An Analysis of Rain Water Harvesting Technologies and Water Quality for Irrigation and Adoption by Communities in Odwayne District, Somaliland

By

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DECLARATION

This thesis is my original work has not been presented for an award in any other university.

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DEDICATION

I dedicate this work to my esteemed parents and my beloved wife, whose unwavering support has been indispensable throughout the completion of this project. Their constant encouragement and inspiration have been instrumental in my academic journey. Additionally, I extend my heartfelt gratitude to my caring mother, brothers, and sisters for their invaluable guidance, which has significantly contributed to the successful culmination of this thesis.

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ACRONYMS AND ABBREVIATIONS

ASALs	Arid and semi-arid lands
CV	Coefficient of variation
EC	Electric Conductivity
ESP	Exchangeable Sodium Proportions
FAO	Food and Agricultural Organization of the United Nation
FGD	Focus Group Discussion
GDP	Gross Domestic Product
IGAD	Intergovernmental Authority on Development
IUCN	International Union for Conservation of Nature
KIIs	Key Informant Interviews
Ksh	Kenyan Shilling
LEISA	Low External Input Sustainable Agriculture
MM	Millimeters
MoA	Ministry of Agriculture of Somaliland
NGO's	Non-governmental Organizations
PRM	Poisson Regression Model
PVC	Polyvinyl Chloride
RWH	Rainwater Harvesting
SAR	Sodium Absorption Rate
SPSS	Statistical Package for Social Scientists
SSA	Sub Saharan Africa
SWALIM	Somalia Water and Land Information Management
TDS	Total Dissolved Solids
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNICEF	United Nations Children's Education Fund
USD	United State Dollars
VIF	Variance Inflation Factor

GENERAL ABSTRACT

In recent years, there have been concerted efforts to encourage the adoption of rainwater harvesting (RWH) technologies in Somaliland, chiefly through the construction of dams, shallow wells, and underground water tanks in the Odwayne District. Despite the importance of these technologies as alternatives to traditional sources of water in the region, their uptake has been low. Moreover, there is a dearth of studies evaluating farmers' perception and utilization of RWH, as well as its impact on their livelihoods and the environment. To address these gaps, evidence-based information is needed to guide the development of RWH policies and programs. Furthermore, it is crucial to evaluate different water harvesting techniques to determine their sustainability and impact on community livelihoods, and to inform future interventions. The present study seeks to assess agropastoral' knowledge and management of various RWH technologies, compare their effects on water quality and soil, and identify the most sustainable options for future interventions.

A multistage sampling technique was used to collect data from a total of 180 farmers (100 non-applicants and 80 PED applicants). Key informant interviews (KIIs) and group discussions (FGDs) were also conducted to refine the questionnaire; data collected during the KIIs and FGDs were analyzed and used to validate the descriptive results. Water samples were collected from dams, *Barkeds* and shallow wells during the dry and wet seasons.

A binary logit model was used to estimate factors influencing the technology adoption and a Poisson regression model (PRM) was used to determine factors influencing the intensity of technology adoption. Soil and water physicochemical data were collected, analyzed for each sample, and compared according to the Food and Agriculture Organization of the United Nations (FAO) standards for irrigation water quality. Survey, soil and water data were analyzed with STATA version 14 and Statistical Software for Social Scientists (SPSS) version 22, respectively.

The results of the demonstration show that educational level and access to training have statistical differences between users and non-users of RHW technology. *Berkads* was also found to be the main source of water for households and livestock in the area. Social capital and collective action are very high due to the large number of respondents who are members of water associations.

Results from the Logit model showed that household size, education, land size, access to training, and information were also found to significantly influence the adoption of RWH technologies. Results from PRM showed that variables such as access to RWH information, frequency of fetching water, water shortage, total farm income as well as the adequacy of water were found to significantly influence the intensity of adoption.

This study also compared the levels of parameters obtained from three water harvesting technologies with the recommended degree of restriction of the use of the water. The key finding was that shallow wells were predominantly saline shallow wells compared to the other harvesting technologies. The study also found out that the drier season had higher electric conductivity compared to the mid and rainy seasons. *In-situ* water quality aspects are mainly affected by the inherent aspect of the parent material thus site experiences dryland salinity.

Based on these results, the government should develop permanent water resources for community use, such as wells and boreholes. Group training sessions can also be organized to increase the technical knowledge of local people and facilitate the flow of information about RWH technologies. This can be done in collaboration with donor agencies and local NGOs. Studies have shown that dams and *Berkads* are best suited to produce hot water for irrigation in the Odwayne region. Shallow wells have high salinity, which affects soil fertility and plant growth. Therefore, in light of climate change, sustainable agricultural production in drylands requires an appropriate rehabilitation plan.

CHAPTER ONE

INTRODUCTION

1.1 Background Information

The yearly increase in global population has a direct implication on the availability of water, the higher the population is the increase in water demand. The exploitation of surface and groundwater resources is being carried out faster than they can be recharged (Julius, 2013). Therefore, water-saving has become a need for the present times. Rainwater harvesting (RWH) involves the capture of rainwater at the time of the downpour or where it falls, storing the water above the ground, or underground for later use. As the groundwater resources get depleted, rainwater harvesting has become a way of solving water availability problems (Santos *et al.*, 2009). Rainwater harvesting has been adopted in many countries as a sustainable source of decentralized water supply. Rainwater harvesting is an efficient use that benefits households and improves water quantity and quality (Morey *et al.*, 2016).

