mainstreaming of climate change adaptation and mitigation initiatives for management of GHG emission inventory (Government of Kenya, 2016a). It recognised agriculture and forestry as the largest emitters of GHG emissions at 67% but lacks a finance strategy to build resilience of local community against negative impacts of climate change. There was no specific legislation and policy guidelines on management of groundwater for agricultural production.

The County government irrigation development unit is required to establish and maintain irrigation database, systematic monitoring and evaluation system, viable farmer organizations (Government of Kenya, 2017). The existing monitoring and evaluation system is inadequate to fit into the requirement of scattered farmer households and assess performance of groundwater use from shallow wells. Both the County Government Irrigation Development Unit and National Irrigation Development Authority did not identify community driven smallholder schemes or built capacity of farmers. Lack of formal organization structures at farm level hampers management of water users' association conflicts (Food Agriculture Organization, 2011). Smallholder farmers could benefit from these policy guidelines like water storage infrastructure and financing arrangements with appropriate reviews that are specific to groundwater use from shallow wells by people with low incomes (Alley *et al.,* 1998; Bates *et al.,* 2008; Olsson *et al.,* 2014).

There were several traditional or Indigenous Knowledge that farmer households applied. They used them during drought to minimize the negative impacts of Climate Change (Kulindwa *et al*., 2004; Makhakha and Nafuna, 2019). A Focus Group discussion enumerated several traditional knowledges practised among the *Bukusu* community during drought period. However, lack of documentation of such knowledge is at risk of disappearing altogether when old generation pass on when it can offer solution to problems posed by climate change. The strong social bonds existing among members of the age-sets and traditional festivals like circumcision and sports. This can form a platform for creation of public awareness of indigenous knowledge for climate change adaptation (Makhakha and Nafuna, 2019).

Access to agricultural and weather information improves the chances of utilizing groundwater for agricultural production (Brogaard *et al.,* 2011; Bosire *et al.,* 2015). There were varied sources of agricultural and weather information including fellow farmers, Ministry of Agriculture, NGOs and Private sectors and mass media communication like newspapers, brochures, internet and television. NGOs and Private sectors mostly offered agricultural extension services in Lwanda village with minimum government involvement. The main NGOs training farmers are Community Health Agriculture Education and Market Partnership and One Acre Fund on vegetable and maize production respectively. The private companies included Money Maker pump sales team, Kenya Breweries Limited. Few farmers accessed agricultural information from public institutions like Ministry of Agriculture, Mabanga Farmers Training Centre, Bungoma Agricultural Show of Kenya (ASK) and public chief's *baraza*. The mode in which farmers accessed Agricultural information was not structured except by the NGOs and Mabanga Farmers Training Centre. Most farmers who accessed agricultural information by attending training on crop production, livestock production, Irrigation and water Management applied this information. Some of the farmers who attended training applied the agricultural information for land preparation, Maize spacing, vegetable irrigation, vegetable and nursery beds preparation, groundnuts and sorghum production. Farmers who did not attend structured training never applied the agricultural information they received since they did not trust information source or such training did not focus on the need of the farmer (Bosire *et al.,* 2015). Farmer training could be structured and during preparation of training programmes farmers should be involved to incorporate their training needs (Antle *et al.,* 2012). Most farmers in Lwanda village accessed weather information through radio but only seventeen percentages were using weather information on crop and livestock production. This limited utilization of weather information was due to lack of clear interpretation to make sense to local community (Bosire *et al.,* 2015).

4.5.3 Discussion on identification of technologies and strategies being used by smallholder farmers for using groundwater from shallow wells

This discussion explains the implication of the results of strategies and technologies employed by smallholder farmers to develop groundwater for agricultural production. Shallow wells development initiatives focus on effective designs to reduce the number of times for excavation of shallow wells. This ensures that shallow wells did not dry up due to inadequate depth and sedimentation caused by collapsing of walls and termite activity. Groundwater storage initiatives are external mechanisms to accumulate groundwater to provide room to harvest more water during peak rainfall period when Water Rest Level is high and close to ground surface. This involves less energy when abstracting the water.

Groundwater supply interventions ensure effective water distribution system that minimizes wastage such as using irrigation drips, sprinkler, gravity irrigation systems and water quality control and monitoring at household levels (Majule and Mary, 2009; Mukheibir, 2010). Groundwater supply strategies should be geared towards improvement of drawing water from shallow wells considering the enormous amount of water required for irrigation and number of households drawing water at the same time (Cynthia and Tubiello, 2007; Mukheibir, 2008; Esilaba *et al.,* 2014). Cross cutting interventions that included capacity building and resource pooling in terms of material, labour and finances were also identified as important factors to enhance community resilience to impact of climate change (Boko *et al.,* 2009; Lemma and Wondimagegn, 2018).

All farmers dug shallow wells manually because they could not afford high cost of drilling shallow wells. These wells are usually limited in depth. They also took a long period to complete depending on the parent rock material, effort and performance of well digger (Bill *et al.,* 2017). The contractors of drilling equipment reside far away in semi-arid areas or big towns. The cost of transporting the heavy equipment was expensive and inhibiting. Majority of farmers used can and rope to draw water from shallow wells but very few farmers used hand and electric water pumps. Neither farmers used claw bar nor winches to draw water from shallow wells. They drew water manually, which was also tedious and inadequate to meet enormous water requirements for agricultural production (Albert *et al.*, 2011 and Garry *et al*., 2015). Few farmers had installed overhead water storage tanks and modern irrigation systems (Morton, 2007). Lack of funds and technical knowhow have hindered most farmers from exploiting enormous benefits of using groundwater for agricultural production by investment in water pumps, storage overhead tanks, and gravity irrigation system (Smit and Wandel, 2006; Brogaard *et al.,* 2011; Bosire *et al.*, 2015). The farmers are still using archaic irrigation methods like buckets and watering cans that are not effective compared to superior technologies like sprinklers and drip irrigation to improve groundwater management (Corbeels *et al.,* 2009; Bosire *et al.,* 2015). Irrigation timing is also very important. Irrigation done in the evenings conserve moisture and allow more water to infiltrate the ground unlike in the morning when most water will evaporate as a result of high temperature.

The farmers' incapacity to form a viable water users association to pool their resources together limited their adaptive capacity. They cannot benefit from collective bargain power to access financial resources were also a noted disadvantage (Adger, 2006; Barnes *et al*., 2008 and Bill *et al.,* 2017). During a Focus Group Discussion, the participants cited capacity-building areas to improve strategies and technologies for groundwater use for agricultural production. Majority indicated improvement in external water storage facilities, training and licensing of artisans. There was no program to organize farmers in groups such as groundwater user's association to assist them mobilize resources, access public training or link farmers to public or private institutions for effective public private partnerships even though there were existing legislations. Strategies to register a groundwater users' association would assist in resource mobilization to drill wells, casing of shallow wells, procurement of water pumps and storage tanks, irrigation system and scheme (Godau *et al.,* 2019; Bill *et al.,* 2017). Lack of structured training program that was well co-ordinated for farmers and artisans limited acquisition of necessary skills needed in management of shallow well water for maximum output for agricultural production (Burton *et al.,* 2002; Bosire *et al.,* 2015). County governments can organize farmers to form a water users' association to exploit existing synergy to pool the much-needed resources in development of shallow wells for agricultural production. County and National governments and other interested private sector could link farmers and create effective public private partnerships to improve groundwater use for agricultural production in village and access to finance (Adger, 2006; Baron *et al*., 2013). Constituency Development Funds, Women Development Fund, Youth Development Fund and devolved Funds are some of the financing avenues to build farmers resilience against climate change impacts Chandrasekhar and Mukhopadhya (2010). Corporate social responsibility programmes for companies like Safaricom, Equity bank and others can support this worth course as well. Climate Change Fund from national and International community should consider development of infrastructure of shallow wells. Nile International Treaty beneficiaries could also support development of shallow wells for farmers as a compensation for prohibiting them from using the said waters that deny them their upstream primacy since the Lake Victoria region remained isolated for decades (Christian *et al.,* 2016). REDD+ also offers a finance avenue for farmers by quantifying the amount of carbon absorbed from land surface under irrigation during dry season when most vegetation dried up to reduce carbon sink for GHG emissions (Cai *et al*., 2008; Christian *et al.,* 2018). The Focus group discussion and key information informants identified five major benefits for groundwater use from shallow wells with majority being 34 percent and thirty one percent of participants identified the benefits of groundwater as being near to point of source and use and easily accessible by local community residing in remote areas.