Rainwater harvesting is defined as the collection of rainwater from rooftops and other artificial reservoirs, artificial surfaces, and natural or rock drainage areas for industrial, domestic, agricultural and environmental uses (Ezenwaji, 2014). According to Dean et al. (2012), CBE, when applied under the right conditions, is practical and economical and can be a sustainable source of clean water. In principle, rainwater harvesting is an easy-to-use technique that requires little experience or expertise and therefore offers many potential benefits.

Somali economy depends mainly on the natural environment, to the livestock sector, the usage of natural goods, and agriculture. The people's livelihoods rely on these assets, together with clean water, the use of natural medicinal and other natural resources at households (building, thatch, and fuel). Livestock constitutes the main source of income and contributes greatly to the Gross Domestic Product (GDP) in both Somalia and Somaliland. Livestock production is leading in Somaliland contributing a GDP of 60 % whereas in Somalia it contributes to 40 % of the GDP. Somaliland is the biggest exporter of livestock products, accounting for 91 % of animal products being mainly sheep and goats (IGAD, 2013). Unlike livestock production, agriculture or farming contributes between 8 % and 15 % of the Gross Domestic Product in Somaliland (MoA, 2017). Several seasonal rivers exist in Somaliland which run only in the rainy seasons and after serious storms. Their flow is typically accompanied by flash floods. During the dry seasons, the river valleys stay dry, though sub-surface wells are often established in some river beds in cases where the water level is shallow. Surface water collection is additionally practiced in natural depressions like water ponds (*Balli*), artificial earth dams (*Waro*), and artificial cisterns (*Berkads*) largely used for domestic and livestock use.

1.2 Statement of the Research Problem

Somalia is classified as one of the world's poorest countries, having suffered twenty-eight years of civil war. The situation has been aggravated by the failure of seasonal rains and recurrent drought for the last few decades (IUCN, 2006). About 95 % of Somalia is arid or semi-arid lands (ASALs). The country lies within the "Horn of Africa Biodiversity Hotspot" and leeward side of Kenya and Ethiopia highlands, which is characterized by sparsely vegetated, arid, and rocky plains, but furthermore shows abundant bushland, wooded valleys, and hills and grasslands (Muchiri, 2007).

In Somaliland, smallholder farmers face a number of challenges to mitigate the dry season and improve water productivity in rain-fed agriculture. As a result, government agencies and development organizations have made commendable efforts to support community-based wastewater management projects. The goal is to increase the food production of Somaliland communities, making them more resilient to frequent droughts. This is done mainly through the construction of dams, shallow wells and *Berkads* (underground reservoirs) in Odwayne district. However, there are no studies that analyze the perception of rainwater harvesting, its use, acceptability and contribution to farmers' livelihoods, as well as the sustainability and environmental impact of building these large-scale irrigation water infrastructures.

Oduor (2007) showed that Somaliland and Somalia are still in process of implementing and developing policies regarding water use. Hence harvesting of rainwater is not sufficiently included in policy documents in Somaliland. This creates the need for evidence-based information to support the governments in the development of rainwater harvesting policies in programs and projects. Though many organizations are involved in water-related activities, there is inadequate capacity by the community and government to take benefit of the potential offered by harvesting rainwater. Additionally, there is a need to evaluate the adoption of various water harvesting for the identification of the best options that are environmentally sustainable and provide better livelihoods to communities to guide future interventions. This study, therefore, tries to address the aforementioned knowledge gaps.

1.3 Objectives of the study

1.3.1 General objective

The study aimed at assessing knowledge, perceptions, adoption of rainwater harvesting technologies and the quality of harvested water for irrigation use in Odwayne District Somaliland.

1.3.2 Specific Objectives

1. To evaluate agropastoral perceptions and knowledge about rainwater harvesting and the existing management and organizational structures for different rainwater harvesting technologies in Odwayne District, Somaliland.
2. To assess the factors that influence the adoption and adoption intensity of rainwater harvesting (RWH) technologies in Odwayne District, Somaliland
3. To assess the effect of rainwater harvesting technologies on irrigation water quality in Odwayne District, Somaliland.

1.4 Research Questions

1. What are the agropastoralists' perceptions and knowledge about rainwater harvesting, existing knowledge, and organizational structures for different rainwater harvesting technologies in Odwayne District, Somaliland?
2. To what extent do rainwater harvesting (RWH) technologies and utilization contribute to the productivity of crops and pastures by agropastoralists in Odwayne District, Somaliland?
3. Are there differences in water and soil qualities in selected water harvesting technologies?