A Focus Group discussion and interview with Key information informants identified five major challenges of groundwater use. Majority of the participants identified low water volume at peak water demand during dry season, exorbitant labour charges, poor workmanship and anticipated prohibitive legislation of increasing water bills as the major challenges. However, in focus group discussion the participants introduced two new issues of financing and poor workmanship. This was due to group think dynamics or the presence of public officials whom the participants felt could be in position of making decision to finance the farmers and regulate digging of wells to acceptable standards.

Low water volume in shallow wells could be resolved by harvesting groundwater during rainfall season to be stored for later use during dry periods (Falkenmark and Rockström, 2010). Both farmers and artisans can negotiate high exorbitant labour costs charged and anticipated high water bill charges in advance to reach an agreement. They can also organize themselves to belong to insurance scheme to cover costs incurred in excavation for compensation when water is lacking (Huang *et al*., 2010). Groundwater users can enhance water quality by carrying out periodic water quality tests and by implementing the recommendation of water experts.

There was general public awareness of climate change effects by the farmers due to reducing water in shallow wells and drying up of shallow well Groundwater use is in extreme cases. Sedimentation of shallow wells due to collapsing of walls, termite activity of building anthills on walls of shallow wells and shifting of groundwater pathway were other causes of drying up of shallow wells (Barreteau *et al.,* 2016; Adiku *et al.,* 2016).

4.5.4 Discussion on establishment of an Adaptation Action Plan for groundwater use from shallow wells for agricultural production to minimize climate change impact

Application of an Adaptation Action Plan is most effective when it incorporated broad perspectives of the vulnerability features identified by farmers and other stakeholders to enhance ownership by users (Adger, 2006; Berkes and Ross, 2013; Austine *et al.,* 2018). This Adaptation Action Plan was established after understanding the interactions of climatic conditions, groundwater, smallholder farmer household characteristics, indigenous knowledge, information access, institutional arrangements, strategies and technologies, and after incorporating inputs of various stakeholders. Development process of an Adaptation Action Plan undergoes a complete project cycle stages that includes scoping, aggregation of diagnostic information, needs assessment, action planning, monitoring and evaluation (Global Child Nutrition Foundation, 2009; Darryn *et al*., 2012). Identification of monitoring indicators and timings is very crucial. This is what determines the success of any Adaptation Action Plan. Groundwater strategic interventions greatly affected groundwater availability for agricultural production (Llamas and Martinez-Santos 2005; Falkenmark *et al.,* 2009). They consisted of well designs, controlling sedimentation, training of farmers and artisans, financing to invest in groundwater, water quality control and testing, legislation and precursor conditions for decommissioning. Assigning responsibilities to various actors separate their roles and functions and identify inter-relation to promote accountability and corporation in management of groundwater from shallow wells. Timing as a factor of budget enables estimation of adaptation costs with a specific period like one year to assist in monitoring a certain performance indicator (Allen, 1992). It helps to assess and give feedback for review while implementing a CCAT.

An Adaptation Action Plan as a planning tool can build resilience of groundwater well users to give them ample time to assemble resources needed (Darryn *et al*., 2012). GHG emission reduction projection of different crops is possible by implementing an Adaptation Action Plan of this study. It assists in identifying the type of crops grown, land surface and groundwater available to enable prediction of the amount of CO_2 absorbed by different crops on different land surfaces. The GHG emission projections assist in quantifying the amount of atmospheric CO_2 reduced through photosynthesis and from soil carbon. GHG emission reduction depends on different crops types, number of growing seasons and amount of land surface as illustrated for maize production. Several cropping seasons during the year can reduce GHG emission in terms of atmospheric CO_2 and Soil carbon by utilizing groundwater for agricultural production to stabilize global warming.

The GHG emission reduction schedule can be managed at farm level to provide estimates that are more accurate by multiplying the factor that corresponds with the minimum acreage for GHG emission inventory management and reporting as a Nationally Determined Contribution. The study adopted Winrock international threshold of soil carbon of 109ton/ha and 17820kg of CO_2 absorbed by maize per acre. The choice of maize is suitable since it was the staple food crop in village. There were two DART index thresholds identified at the start of rainfall recharge during long and short rainfall seasons. DART index threshold was lowest after prolonged dry season in February at (-8.4) and the second DART index threshold was during short rainfall in August at (-4.4). The lower the DART index Threshold (DIT) the higher the climate change impact on groundwater. The DART index threshold period between two DART index threshold levels determines the period of harvesting groundwater and possible groundwater available. This will in turn dictate the type of cropping schedule for either one season or two seasons or three seasons. Application of this an Adaptation Action Plan assists to minimize adaptation costs by increasing effective use of groundwater for agricultural production (Alpha *et al.*, 2009).

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.0 Conclusions

Groundwater use in Lwanda village increased exponentially in the recent years with increasing intensity of climate change effects being felt by smallholder farmers expressed in mean age of most shallow wells of 16 years. Lwanda village received high annual rainfall of 1970.3 mm, which was not evenly distributed, and two months received 48 percent of annual rainfall in agreement with results of Kimosop, (2018). There were only 5 months that had adequate rainfall that coincided with positive DART index in the month of April, May, June, September and October with values ranging between 1.28 and 2.47. These were also the best months to harvest groundwater in Lwanda village. The rainfall positively affects Groundwater volume, Water Rest Level, recharge, potential groundwater use, DART Index, Storativity and transmissivity that corresponds with other research studies of (Kra'sn'y and Lopez, 1989; Dennis and Dennis, 2012). However, there was a negative correlation between rainfall and number of shallow wells drying up because of decreased rainfall recharge during dry season according to Mukheibir, (2010); Dennis and Dennis, (2012). The Mann-Kendall trend analysis values indicated an upward trend for rainfall, groundwater recharge, storativity, volume, transmissivity, groundwater use and number of shallow wells drying up but a decreasing trend for groundwater DART index and a monotonic trend in Water Rest Level. The increasing trend of shallow wells drying up indicates the vulnerability of groundwater to support agricultural production in Lwanda village. Groundwater DART index has a negative level of significant differences indicating the severity of groundwater drying up and inability to support agricultural production. There is an increase in potential groundwater use for agricultural production owing to the positive level of significant because during rainfall irrigation needs are minimal. This water could be storage for agricultural use during dry season. There is no significant difference in rainfall, groundwater recharge, transmissivity and volume. There were two DART index Thresholds at (-8.4) and (-4.8) during the onset of long and short rain season when groundwater recharge commenced indicating that shallow wells are at risk of drying up because of seasonal rainfall.