1.5 Justification of the study

Results obtained from this study provide information regarding the existing rainwater harvesting technologies in Somaliland, their sustainability, and their utilization by the communities for effective planning of future interventions. The study evaluates the different utilization strategies and the benefits derived and identifies the most effective approaches that enhance sustainability. The study will also look at the community’s perceptions and organizational structures in managing rainwater harvested and their effectiveness. This information will help policymakers to come up with more rational policies on rainwater harvesting, their effective utilization, and their sustainability for better livelihoods of the communities. It will also help the government to make more rational decisions on which rainwater harvesting technologies to promote in the annual budgetary inclusion of capital investments. Once this is done, producers' activities are likely to be enhanced, hence, farmer's household income, welfare, and national growth at large improved

CHAPTER TWO

LITERATURE REVIEW

2.1 Rainwater Harvesting, Challenges and Benefits in Somaliland

Rainwater harvesting encompasses all techniques of conserving, collecting and storage of rainwater into natural reservoirs or tanks, or infiltration or recharging to the groundwater to improve groundwater storage (Hatibu *et al.*, 2000). Rainwater harvesting uses is an extensive choice of practices for capturing all kinds of surface runoff then stored into a natural and artificial catchment or onsite stored where it falls for purpose of different uses of agriculture, domestic and livestock drinking or by addition of groundwater level (Mbilinyi *et al*., 2005).

Somaliland is characterised by low rainfall and high temperatures, resulting in high evaporation of surface water. Due to the climatic conditions, large areas of land are used as reservoirs, which is necessary to create sufficient flow in ponds and dams. After the rains, large amounts of accumulated sludge enter the reservoirs, reducing their life span. Consequently, operating costs are higher with manual or mechanical dilution. Some NGOs, such as the Hargeisa Rural Development Cooperation, estimate that the cost of leachate disposal for a tank of about 1,000 m2 is $20,000 to $30,000, and most concrete tank systems, including *Berkeds*, are cracked (Odour, 2007).

The quality of construction in *Berkads* has changed significantly since the 1950s. In the 1970s, water quality deteriorated considerably due to conflict, lack of maintenance during displacement and poor construction (Muthusi, 2007). At the time, most efforts were aimed at making *Berkads* as fast and cheap as possible. An assessment of rural water supply by the Somali Water and Land Information Management Company (SWALIM) showed that more than half of the *Berkads* were damaged. The challenge is to improve the standards of their design, construction and reconstruction (SWIMS, 2007).

Rainwater harvesting has the potential to significantly improve the livelihoods of rural communities. By utilizing runoff water, it can enhance agricultural productivity, promote food security, involve local community members in the planning and implementation process, and create employment opportunities for artisans and processors within the community (FAO, 1997).

2.1.1 Indigenous Technologies of RWH in Somaliland

Rainwater harvesting in Somaliland has a long history, dating back to the colonial period. The presence of structures like berkads, waro, and xadlings serves as evidence of the traditional practices of harnessing rainwater (Muthusi, 2009). In the dry season, communities often migrate in search of water and pasture for their livestock, relying on camels as the primary means of water transportation. Water is transported more frequently during the dry season and less frequently during the rainy season (Nele, 2003). In areas with sufficient water sources such as rivers or shallow wells, goats and sheep are raised. The introduction of berkads and private dams has played a role in facilitating increased settlement in the region. The first berkads were constructed in the 1950s, during the British colonial rule (Foerch, 2003). The historical context provides valuable insight into the long-standing practices of rainwater harvesting in Somaliland.

2.2 Rainwater Harvesting practices in Somaliland

Numerous RWH technologies previously used and recently developed in Somaliland can be categorized into two: macro and micro catchments, and rooftop harvesting techniques. Macro-catchment technologies entail the gathering of runoff from huge areas which might be at a considerable distance from where it is being used. These technologies deal with large runoff flows diverted from surfaces including roads, hillsides, and pastures. Hillside sheet/rill runoff usage, rock catchments, sand, and earth dams (Mati, 2007). Micro-catchment technologies acquire runoff close to the growing crop and refill the soil moisture. Micro-catchment technologies are specially used for the cultivation of medium water-demanding crops like maize, sorghum, and groundnuts. Some of the technologies include strip catchment tillage, Zai pits, contour bunds, semi-circular bunds, and a meskat-kind system. Whereas rooftop technologies *(berkad guri)* are common in towns and some villages and have the benefit of collecting relatively clean water (Muthusi, 2007).

2.2.1 Runoff based Rainwater Harvesting

Rainwater harvesting involves collecting surface water flows already collected in the watershed, collecting rainwater from large areas (hills and slopes) through canals, rivers, roads, and streams, and conveying it to agricultural lands far from the watershed (Mati, 2012). This type of RWH is characterized by the predominance of turbulent runoff and the direction of rainfall flow in the watershed (Hatibu and Mahoo, 1999). In runoff-based RWH systems, the runoff can come from the field itself or from an external catchment. This includes direct use on the field or temporary storage for supplemental irrigation. It is classified by two criteria: the amount of water stored and/or used and the length of the watershed (Teweldebrihan, 2014).

At the community level, earthen dams and catchments are constructed to store large amounts of water, primarily for livestock and small-scale irrigation. In the watersheds of Kenya, Somalia, parts of Uganda (south and northeast), and Ethiopia (south, east, and north), these earthen catchments and dams are essential for livestock production. Clay dams in Kenya were built with the help of white settlers. In Somaliland, underground water tanks (100-300 cubic meters), lined with concrete or mortar, are used to keep livestock and certain animals (dairy cows and calves, weak or sick animals out of the main herd). Dug wells and ponds (often called charcoal dams) were also used to supply water to households and livestock, especially on flat land.

2.2.2 *In-situ* Rainwater Harvesting

In any RWH framework, the primary step involves strategies that upgrade the quantity of water spared within the soil profile. Hence, those kinds of water collecting structures include ways which are able to increase the amount of dampness within the profile through holding water wherever it falls; there's no partition among the region where precipitation is gathered and where it is put away. This sort of water collecting is significant in regions in which the soil water capability is expansive adequate additionally the precipitation amount is rise to or more prominent than the amount required with the help of crops (Hatibu and Mahoo, 1999). On-site water harvesting innovations focus on retaining rainwater in built-up fields and croplands, as opposed to agricultural systems that focus on runoff (Matthews, 2014). The most common innovation is conservation tillage, which aims to retain as much water as possible in the soil.

In situ water conservation is one of the most effective and efficient innovations that can be incorporated into almost any land use structure (Rockstrom, 2000). To date, ex situ management is the least widespread and relies on regional and traditional practices (Reij, 1996, Reijntjes *et al.*, 1998). The primary aim is to mitigate soil degradation processes and effectively manage the adverse impacts of runoff. It is widely recognized that soil conservation measures play a crucial role in reducing runoff. One outcome of implementing on-site water conservation practices is the accumulation of sediment in designated areas, effectively limiting its dispersion across the field.

2.2.2.1 Small external catchment systems

It consists of shallow flooding, surface runoff, and spreading over farmland and fields, with the formation of embankments and landing channels. Runoff is channeled through conventional channels, road culverts, diversion channels and drainage ditches (Ngigi, 2003). In some areas of Kenya (Machakos, Kitui, and Laikipia), runoff from roads and runways is collected and used to recharge water systems and agricultural land. A similar system exists in southwestern Uganda, where runoff from ditches, bushes and road debris flows into banana plantations (Kiggundu, 2002).

2.2.2.2Micro-catchment systems

Micro-harvesting concentrates runoff within farmland on stems, particularly trees containing natural products, crop clusters, and row crops, essentially changing the structure and areas of cultivation (Blanchard, 2012). Field-based HWH approaches include Negalimus in Kitui, Kenya, which divides cropland into sub-communities to allow for the flow of individual crops, such as papayas and oranges, and Chololo Pit in Dodoma, Tanzania, which allows for the cultivation of multiple crops, such as maize and sorghum. Some innovations have also been made. The strategy of digging shallow pits to concentrate runoff and reduce waste and manure is found in many AES growing areas. Napier grass and banana or papaya are grown in the Zai (Burkina Faso), Matengo (southern part of Tanzania), and Tambukiza (Kenya) boreholes. The names are numerous (Ngigi 2003).

Micro-irrigation methods promoted and used in different parts of SSA include rice terraces and moisture retention trenches. Fanya Chini terraces: in the Arusha region of Tanzania, techniques have been developed to throw the soil downwards rather than upwards. Fanya Ju terraces are created by digging into the soil along contour lines to create slopes. In semi-arid areas with relatively steep slopes, soil erosion can be significantly reduced (Tiffen, 1994; Thomas, 1997). Stone walls and ditches are used to retain water in the arid areas of southern Kenya, while stone ditches and terraces are used in Ethiopia. In northwestern Somalia, retaining walls have been reported to increase sorghum yields by 80% (Critchley, 1987).

2.3 Factors Influencing Rainwater Harvesting in Somaliland

2.3.1 Rainfall

Somaliland receives relatively low and erratic rainfall, mainly due to downdrafts and intermittent humidity. The country is also downwind of the Kenyan and Ethiopian highlands. The first season, "G'u", runs from March to July, while the second, "Deyr", runs from August to November. Rainfall in these seasons is generally heaviest from April to June and October to November. The two dry seasons are *'Jilal'* and *'Hagai'*, from December to March and July to August respectively (Muchiri, 2006).

2.3.2 Potential evapotranspiration

Somaliland has a very high evapotranspiration capacity, higher than the total rainfall. Annual evapotranspiration in the western and *Togdheer* regions ranges from 1000 mm to 3000 mm (Muchiri, 2006). Therefore, the southern region is more suitable for surface water reservoirs than the northern and northeastern regions. Potential evapotranspiration is particularly important in the design of on-site stormwater management systems. The ratio of potential evapotranspiration to precipitation helps determine appropriate locations for erosion control and groundwater storage, which should be less than 0.6 in dry areas and greater than 0.6 in wet areas (Petersen, 2017).

2.3.3 Air temperature and wind speed

Temperature and wind speed are important in open tank and RWH design, especially when evaporative losses are considered. Suggested temperatures in Somaliland are generally too high throughout the year, although they are slightly worse during the Hagai season. The average monthly temperature is 31-33°C in the Burao and Togdheer regions and 36-38°C in the northern Berbera region in March (Mutua, 2009). Local people report higher temperatures in some areas. In Somaliland, the coldest months are from November to February and the hottest months are July and August (Muchiri, 2007).

2.3.4 Soil types

Soil type is critical in determining whether the collection system is subject to direct rainfall or runoff. Soils with low infiltration capacity can be used for runoff-type structures, while soils with high infiltration and storage capacity (natural or artificial) are more suitable for in situ water collection structures (Muchiri, 2009).