There was low adaptive capacity by farmers to use groundwater for agricultural production as there lacked formal records on irrigation at farm level. Farmers in Lwanda village remain highly vulnerable as they depend on rain-fed agriculture without capacity to utilize groundwater to cope with drought event experienced in the month of January, February, November and December when 53 percent of shallow wells dried up. Farmer households remained at a risk of partial malnutrition due to limited supply of milk and vegetables during drought. This period coincides with high prices due to high demand and limited supplies. A single shallow well served between 1 and 12 households. One hundred and sixty-seven households were benefiting from 30 shallow wells vulnerable to adverse impact of climate change. Majority of households were living below poverty level of one dollar per day with annual income of less than KS160, 000 (Chandrasekhar and Mukhopadhya, 2010). It becomes impossible for farmers to invest in development of groundwater for agricultural production even though they are in need of more food. There was no structured training of farmers on groundwater use and climate change adaptation awareness. Most of farmers never applied the information received because of lack of trust of various information sources available. Lack of specific legislation to govern exploitation of groundwater from shallow wells for commercial agricultural production contributed to weak linkages between farmers and other actors to build farmers adaptive capacity to negative impacts of climate change. Legislations are inadequate to meet area specific needs of farmers for groundwater use in agreement with Olago, 2018. There were weak linkages between farmers and public institutions with less practised monitoring and evaluation of groundwater. Lack of organization of shallow well users in water users' associations denied them opportunity to access public services from designated institutions such as training, design of water structures and other related water irrigation needs. Most farmers who had accessed weather information did not apply it since majority of farmers were old with little trust of informal sources of weather information. NGOs and radio were the most popular source of agricultural and weather information respectively in concurrence with Bosire *et al.,* 2015. Most farmers identified climate change impacts of seasonal rainfall to be the major cause of drying up of shallow wells followed by sedimentation from collapsing walls, termite activity and shift in pathway of groundwater respectively. There was no formal platform for Indigenous Knowledge integration to climate change adaptation eventhough it can offer solution to Climate change impacts. The lack of recognition of Indigenous Knowledge is likely to result to forgotten of these traditional interventions by young generations.

The current legislations have general guidelines that do not necessarily address the niche requirements of shallow well water that is very specific considering its nature of spread, land surface area and the minimum number or amount required for decision making especially in making policy (Government of Kenya 2016b). The local community was highly vulnerable to climate change impacts considering their low adaptive capacity expressed in low uptake of irrigation technologies due to aging farmers, low household incomes and limited specific policy on shallow wells to support farmers' initiatives. The current legislations have general guidelines that do not necessarily address the niche requirements of shallow well water that is very specific considering its nature of spread, land surface area and small number of households. The existing monitoring and evaluation system need to fit into the requirement of farmer households to allow assessment of performance of groundwater use from shallow wells.

Farmers in Lwanda village have not yet employed effective technologies to utilize groundwater for agricultural production due to lack of ambition, technical knowhow and financial arrangements to adopt advanced technologies. Irrigation regime varied indicating that farmers needed further training on irrigation interval and timing for different crops and growth stages. Generally, strategies of groundwater use from shallow wells for agricultural production remain under developed due to lack of technical knowhow and inadequate linkages between farmers and other actors to enhance their capacities. Priority areas of strategy development were water storage, training, licensing of artisans, and reduction of sedimentation, standardization of well design and excavation costs. There were several legislations and institutions but lacked specific guidelines and designated staff for monitoring groundwater use. Capacity building in terms of legislation, staffing and access to finances are not yet developed. This affects assessment shallow well users at farm household levels to adapt to climate change. However, ground water uses from shallow well may guarantee promising outcomes in the emerging climate change. Lack of organization of shallow well users' associations denied them an opportunity to mobilize finances to invest in latest technologies like water pumps, drips, sprinklers, water storage tanks and drilling equipment that can assist them increase land surface under irrigation for increased agricultural production to minimize climate change impacts of seasonal rainfall. Lack of groundwater specific legislation to guide its use at farm level has hampered initiation of essential institutional structures to monitor resources and involve farmers for effective management of groundwater (Government of Kenya, 2017).

The first DART index threshold (DIT_1) was at (-8.4) in February and second DART index Threshold (DIT_2) was at (-4.4) that corresponded with rainfall recharge after a drought event during dry season. Application of a Climate Change Action Toolkit can assist in reduction of Green House gas emissions by 8.188 tons of CO_2 absorbed by the maize during photosynthesis to reduce soil carbon by 18% when farmers grow maize for three seasons per year. The research study adopted Winrock international threshold of soil carbon of 109ton/ha and 36000lb of CO_2 absorbed by maize per acre. More soil carbon dioxide could be absorbed when growing seasons under maize production increased from one to three seasons made possible by supplementary irrigation from groundwater.

Groundwater use has more benefits than disadvantages. Building adaptive capacity of farmers against negative climate change impacts can deal with the disadvantages. Mechanical drilling of shallow wells deeper than the current depth of about 19.8 metres can assist in managing negative climate change impacts that cause groundwater table to recede. Casing of walls of shallow wells can reduce sedimentation due to collapsing walls during rainfall and termite activities experienced during drought events. Organization of farmers in groups can assist them access financing to hire drilling equipment to lower cost. The adoption of standard well design and improving approval and monitoring mechanisms by government officials can assist to handle poor workmanship and lack of expertise in identifying presence of groundwater.

Finally, Lwanda village community have never developed a Climate Change Action Toolkit. This Climate Change Action Toolkit becomes the first one that was developed in consultation with stakeholders to address some of the inadequacies discovered during research study to build local community resilience against climate change.

5.1 Recommendations

a) A Climate Change Action Toolkit suggested in the research can assist various actors to address maladaptation to reduce rehabilitation costs of shallow wells due to sedimentation.

b) The researchers can pilot the suggested groundwater use technologies and strategies to provide proved data of superior ones and improve information dissemination to farmers to improve technology uptake and their adaptive capacity to climate change impacts as they remain under developed.

c) The policy makers can develop groundwater use from shallow wells software Application (App) to assist to disseminate information on various technologies and strategies on climate change adaptations to enhance technology uptake by youthful farmers.

d) Farmers can form groundwater user's association to pool resources for sustainable groundwater use agricultural production.

e) Policy makers can adopt DART index methodology to guide in procuring insurance cover for agricultural enterprises as a risk management indicator against negative climate change impacts.

f) Policy makers can adopt GHG emission reduction cropping schedule at farm level to assist in measuring GHG emission for purpose of managing GHG inventory and reporting as a Nationally Determined Contribution.

g) There is need to recognize Indigenous Knowledge as important interventions to Climate change impacts and incorporate it in climate change adaptation at local levels.

h) Further research study on soil erosion and rainfall recharge should be investigated further to improve knowledge on ground water recharge and sedimentation.

REFERENCES

Aamir, J. (2014) Men's perception of women's role and girls' education among Pashtun tribes of Pakistan: Qualitative Delphi study. University of Alberta, *Cultural and Pedagogical Inquiry,* **6**(2): 17-34.

Adger, W.N. (2006) Vulnerability. *Global Environmental Change*, 1**6(**3): 268–281.

Adger, W.N., Huq, S., Mace, M. J. and Paavola, J. (2006) Fairness in adaptation to climate change**.** *Climatic Change,* **96**(2): 259-267.

Agatha, C. H. and Hughes, T. P. (2001) Technologies of power**.** MIT press, Cambridge, Massachusetts, London, England, 1-337.

Ahn, K.H., Merwade, V. (2014) Quantifying the relative impact of climate and human activities on stream flow. *J. Hydrol*. **515,** 257-266.

Akhtar, S.M., Cowie, A. L., Gorissen, L., Jones, J.,W., Kellner, K, Lal, R., Lehmann, J., Paulsch, A., Penman, T. D., Twomlow, S.,Tyrrell, T. D., Wilkes, A. and Winslow, M. D. (2011)Towards sustainable land management in the drylands: Scientific connections in monitoring and assessing dryland degradation, climate change and biodiversity. Wiley, https://doi.org/10.1002/ldr.1086.

Albert, T., Edward, K., Michael, L., Mumma, A. and Rafik, H. (2011) Kenya groundwater governance case study, World Bank www.worldbank.org/water, 1-105.

Alex, S., Bockelmann-Evans, B. and Thorsten, S. (2018) an approximation of a natural, rough gravel riverbed both physically and numerically, *Geosciences*, (8): 449; 1-14.

Allen, G.R., Pereira, L.S., Raes, D., Richard, G. and Smith M. (2006) Crop Evapotranspiration (Guidelines for Computing Crop Water Requirements*)* FAO, Italy, 1-333.

Allen, J.J., Beek, M., Bierkens, M., Chen, T.R., Doell, B., Edmunds, J.S., Famiglietti, M., Fan, A., Green, L., Gurdak, Y., Hiscock, M., Holman, J.F.P., Konikow, M., Leblanc, L., Longuevergne, Y., MacDonald, M.F.P., Maxwell, Y., Rodell, P., Scanlon, G., Shamsudduha, M.D., Taniguchi, J., Taylor, H., TreidelI. R., Wada, R., Yechieli M.R. and Yeh, K. (2013) Groundwater and climate change. *Nature Climate Change,* **3**(4): 322-329.

Alley, W.M., Franke, O.L., Harvey, J.W. and Winter, T.C. (1998) Groundwater and Surface Water: A Single Resource. *U.S. Geological Survey Circular,* 1139*, https://www.researchgate.net/publication/243787829 Ground water and surface water a single resource U/link/55469c220cf234bdb21d8ff8/d 1-88.*

Alpha, K., Jane, K., Jodie, K. and Sheila, K. (2009) An overview of expected impacts, adaptation and mitigation challenges, and funding requirements. *Climate Change and Developing Country Agriculture,* **2**:1-61.

Antle, J.M., Claessens, L., Herero, M., Stoorvogel, J.J., Thornton P.K. and Valdivia R.O. (2012) A method for evaluating climate change adaptation strategies for small-scale farmers using survey, experimental and modelled data. *Agricultural Systems,* **111**:85-95.

Adiku, S.G.K., Agyei, P., Codjoe, S.N.A., Dougill, A.J., Dovie D.B.K., Lamboll, R. and Quinn, C.H. (2016) Perceived stressors of vulnerability across scales in savannah zone of Ghana. *Reg Environ Change,* **17**(1). 213-227. ISSN 1436-3798 (Print), 1436-378X (Online) (DOI: https://doi.org/10.1007/s10113-016-0993-4).

Arjen, Y.H. and Mekonnen, M.M. (2014) Water conservation through trade: the case of Kenya, Netherlands. *International*, **39**(4): 451-468.

Asheem, S. (2019) The science and impact of climate change. USA, *Advances in Geographical and Environmental Sciences*, **13**: 2014 – 2020.

Austine, P., George, T., Chipea, W. and Chawinga, D. (2018) Information needs and barriers of rural smallholder farmers in developing countries: A case study of rural smallholder farmers in Malawi. *Sage Journals:* DOI 10.1177/0266666918755222.

Baron, J. S., Bernhardt, E.S., Boyer, E. W., Chan, F., Finlay, J.C., Hall, E.K., Harrison, J. A. and Nolan, B. (2013) The interactive effects of excess reactive nitrogen and climate change on aquatic ecosystems and water resources of the United States. *Biogeochemistry* **114**: 71–92.

.

Barreteau, O., Hunt, R.J., Jakeman, A., Rinaudo, J. D. and Ross, A. (2016) Integrated ground water Management. *Springer Nature America, Inc:* 3-141: DOI 10.1007/978-3-319-23576-9.

Bartelt, L. A, Bolick, D. T, Mayneris-Perxachs, J, Kolling, G. L., Medlock, G. L., Zaenker, E. I., Donowitz, J., Thomas-Beckett, R. V., Rogala, A., Carroll, I.M., Singer, S.M., Papin, J., Swann, J.R. and Guerrant, R.L. (2017) Cross-modulation of pathogen-specific pathways enhances malnutrition during enteric co-infection with *Giardia lamblia* and enters aggregative *Escherichia Coli*. *PLoS Pathogen,* **13**, e1006471, DOI: 10.1371.

Barnes, L., Berry, M., Burton, B., Cutter, S.L., Evans, E., Tate E. and Webb, J. (2008) A place-based model for understanding community resilience to natural disasters. *Global Environmental Change,* **18** (4): 598-606.

Barongo, J., Olago, D.O. and Opere, A. (2009) Holocene palaeohydrology, groundwater and climate change in the lake basins of the Central Kenya Rift. *Hydrological Sciences Journal*, **54** (4): 765-780.

Bates, B.C., Kundzewicz, Z.W., Palutikof, J.P. and Wu, S. (2008) Climate Change and Water. Intergovernmental Panel on Climate Change (IPCC).1- 210. https://www.ipcc.ch/publication/climate change and water 2.

Bazaz, A., Daron, J., Kituyi, E., Krishnaswamy, J., Singh, C., Spear, D., Zaroug, M. and Ziervogel, G. (2017) The utility of weather and climate information for adaptation decision-making: current uses and future prospects in Africa and India, https://doi.org/10.1080/17565529.2017.1318744**,** 389-405.

Bechir, C., Behera, C. N., Czeslaw, M., Gunter, B., Heinz, K., John, G., Patricia, K. M. and Ursula O.S. (2009) Facing global environmental change: Environmental, human, energy, food, health and water security concepts. *Environmental Sciences,* **4** (1): 21-118.

Beek, L.P.H., Bierkens, M.F.B., Kempten. C.M., Reckman J.W.T.M., Vasak, S. and Wada, Y. (2010) Global depletion of groundwater resources. Blackwell publishing ltd*,* *Geophysical Research Letters,* **37**(20): 1-5.

Behnassi, M.., Ramachandran, G., Shelat, K. and Syomiti, M.M. (2014) Vulnerability Assessment of climate change on sea level rise impacts on some economic sectors in Binh Dinh province, Vietnam, *Earth and Environmental Sciences*, **DOI:** 10.4236/ajcc.2019.82017, 302-324.

Behrangi, A., Brian, F. T. and James, S. F. (2016) Precipitation Intensity Effects on Groundwater Recharge in the South Western. USA, *Water* ***8*** **(**90): 1-15.

Berkes, F. and Ross, A. (2013) Community resilience: toward an integrated approach. *Society & Natural Resources,* **26** (1): 1-16.

Beverly, J.E., Blegen, N., Faith, T.J., Peppe, J.D. and Tryon, A.C. (2014) Biogeographic and Evolutionary Implications of an Extinct Late Pleistocene Impala from the Lake Victoria Basin, Kenya. J*ournal of Mammalian Evolution*, 21, 213–222.

Bilenkisi, F., Gulcin, T. and Mahmut, S. G. (2015) Impact of household heads' education levels on the poverty risk; evidence from Turkey. *Educational Sciences Theory and Practice,* **15**(2): 337-348.

Bill, B. G, Bridget L.G., Logan D. H. and Mallory K. V. (2017) The Impact of Discount Rate and Price on Intertemporal Groundwater Models in Southwest Kansas. *Journal of Water Resource and Protection,* **B** (7): 1-15.

Birren, F. (2006) Colour Psychology and colour therapy; a factual study of the influence of human life. Whitefish MT: Kessinger Publishing. 1-86, ISBN 978-1425424107, OCLC 74452551.