2.4 Organizational structure and governance of RWH

Water administration includes the overseeing of water on a day-by-day, week-by-week, regular and yearly premise utilizing a coordinates framework including clients which is individuals, foundation, back, and other inputs and assets. Though water administration is the arrangement of political, community, monetary, and organizational frameworks that are put to alter and oversee water assets and the conveyance of water administrations, at distinctive levels of society (Rogers and Corridor, 2007). The suggestion for water administration is an expanding requirement for shrewd catchment administration choices in Sub Saharan Africa in common and regular water collecting catchments in specific since water is such a constraining figure (Huitema, 2009). The part of regulation administration is changing from giving advancement to giving administrative and oversight administrations. This part of 'honest broker' will require to prove given by water bookkeeping to oversee over the top and clashing water requests and arrange trade-offs (Chaffin, 2014).

Administration comprises the rules, components, and forms through which water assets are gotten to, utilized, controlled, exchanged, and related clashes are overseen. The administration recognizes the basic political measurements of those assets which are progressively challenged (Hak, 2016). Administration frameworks decide who gets what water, when and how, and who has the proper water and related administrations and their benefits (Allan, 2012). Framework and bequest water laws, costs, rules, and residency decide who gets what water in a river bowl, particularly when there's water deficiency. Water bookkeeping gives straightforwardness for how water allotments are made and how trade-offs are tended to for moved forward water governance.

2.5 Utilization of Rainwater Harvesting

For food production to continue to increase with population growth, water productivity must improve significantly in future generations to produce more food (Rockstrom 2002). More than 60% of the population depends on rainfed agriculture, and in Sub-Saharan Africa, rainfed agriculture accounts for about 30-40% of the region's GDP (World Bank 1997). About 95% of agriculture is rainfed and only 5% is irrigated. This suggests that rainfed agriculture will remain the cornerstone of food production in SSA for the foreseeable future.

The study area is an arid region with very low conventional agricultural yields. This is due to relatively low and erratic rainfall and poor rainwater harvesting, as the soils are predominantly coarse-grained clay, with high losses through runoff and evaporation from the soil surface (Hensley et al., 2000; UN-HABITAT, 2003).

Rainwater harvesting and management systems in Somaliland are classified according to the purpose for which they are used. They include crop production, livestock production, and domestic water use and storage systems (Biazin, 2012). Crop production systems are collection and storage systems, where runoff water is collected and stored in tanks for later use, or direct rainwater harvesting systems, where water is stored in the soil on site. Methods that benefit from direct runoff and are used for supplemental or complete irrigation include sediment tanks, ponds, dams, and flood or river water. These methods are common in south-central and southern Somaliland and parts of northwestern Somaliland. Other areas, especially the southern coastal areas, benefit from flooding, particularly in the Juba and Shabelle river basins (Venema, 2007). On the other hand, some pastoral systems use runoff and groundwater to produce livestock.

Runoff is collected and stored in natural depressions or in artificial reservoirs such as ponds, *Berkads* and dams. The stored water is regularly used for agricultural production and domestic needs. In areas with shallow groundwater, water is also withdrawn for animal use (Petersen, 2012). Finally, domestic water collection and storage systems directly use rainwater and groundwater. Rainwater is collected from roofs and rocks and stored in concrete tanks, locally called *Berkad guri*. In areas with sufficient rainfall, rainwater is stored in sandy river beds. Water for domestic use can also be drawn from shallow wells and springs (World Bank 2003).

2.6 Water quality

Understanding irrigation water quality data is essential for effective long-term water management. The quality of water in an irrigation system is determined by its impact on the soil and crops and by its management (Faillace, 1986). High crop quality can only be achieved by using high quality water and the choice of inputs is optimal. The properties of water that describe its quality vary from source to source (Rawat, 2018). Water properties vary widely, including soil and climate. Locally available water quality can also vary considerably, depending on whether it comes from surface water sources such as streams and lakes, topographically altered aquifers, or chemically treated aquifers (Warrier, 2017). The chemical composition of the feed water can affect plant growth, including toxic water quality or lack thereof, or provide additional comfort to plants (Acosta-Motos *et al.,* 2017).

2.6.1 Water Quality and Irrigated Agriculture

The quality of irrigation water depends on the type of salt and its dissolved content. Indeed, different soils have higher total salt concentrations, which can cause problems for crops and reduce yields (Andreas, 2007). Water quality is determined by its physical, chemical and microbiological characteristics. These water quality characteristics vary considerably around the world. Therefore, criteria for natural water sources used for different functions must be established based on almost all of the specific water quality parameters that affect the potential use of the water. Physical water parameters include color, odor, turbidity, evidence, temperature, and conductivity, which are good indicators of pollution (Kumat *et al.,* 2007). The suitability of water for a particular use is determined by its long-term consequences and severity. Soil issues such as salinity, iodine content, alkalinity, toxicity, and permeability are mentioned in the following sections.

2.6.1.1 Salinity

Salt damage occurs when large amounts of salt accumulate in the upper soil layers (root zone). In saline areas, plants can no longer extract the necessary amount of water from the soil, which increases the demand for water (Bauder, 2008). These salts are water soluble and are primarily transported by water. In order to achieve greater production of cuttings, large clumps should be directed to an appropriate water source and used in excess. In areas with high salinity, it is important to filter the salts collected in the root zone to reduce salinity (Warrier, 2017).