Bob, S. Z., Coaxing, L., Jose, S., Jun, W., Kees, D., Li, W., Massimo, M., Peter, T., Qinhuo, L., Wout, V., Yanbo, H., Yaoming, M., Younqi, C. and Zhao, L.L. (2004) Earth observation of water cycle and applications in drought monitoring and prediction. International Institute for Geo- Information Science and Earth observation, the dragon drought project. Enschede, Netherlands: 1-78. https://earth.esa.int/documents/973910/992126/su3.pdf.

Boko, M., Githeko, A., Medany, M., Niang, I., Nyong, A., Osman, E.B., Tabo, R., Vogel, C. and Yanda, P. (2008) Africa Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 433-467 https://archive.ipcc.ch/publications and data/ar4/wg2/en/ch9.html.

Bosire, O.O., Janneke, M., Ocholla, D., Ocholla, L. and Tinashe M. (2015) Access to and utilization of information and communication technologies by Agricultural researchers and extension workers in Zimbabwe. *Journal Information Technology for Development,* **21**(1): 67-84.

Bovolo, C., Parkin, G. and Sophocleous, M. (2009) Groundwater resources, climate and vulnerability. *Environmental Research Letters*, **4**(3): 1-5.

Brekke, L.D., Kiang, J.E., Olsen, J.R., Pulwarty, R.S., Raff, D.A., Turnipseed, D.P., Webb, R.S. and White, K. D. (2009) Climate change and water resources management: A federal perspective. *U.S. Geological Survey*: 1-65.

Bridget, L. G., David, G. L., Hina, F., Lal, K. A., Rachna, T. and Robert, T. (2017) Extending the Economic Life of the Ogallala Aquifer with Water Conservation Policies in the Texas Panhandle: 255-270, DOI:10.4236/jwarp.2017.93017.

Brogaard, S., Genesis, T. Y. and Lennart, O. (2012) Crop Water Requirements in Cameroon's Savanna Zones under Climate Change Scenarios and adaptation needs. Crop Production Technologies, Dr. Peeyush Sharma (Ed.), ISBN: 978-953-307-787-1, Intechopen, http://www.intechopen.com/books/crop-production-technologies/crop-water-requirements in cameroon savanna zones under climate change scenarios and adaptation ne.

Burke, J., Faurès, J.M. and Turral, H. (2008) Climate Change, Water and Food Security, FAO, Italy: 1-200. http://www.fao.org/3/i2096e/i2096e.pdf.

Burke, M.B., Falcon, P.W., Lobell, D.B., Mastrandrea, D.M., Naylor, L.R. and Tebaldi, C. (2008) Prioritizing Climate Change Adaptation Needs for Food Security in 2030. *Science*, **319** (5863): 607-610.

Burton, I., Huq, S., Lim, B., Pilifosova, O. and Schipper, E.L. (2002) From Impacts Assessment to Adaptation Priorities: the shaping of Adaptation Policy. *Climate Policy,* Amsterdam, **2:** 45-159.

Cai, Z., Gwary, D., Howden, M., Janzen, H., Kumar, P., Martino, D., McAllister, T., McCarl, B., Ogle, S., O'Mara, F., Pan, G., Rice, C., Romanenkov, V., Scholes, R., Schneider, U., Sirotenko, O., Smith, J., Smith, P., Towprayoon, S. and Wattenbach, W. (2008) Greenhouse gas mitigation in agriculture. *Philosophical Transactions of the Royal Society Biological Sciences,* **363** (1492)789-813.

Carpenter, A.K., Holling, C.S., Stephen, C. and Walker, B. (2004) Resilience, Adaptability and Transformability in Social – ecological Systems. *Ecology and Society,* **9** (2)5: 1-9.

Chandrasekhar, S. and Mukhopadhya, A. (2010) *"Poverty and Well-being in Indian Cities during the Reforms Era"* Poverty and Public Policy, The Berkeley electronic press, **2** (7):1-23.

Chen, W.Y., Lackner, M. and Suzuki, T. (2017) Handbook of Climate Change Mitigation and Adaptation". Springer Nature America, Inc: 1-9. https://www.springer.com/gp/book/9783319144085.

Christian, S., Hellegers, P.J.G.J., Jerl, E.C., Kabat, P., Roest, C.W.J., Smit, A. A.M.F.R. and Walsum, P.E.V. (2016) Role of rain-fed agriculture in securing food production in the Nile Basin, *Environmental Science & Policy* 61:14-23 DOI: 10.1016/j.envsci.2016.03.007.

Christian, H., Mal, S. and Singh, R.B. (2018) Climate change extreme events and disaster reduction towards development goals. Edited book. Sustainable Development Goals Series, Springer Nature America: 1-309. https://www.geo.uzh.ch/~chuggel/publication.html.

Corbeels, M., Giller, E.K., Tittonell, P. and Witter, E. (2009) Conservation agriculture and smallholder farming in Africa: *Field Crops Research*, **114** (1): 23-34.

Cuo, L., Giambelluca, T. W. and Ziegler, A.D. (2011) Lumped parameter sensitivity analysis of a distributed hydrological model within a tropical and temperate catchment. *Hydrol. Process.* **25**, 2405-2421.

Cynthia, R. and Tubiello, F.N. (2007) Adaptation and mitigation strategies in agriculture: An analysis of potential synergies Mitigation and Adaptation Strategies. *Global Change,* **12** (5): 855-873.

Daniel, F. M. and Rachel, N. N. (2016) Impact of household size on poverty; an analysis of various low-income townships in northern Free State region, South Africa. *UEPA **30** (2).* ISSN 2308-7854 (online); ISSN 0850-5780.

Daniel, S.C., Elizabeth, G., Michael, H., Murray, C. S. and Stefan, G. (2008) Climate change adaptation and mitigation in the tourism sector: frameworks, tools and practices. UNEP. http://purl.unep.org/sdg/SDGIO 00000047.

Darryn, M., Hartmut, F. and Iftekhar, A. (2012) Integrated disaster risk reduction and climate change; participatory Analysis (PCVA) Toolkit. RMIT University, Melbourne: 1-36.

Dassargues, C. and Gogu, R. (2000) Current trends and future challenges in groundwater vulnerability assessment using overlay and index methods. *Environmental Geology,* **39** (6): 549-559.

Dennis, I. and Dennis, R. (2012) Climate change vulnerability index for South African aquifers. *Water South Africa, **38*** (3): 1-10.

Dennis, T., Duncan, B., George, B.A., Maryam, R. and Tanya, L. A. (2012) A Bayesian synthesis of predictions from different models for setting water quality criteria. *Ecological Modelling* 242: 127- 145.

EFSA Panel on Plant Protection Products and their Residues (PPR) (2013) Scientific Opinion on the report of the FOCUS groundwater-working group (FOCUS, 2009): assessment of lower tiers. *EFSA Journal*; **11**(2):3114. 1-29, DOI: 10.2903/j.efsa.2013.3114.

Egeru, A., Osaliya, R. M., Opiyo, L. and Mburu, J. (2014) Assessing the spatio-temporal climate variability in semi-arid Karamoja sub-region in North-Eastern Uganda. *International Journal of Environmental Studies* **71**(4 :)
DOI: 10.1080/00207233.2014.919729.