2.6.1.2 Sodicity

Soils with high sodium ion content are called sodic soils. From an agricultural perspective, sodic soils are soils that contain sufficient exchangeable sodium to adversely affect the reproduction of most crops. Excessive amounts of exchangeable sodium can have a detrimental effect on the physical and natural properties of the soil and significantly or completely inhibit plant growth. In saturated soils, the soil surface becomes a hard, impermeable layer that cannot support standing water, limiting the airflow necessary for natural soil movement (Haritash, 2016). This results in poor plant growth and ultimately lower yields.

2.6.1.3 Alkalinity

The ability of water to neutralize additional acids is called pH and is the most important criterion when choosing a high pH medium for rooting. Over time, the pH scale can be altered by higher pH water. Alkalinity is usually measured by the degree of calcium bicarbonate or calcium carbonate (Koech, 2016). Adding acid to the water to neutralize high bicarbonate levels, or using fertilizers containing ammonia, is not recommended. These plants grow exclusively in cold regions and have a low tolerance for ammonium, requiring unusual treatments (Warrier, 2017).

2.6.1.4 Toxicity

Because water contains nutrients mixed with water, qualitative toxicity can occur when plants take in water containing ionic components. High concentrations of toxic components can inhibit plant growth and development and result in low yields. The main ionic components are boron, sodium and chloride. High concentrations are not the cause of ham (Tsado *et al.*, 2014). Water infiltration and salinity can also cause damage. As they prepare for transpiration, degraded particles move into the water and accumulate to dissolve. These particles block the plant's stomata. Coordinated application of toxic particles that can be absorbed by sprinklers can also cause toxicity problems. Sodium and chlorine toxicity is dangerous to sensitive plants such as citrus (Wimbaningrum, 2015).

2.6.1.5 Water Infiltration

The rate of infiltration or water uptake can be an important condition for the delivery of water from the soil surface to the root zone and for the reduction of salinity by filtration. Infiltration problems occur when infiltration rates fall to unattractive levels. Due to low infiltration rates, very little water reaches the plant roots or remains on the soil surface. Furthermore, the rate of water infiltration into the soil varies over a wide range, depending on soil structure, soil compaction, available natural materials, water quality and soil chemistry.

2.7 Study Area

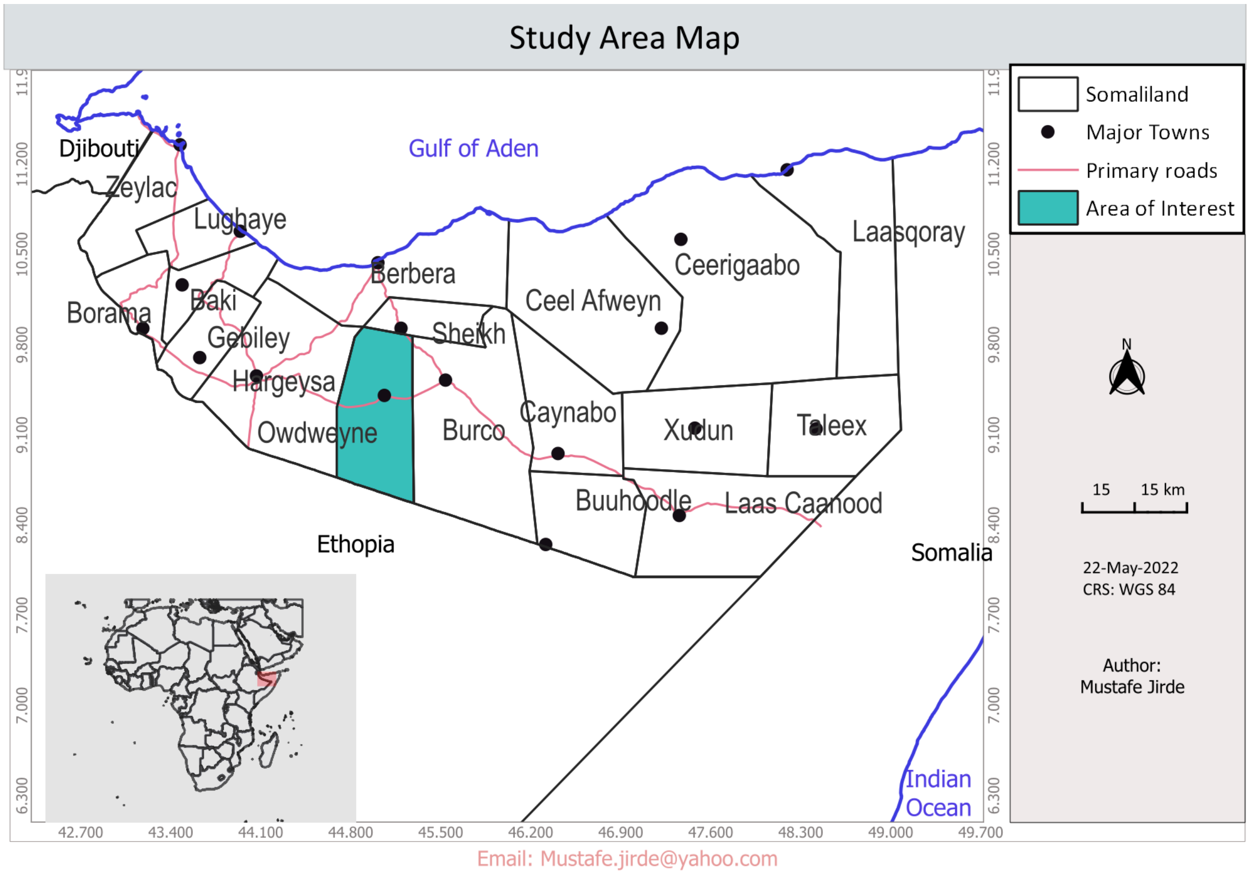

Figure 2.1: Study area map of Odwayne District of Somaliland

The study was conducted in Odwayne District, Somaliland (Figure 2.1). The climate is generally dry, with an average annual rainfall of 474 mm, with rainfall divided into two seasons: a long rainy season, "Gu", which begins in March, and a short rainy season, "Dale", from August to October. The average annual temperature is 27°C. Seasonal rivers are the main source of water during the rainy season, but dry up after the rainy season. The region is subject to high temperatures and high evaporation rates. In terms of land use, most of the land in the Odwayne area is used for agricultural grazing, mainly by smallholders. Goats, sheep and camels are raised in the area.

CHAPTER THREE

An Analysis of perceptions, knowledge, and management of rainwater harvesting (RWH) technologies among Agropastoralists in Odwayne District, Somaliland

3.1 Abstract

Despite the increased efforts in promoting rainwater harvesting (RWH) technologies, the benefits accrued from the adoption remain low. Understanding the causes of low adoption and the socioeconomic differences between adopters and non-adopters is important to inform interventions aimed at increasing the adoption. This study, therefore, sought to address this by assessing the differences in socio-economic and institutional attributes among adopters and non-adopters of RWH technologies, the knowledge, and perceptions of agropastoral regarding RWH, while also documenting the existing management and organizational structures for different RWH technologies in Odwayne District, Somaliland. Information from this study is essential in providing information about the existing RWH technologies for the effective planning of future interventions. Participatory rural appraisal techniques were used in collecting qualitative data regarding the attitude and practices of rainwater harvesting techniques in the area. A multistage sampling technique was used to collect primary data from 194 respondents using a semi-structured questionnaire. Descriptive statistics like frequency and percentages were used to present the data from the study. Results showed a significant difference in terms of education and access to training among adopters compared to non-adopters of RWH technologies. The majority of the adopters of RWH technologies (88.8%) belonged to water associations. This shows that social capital among the adopters was very high. Membership to the water association/group is deemed necessary as members benefit from information sharing, access to water resources, and usage through collective action. The study also finds that crop-livestock integration was commonly practiced by more than three-quarters (75.6%) of both adopters and non-adopters in the area, thus multiple water use sources should be considered in future investments. Elders played a critical role in water resource regulation through the resolution of conflicts and disputes that arose from the access and utilization of the resources. The results of this study confirm most of the adopters of the RWH technologies had positive perceptions (ranging from good to excellent) regarding the RWH technologies. This shows that the technologies served their purpose and were effective in ensuring the availability of water for the communities during

seasons where water was scarce. The extension also played a critical role in providing information to the communities regarding important aspects such as climate change, water treatment, water catchment as well as RWH. Based on these results, the government should develop permanent water sources that are adequate for multiple use through collaboration with development organizations and NGOs. Technical knowledge among community members can also be improved through training and extension services as noted to be critical source of information among the adopters. Policies and interventions by the government should target the promotion of water harvesting techniques through the provision of capital as well as equipment that can be used to facilitate water harvesting by the communities.

Keywords: Community perceptions; Technology adoption; Rainwater harvesting.

3.2 Introduction

Agriculture plays a crucial role in the economy of many African countries, including Somaliland, but it heavily relies on rainfed systems that are susceptible to scarcity and unreliable rainfall (Biazin *et al.,* 2011). The Somali economy is primarily dependent on the livestock subsector, which is greatly influenced by the environment (IGAD, 2013). However, variability in rainfall patterns and unsustainable exploitation of soil and water resources in Somaliland have strained soil functionality and negatively impacted livelihoods (Qadir *et al.*, 2013). In the face of climate variability, there is a growing need for efficient soil and water resource utilization to improve livelihoods, particularly in the drylands (Recha *et al.,* 2014). Agro-pastoral farmers in Somaliland have been facing challenges in enhancing water productivity in rainfed agriculture, leading to increased interest in adopting rainwater harvesting (RWH) technologies and soil and water conservation measures (Motsi *et al.*, 2004). Despite efforts to promote RWH technologies, their adoption remains low, and there is a lack of empirical information regarding RWH in countries like Somaliland. This study aims to address these gaps by assessing socioeconomic differences between adopters and non-adopters of RWH technologies, exploring agropastoralists' knowledge and perceptions of RWH, and documenting the management and organizational structures of RWH technologies in Odwayne District, Somaliland. The findings will contribute to future interventions and policy-making in rainwater harvesting and sustainable water resource management in the region.