Eriksen, S. and Lind, J. (2009) Adaptation as a political process: Adjusting to drought and conflict in Kenya's Drylands. *Environmental Management*, **43(**5): 817-835**.**

Esilaba, O., Filho, A., Walter, L., Rao, K.P.C. and Sridhar, G. (2015) "Adapting African Agriculture to Climate Change". Springer International Publishing Switzerland Springer

Nature America, Inc: 1-235.ISSN 1610-2010 ISSN 1610-2002 (electronic) Climate Change Management ISBN 978-3-319-12999-0 ISBN 978-3-319-13000-2 (eBook). DOI10.1007/978-3-319130002. https://www.researchgate.net/publication/272496296 Adapting African Agriculture to Climate Change.

Falkenmark, M., Karlberg, L. and Rockström, J. (2009) Present and future water requirements for feeding humanity. Sweden. *Food Security,* **1**(1): 59–69.

Falkenmark, M. and Rockström, J. (2010) Building Water Resilience in the Face of Global Change: From a Blue-Only to a Green-Blue Water Approach to Land-Water Management, *Journal of Water Resources Planning and Management,* **136** (6): 606-610.

Flannery, T. and McKenzie, A. (2013) Climate Action Toolkit. Climate Council: 1-72. https://www.climatecouncil.org.au/author/amanda-mckenzie.

Field Museum (2019) Chicago Community Climate Action Toolkit. Field Museum.org website: 1-4. https://climatechicago.fieldmuseum.org.

First Bungoma County Integrated Development Plan (2013) Development Plan between 2013 and 2017, Bungoma: 1-237. https://bungoma.go.ke.

Food and Agriculture Organization (2011) The State of Food and Agriculture. Women in Agriculture: Closing the Gap for Development. *Lancet,* **2**:1-147.

Francis, O., Moses, N., Oliver, V.W. and Philip, O. (2014) Trend analysis of rainfall and temperature variability and environments of Turkana Kenya. *Environmental Research Journal* **8**(2): 30-43.

Funk, C., Husak, J.G Laura, H. and Michaelsen, J. (2011) Effects of temperature changes on maize production in Mozambique, University of California, Santa Barbara. *Climate Research,* **46** (3): 211-222.

Garrido, A., Gun, J.V.D., Lopez-Gunn, E., Kirstin, I.C. and Villiholth, K.G. (2018) Advances in groundwater governance, Leiden, Netherlands: CRC Press.1- 594. https://wle.cgiar.org.

Garry, J.O.L., Liu, L.D., Macadam, I., Muhuddin, R.A. and Yonghui ,Y. (2015) Water use efficiency and crop water balance of rainfed wheat in a semi-arid environment: sensitivity of future changes to projected climate changes and soil type. *Theoretical and Applied Climatology* **123**(3), DOI: 10.1007/s00704-015-1376-3.

Giordano, M. (2006) Agricultural groundwater use and rural livelihoods in sub-Saharan Africana first-cut assessment. *Hydrogeology journal*, **14** (3): 310-318.

Global Child Nutrition Foundation (2009) School feeding toolkit. Save the Children, United Kingdom, 1-98.

Godau, T., Lungomesha, S. and Max, K. (2019) Manual for estimating irrigation water use using remote sensing and GIS. Federal Ministry for Economic Cooperation and Development, Lusaka. 1-43. https://www.deutscher-rohstoffeffizienz-preis.de/EN/Themen/Wasser/Projekte/laufend/TZ/Zambia/.

Government of Kenya (2010) The Constitution of Kenya. Government Printers: 1-194. http://extwprlegs1.fao.org/docs/pdf/ken127322.pdf.

Government of Kenya (2012) Kenya Vision 2030, Office of the Prime Minister, Ministry of state for planning, National Development and Vision 2030, Sessional paper No 10, 1-172.

Government of Kenya (2013) The crops Act, Government Printers: 1-71. http://www.kilimo.go.ke/wp-content/uploads.

Government of Kenya (2016a) National climate change framework policy. Ministry of Environment and Natural Resources: 1-38. http://www.environment.go.ke/wp-content/uploads/2018/08/Climate Change Framework Policy May2017.pdf.

Government of Kenya (2016b) Water Act. Government Printers: 1-116. https://wasreb.go.ke/downloads/Water Act 2016.pdf.

Government of Kenya (2017) Irrigation Act. Government Printers: 1-116. https://wasreb.go.ke/downloads/Water Act 2016.pdf.

Grimvall. A. and Libiseller C., (2002) Performance of partial Mann-Kendall tests for trend detection in the presence of covariates. *Environmetrics* **13**, 17-84. DOI:10.1002/env.507.

Grosbois, A. M. (2017) Unprecedented satellite survey of global surface water and ocean topography. *Environmental Earth Sciences* **76**(22). DOI: 10.1007/s12665-017-7098-3.

Hanjra, M.A. and Qureshi, M. (2010) Global water crisis and future food security in an era of climate change. *Food Policy*, **35** (5): 365-377.

Hein, L., Mutoko, C.M. and Shisanya, A.C. (2014) Farm diversity resource use efficiency and sustainable land management in the western highlands of Kenya. Elsevier Ltd. *Journal of Rural Studies,* **36:**108-120.

High, C. and Pelling, M. (2005) Understanding adaptation: what can social capital offer assessments of adaptive capacity? *Global Environmental Change,* **15:**308–319.

Hoehn, L. and Niven, I. (1985) "Averages on the Move." *Math. Mag.* **58**, 151-156.

Huang, J., Jikun, H., Rozelle, O., Wang, L. and Zhang, S. (2010) Access to groundwater and agricultural production in China. *Agricultural Water Management,* **97**(10):1609-1616.

Jiri, K. (1993) Classification of transmissivity magnitude and variation. *Groundwater*, **31** (2): 1-7.

Kamal, N. and Pachauri, S. (2018) Mann-Kendall Test-A Novel Approach for Statistical Analysis IJCTT Journal **63**(1): 104 DOI:10.14445/22312803/*IJCTT*-V63P10 www.ijcttjournal.org/archives/ijctt-v63p104.

Kauzeni, S., Majule, E.A. and Mujwahuzi, M. (2013) Exploring opportunities for climate change adaptation in semi-arid areas of Tanzania: A case of Nzega District in Tabora region. *African Journal of Environmental Science and Technology*, **B** (8): 758-769.

Keeping, E. S. and Kenney, J. F. (1962) "Root Mean Square." *Mathematics of Statistics, 3rd ed.* Princeton, NJ: Van Nostrand, pp. 59-60, 1962.

Kent, M. (2011) The Water stewardship and Replenish report, Coca Cola Company: 1-92. https://www.coca-colacompany.com/sustainable-business/water-stewardship.

Kenya National Bureau of Statistics (2010) The Population and Housing Census report. Nairobi, Kenya: 1-546. https://www.knbs.or.ke.

Kerandi, N. M. and Omotosho, J.A. (2008) Seasonal Rainfall Prediction in Kenya Using Empirical Methods Kenya, *Kenya Meteorol. Society,* **2**(2): 114–124.

Kjell, G. and Pervez, G. (2006) Research Methods in Business studies, a practical guide: Prentice Hall, United Kingdom, 3rd edition: 1-247.

Kimosop, P. (2018) Characterization of drought in the Kerio Valley Basin, Kenya using the Standardized Precipitation Evapotranspiration Index: 1960‒2016. *Singapore Journal of Tropical Geography*, https://doi.org/10.1111/sjtg.12270.

Kra’sn’y, J. and Lopez, A. (1989) The General Hydrogeological Map of Nicaragua 1:250,000; Principles of Compilation and Content. Mem. Internat. Symp. on Hydrogeol. maps as tools for economic and social development, Hannover: 413-422.

Kulindwa, K., Micheni, N.M., Odada, E.O., Olago, D.O. and Wandiga, A.S. (2004) Mitigation of environmental problems in Lake Victoria, East Africa: Causal chain and policy options analyses, *Ambio,* **33** (1): 13-23.

Kruger, A.C. and Nxumalo, M. P. (2017) Historical rainfall trends in South Africa. *Water*, **43**(2): 1-13.

Küng, R. (2003) Addressing the dimensions of Transboundary water use. The Nile basin initiative, *Mountain Research and Development*, **23** (1): 4-6.

IPCC (2007) Climate Change Synthesis Report. Contribution of Working Groups I, II and III to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom: 1-987. https://www.ipcc.ch/site/assets/uploads/2018/03/ar4_wg2_full_report.pdf

Laki, S.L. (1998) Management of water resources of the Nile Basin. *International Journal of Sustainable Development and World Ecology,* **5** (4): 288-296.

Lakshmi, S., Steinberg, S. and William, A. (2016) Extreme weather, Health and communities; interdisciplinary engagements strategies. Extreme Weather Society: Springer.1-115. https://www.amazon.com/-/es/Sheila-Lakshmi-Steinberg/dp/3319306243

Lemma, S. and Wondimagegn, T. (2016) Climate Change perception and choice of adaptation strategies, *International Journal of Climate Change Strategies and Management*: **8**(2) 253-270.

Llamas, M.R. and Martinez-Santos, P. (2005) Intensive Groundwater Use: Silent Revolution and Potential Source of Social Conflicts. *Water Sci Technol*. **51**(8):167-74.

Loaiciga, H. (2003) Climate change and groundwater, *Annals of the Association of American Geographers,* **93**(1): 30-41.

Loulseged, M. and Yasir, M. (2008) The Nile Basin Water Resources: Overview of Key Research Questions Pertinent to the Nile Basin Initiative Water Management: 1-34. https://www.researchgate.net/publication/237665257

Lyimo, J.G., Majule, E.A. and Mongi, H. (2010) Vulnerability and Adaptation of Rain Fed Agriculture to Climate Change and Variability in semi-arid Tanzania. *African Journal of Environmental Science and Technology,* **4**(6): 371-381.

Majule, A. E. and Mary, A.L. (2009) Impacts of Climate Change, Variability and Adaptation Strategies on Agriculture in Semi-Arid Areas of Tanzania: The Case of Manyoni District in Singida Region, Tanzania. *African Journal of Environmental Science and Technology* **8**, 206-218.

Makhakha, S.W. and Nafuna H.N. (2019) What life is all about - 1000 years history of Bukusu People, C.H.A.E.M.P Printers1-166.

Martin. R. (2019) Global inequality when unequal countries create unequal people. *European Economic Review*, **111**: 85-97.

Moraa, H., Otieno, A. and Salim, A. (2012) Water Governance in Kenya: Ensuring Accessibility, Service Delivery and Citizen Participation. Ihub Research, July, 1- 2. https://files.ihub.co.ke/ihubresearch/uploads/2012/july/1343052795 537.pdf.

Morton, J.F. (2007) The impact of climate change on smallholder and subsistence agriculture. *Proceedings of the National Academy of Sciences of the United States of America*, **104** (50): 19680-5.

Mukheibir, P. (2008) Water resources management strategies for adaptation to climate-induced impacts in South Africa, *Water Resource Management,* **22:** 1259-1276.

Mukheibir, P. (2010) Water access, water scarcity and climate change. *Environmental Management,* **45**(5): 1027-1039.

Ogara, M. Olago, D. and Wetende, E. (2018) Perceptions of climate change variability and adaptation strategies on smallholder dairy farming systems: Insights from Siaya Sub County of Western Kenya. *Environmental Development*, **27**: 14-25. https://doi.org/10.1016/j.envdev.2018.08.001.

Olago, D.O. (2018) Constraints and solutions for groundwater development, supply and governance in urban areas in Kenya. *Hydrogeology Journal*, **27**(3): 1031-1050. https://doi.org/10.1007/s10040-018-1895-y.

Olsson, L., Opondo, M., Tschakert, P., Agrawal, A., Eriksen, S.H., Perch, S. Ma, L. N. and Zakieldeen, S.A. (2014) Livelihoods and Poverty. Cambridge University Pess: 793-832.

Omaid N., Ruchira B. and Xiangzheng D. (2018) The Dynamics of Land Use Cover and the Statistical Assessment of Cropland Change Drivers in the Kabul River Basin Afghanistan. *Sustainability* **10** (2):1-18.
DOI: 10.3390/su10020423. https://www.researchgate.net/publication/322967933.

Omolo, N. (2010) Gender and climate change-induced conflict in pastoral communities: Case study of Turkana in North-Western Kenya. *African Journal on Conflict Resolution,* **10** (2): 81-102.

Osmo, T.S. (2002) Effective water and sanitation policy reform implementation: Need for systemic approach and stakeholder participation. *Water Policy*, **4** (4): 367-388.

Owiro, O. A. (2004) The Nile Treaty, state succession and international treaty commitments: A case study of Nile water treaties, Konrad Adenaur Foundation, Kenya. https://www.kas.de/c/document library/get file.

Pohlert, T. (2020) Non parametric trend tests and change-point detection. 1-18.

Reid, P. and Vogel, C.   (2006) Living and responding to multiple stressors in South Africa –glimpses from KwaZulu-Natal. *Global Environmental Change,* **16** (2): 195–206.

Rumsey, J. D. (2016) Statistics for dummies. John Wiley and sons, 1- 408. ISBN: 978-1-119-29352-1.

Schimel, D. and Wang, G. (2003) Climate change, climate modes and climate impacts. *Environmental Resource*: **1** (1)-1-35.

Smit, B. and Wandel, J. (2006) Global adaptation, adaptive capacity and vulnerability. *Environmental Change*, **16** (3): 282-292.

Smith, N.S., Whitfield, T.W.A.and Wiltshire, T.J. (1990) "The accuracy of NCS, DIN and OSA-UCs colour Atlases. *Colour Research and Application*, **15** (2): 111-116. DOI: 10.1002/col.5080150209.ISSN 0361-2317.

Sophocleous, M. (2002) Interactions between groundwater and surface water: The state of the science. *Hydrogeology Journal,* **10** (1): 52-67.

UNDP (2021) Sustainable Development Goals. www.UNDP.org.accessed on 10th June 2021.

UNFCCC (2005) Compendium on Methods and Tools to Evaluate Impacts of and Vulnerability and Adaptation to Climate Change: 1- 155 https://unfccc.int/files/adaptation/methodologies.

Water Resources Authority (2019) Strategic Plan 2018-2022: 1-22. https://wra.go.ke.

Webster, A. (1992) Applied Statistics for Business and Economics: Richard D. Irwin Inc., USA, 1-996.

Wolf, T. A. (1998) Conflict and Cooperation along international waterways. *Water Policy*, **1**(2): 251-265.

Wondwosen, T.B. (2008) Tran boundary Water Cooperation in Africa: The Case of the Nile Basin Initiative. *Turkish Journal of International Relations,* **7**(4): 34-43.

APPENDICES

Appendix 1: Farmer Household Survey Questionnaire

Climate change action toolkit for groundwater use for agricultural production in Lwanda Village

Farmer household interview schedule

Part I: Personal data

1. Farmer Name: **2. Gender:**

3. Age (18-25years, 26-33 years, 34-41 years, 42-50 years and above 50 years

4. Highest Education level: Basic, Primary, Secondary, Tertiary and University

5. Bungoma County	6. Bungoma south sub county	7. Kanduyi constituency	8. West Sang'alo Ward	9. Lwanda village

Part II: Household socio-demographic characteristics

(1)	(2)	(3)	(4)	(5)
Names of household members	Relationship to HHH 1.head 2. spouse 3. child 4. others	Sex (F/M)	Marital status Single Married	Annual income and sources

1. Land surface in acres: _________________

6. Farm enterprises schedule (checklist) Farmer Name: Well Code No:

Food Crops	Cash crops	Livestock	Wetland surface	Groundwater technologies adopted

2. Crops grown under irrigation

Crops	**Ha.**

PART III: Groundwater harvesting

Shallow well data		**2.Groundwater use**	
1.1 When was the well dug?		2.1 Is water used for drinking and household chores Yes/No	
1.2 What was the depth in it was first dug?		2.2 Is water used for livestock? Yes/No	
1.3 What is the cost of digging a well?		2.3 Is water used for irrigation? Yes/No	
1. 4 How many times in a year has it been rehabilitated		2.4 How do you draw the water from the well? Using electric water pump, Hand pump, Winch, can and rope	
1.5 What is the cost of rehabilitation?			
1.6 Which month of the year do you rehabilitate the well?		2.5When do you irrigate the crops? Morning or evening	
1.7 How do you know that it is time to rehabilitate it?		2.6 After how many days do you irrigate the crops in a week?	
1.8 How long does it take to use the water after rehabilitation?		2.7 What type of irrigation system do you use? Bucket, sprinkler or drip	
1.9 What I the depth of water after rehabilitation?		2.8 have you ever been trained on irrigation? Yes/ No	
1.10 Has it ever dried up? Yes/No		2.9 Do you own a water pump? Yes/ No	
1.11What do you think is the cause of drying up of the well.		2.10 Do you have overhead tank? Yes/No	
1.12 What is your other source of water when it dries up?		2.11 Are you aware of the ministry you should report to any water issues? Yes/ No	
1.13 How far is your other water source?		2.13 What was the reason for digging the well?	
1.14What do you use to cover the well?		2.14 How many households use water from this well?	

PART IV: Information and technology access

1.Agricultural information exchange	**2.Climate information exchange**
1.1 Have you ever received agricultural information? Yes/No	2.1 Have you ever received weather information? 1=Yes 2=No
1.2 What are sources of agricultural information?1=Government ministries 2=radio 3=Television 4=private institutions 5=other farmers 6= not specific organization	2.2 Who are the sources of weather information? =Government ministries 2=radio 3=Television 4=private institutions 5=other farmers 6= not specific organization
1.3 What type of agricultural information have you received? 1=Crops, 2=irrigation,3= markets,4= water management	2.3 How often do you receive weather information and where? 1=weekly 2= monthly 3=quarterly 4= annually 5= not at all
1.4 How often do you receive agricultural ›rmation?1=weekly 2= monthly 3=quarterly annually 5= not at all	2.4 How did you use this weather information to your advantage?

PART V: Data collection forms on groundwater level in Shallow wells in Lwanda

Month: ________________

Farmer Name	Well Code No	Current well depth (m)	Distance from well entrance to water level in meters			
			1st week	2nd week	3rd week	4th week
	1					
	2					
	3					
	4					
	5					
	6					
	7					
	8					
	9					
	10					
	11					
	12					
	13					
	14					
	15					
	16					
	17					
	18					
	19					
	20					
	21					
	22					
	23					
	24					
	25					
	26					
	27					
	28					
	29					
	30					
Sign of data Collector						

PART VI: Field data collection forms on shallow wells dimensions in Lwanda Village

Month: ___________

Farmer Name	Well Code No	Year when the well was first developed	Well dimension				No. of times in a year the well is excavated	If the well has been excavated since it was first dug
			Original depth (m)	Current depth (m)	Change in depth (m)	Diameter in depth(m)		
	1							
	2							
	3							
	4							
	5							
	6							
	7							
	8							
	9							
	10							
	11							
	12							
	13							
	14							
	15							
	16							
	17							
	18							
	19							
	20							
	21							
	22							
	23							
	24							
	25							
	26							
	27							
	28							
	29							
	30							
Sign of data Collect or								

Appendix 2: Focus Group Discussion Check List Schedule

Climate change action toolkit for groundwater use for agricultural production in Lwanda Village in Bungoma

Number of participants: ________________Date: ________________

Information sheet

1.Benefits of shallow wells	**2. Challenges of Shallow wells**
1.1	2.1
1.2	2.2
1.3	2.3
1.4	2.4
1.5	2.5
3.Causes of declining water in shallow wells	
3.1.	
3.2.	
3.3.	
4.Key Focus area that can make using water from shallow well for agricultural production successful	
4.1.	
4.2.	
4.3.	
4.4.	
4.5.	
5.Institutional arrangements- Legislations, institutions and, Policy guiding groundwater usage	
5.1.	5.5
5.2.	5.6
5.3	5.7
5.4	5.8
6.Capacity building for shallow wells development for groundwater harvesting (Vote priority)	
6.1. Adequate staffing capacity	
6.2. Easy Access to information	
6.3. Easy Access to technology	
6.4. Adequate funding	
6.5. High charges in terms of water permit	
6.6. Adequate water storage capacity	
6.7. Frequent monitoring of shallow wells by the relevant ministries	
6.8. Cost of digging wells is	
6.9. Duration when shallow wells remain dry (without water)	
7**. Groundwater use in for agricultural production in Lwanda Village**	
7.1. Livestock Production	
Dairy cattle Indigenous cattle Shoats Chicken	
7.1.1. Livestock with highest water use	Daily water use in litres per livestock
7.1.2. Livestock with lowest water use	Daily water use in litres per livestock
7.2. Crop Production	
Vegetable Food crops Cash crops Tree Nursery	
7.2.1.A Crop with highest water use	Irrigation times per week
7.2.1.A crop with lowest water use	Irrigation times per week
8. Interference with wetlands	
8.1 cultivation of vegetables	8.2 Grazing of livestock

Appendix 3: Key Information Informants Interview Schedule

Climate change action toolkit for groundwater use for agricultural production in Lwanda Village in Bungoma

Name of Ministry: ______________Date:

Information sheet

Checklist to assess groundwater use reporting system by Ministry			
A	Systems for reporting on state of shallow wells done by smallholder farmers		
	Description	Answer (Yes, some extent, No)	Comments
1	There is operational definition of shallow wells		
2	The operational definitions meet national standards -international standards		
3	Are same operational definitions of indicators systematically followed by smallholder farmers?		
4	Data collection of shallow wells is clearly assigned to relevant staff		
5	All actors use standardized data collection forms on shallow wells		
6	Clear instructions how to fill data collection forms		
7	There is legislation on groundwater?		
8	There are policy guidelines on use of groundwater for agricultural production		
9	A water permit license issued on use of shallow wells for agricultural production		
10	There is a clear definition of what constitutes training of farmers –based interventions (presence of course outline, expected knowledge gained)		
11	There is a complete list (inventory) of farmers trained that are periodically updated		
12	There is a complete list (inventory) of shallow wells that are periodically updated		
13	Shallow wells are identified using identity numbers that follow a national system		
14	There is a complete list of Overhead tanks for harvesting groundwater that are periodically updated		
15	Overhead tanks for harvesting groundwater from shallow wells are identified using identity numbers that follow a national system		
16	There is a structured way to capture farmers' participation in groundwater issues.		
17	There is a budget allocated to groundwater (shallow wells)		

Appendix 4: Field Photos

Photo 1: The artisans rehabilitating a shallow well

Photo2: Shallow well artisans excavating the well manually to remove sediments behind them

Photo 3: one of the shallow well owners drawing water manually from a shallow well


Photo 4: Researcher viewing groundwater as the farmer observes.

Photo 5: Local tools used to habilitate shallow well