3.3 Materials and Methods

3.3.1 Sampling and Research Design

Participatory appraisal approaches such as focus group discussion (FGD) and key informant interviews (KIIs) and farmers' survey were used to collect qualitative data. The KIIs were conducted to gain an in-depth understanding of rainwater harvesting as well as to account for the difference in perspective from the different stakeholders. The key informants included lead farmers, extension officers, village elders, government institutions, and NGO officials. The FGDs were conducted with selected participants from the agropastoral community, elders, and government and NGO representatives to collect additional qualitative data on attitude and knowledge regarding rainwater harvesting techniques. Existing technologies, their sustainability, management by community and utilization levels, and benefits to the community were also discussed. The information generated from the FGD and key informant interviews were utilized to refine the study questionnaire used during data collection. Data collected from the FGD was analyzed and used to validate the descriptive results obtained in the study.

A multistage sampling technique was then used to select survey respondents for the study. In stage one, the Odwayne District of Somaliland was purposively selected as the study area as it is one of the regions where there have been increased efforts to promote RWH technologies. The area is also dominated by agro pastorals who practice small-scale agriculture. In the second stage, villages were selected based on the intensity of adoption of RWH technologies. Villages with high adoption rates (many irrigated farms as per district records and KII information as well as those with lower rates of adoption were selected to cater to the differences in adoption. Respondents were divided into two strata: adopters and non-adopters of RWH technologies. A simple random sample was then used to select respondents from the two strata for interviews.

3.3.2 Sample size determination

The study adopted a random sampling procedure in obtaining the respondents for the survey. The sample frame of the study included a representative sample of the individuals living in the community.

The calculated sample was calculated based on the formula of proportional probability to an unknown population by Anderson *et al*. (2011) as stated below:

$$N = Z^2 (1-P) P/e^2 = [0.5(1-0.5) (1.96) 2 / (0.0703)2] = 194$$

Where,

N = sample size, Z = degree of confidence 1.96 %, e = error 0.0703, *p*-value = 0.05

3.3.3 Data collection

A semi-structured questionnaire that was pre-tested before data collection and administered through face-to-face interviews was used to collect the primary data. The questionnaire was divided into different thematic areas that included the socioeconomic characteristics of the respondents, farm characteristics, the types of technologies as well as awareness and perceptions regarding the RWH technologies. A 5-level Likert scale was used to elicit responses from the respondents regarding the different levels of perceptions regarding the costs and use of RWH technologies. The 5 levels include: very poor, poor, good, very good, and excellent.

3.3.4 Data Handling and Statistical Analysis

The collected data from the focus group discussions (FGDs), key informant interviews (KIIs), and the survey was handled and analyzed using a mixed-methods approach. The qualitative data obtained from the FGDs and KIIs were transcribed, coded, and thematically analyzed to identify patterns, themes, and key insights regarding rainwater harvesting techniques, community perspectives, and management practices. These findings were used to refine the study questionnaire for the survey.

For the quantitative data collected through the survey, the responses were entered into the Statistical Package for Social Sciences (SPSS) Version 22 software for data management and analysis. Descriptive statistics such as means, standard deviations, and frequencies were calculated to summarize the data and provide an overview of the respondents' characteristics and attitudes towards RWH technologies. Additionally, a multistage sampling technique was used to select respondents, with adopters and non-adopters of RWH technologies forming two distinct strata. To establish significant differences between these groups, t-tests were conducted using the STATA 14 software.

By combining qualitative and quantitative data analysis approaches, the study aimed to provide a comprehensive understanding of the adoption and perceptions of RWH technologies in the

Odwayne District of Somaliland. The results were presented in tabular, graphical, and narrative formats to effectively communicate the findings and address the research objectives.

3.4 Results and Discussion

3.4.1 Socioeconomic characteristics of adopters and non-adopters of RWH technologies

The socioeconomic and institutional characteristics of the adopters, as well as non-adopters of RWH technologies, are presented in Table 3.1. In both categories (adopters and non-adopters), most respondents were male. This is attributed to the cultural practices in the area where men are primarily responsible for decision-making in the households and community. The men are involved in crop and animal production, whereas, the women play a secondary role in the household chores within the community. This leads to the low likelihood of women being involved in adoption decisions.

Table 3.1: Socioeconomic characteristics the respondents

Variables	Adopters (n= 80)	Non- adopters (n= 100)	Pooled (n= 180)	t-test
Socioeconomic characteristics				
Gender (% male)	78.8	82.0	80.6	0.545
Age (% 35years and below)	58.8	59.0	58.9	0.034
Education level				
No education	77.5	91.0	85.0	1.933*
Primary	21.3	9.0	14.4	
Secondary	-	-	-	
Tertiary/ College	1.25	-	0.6	
Education (% with education)	22.5	9.0	15	2.552***
Average household size	9 (4)	10 (4)	10 (4)	1.108
Main Income source (% farming)	7.5	5.0	6.0	0.693
Farm characteristics				
Average land size (acres)	2.9 (1.1)	3.2 (1.6)	3.1 (1.1)	
Usage of land				
Crop production	-	-	-	0.311
Livestock production	2.5	2.0	2.2	
Crop and livestock combined	75.0	76.0	75.6	
Homestead	-	1.0	0.6	
Other uses	22.5	21.0	21.6	
Awareness of RWH (% yes)	91.4	90.0	90.7	0.283
Institutional characteristics				
Agricultural training access (% yes)	88.8	76.0	81.7	2.214***

Note: ***, **, * are significance levels at 1, 5, and 10 percent respectively

Source: Survey Data (2020).

In terms of age, a majority of the respondents (>70%) in both adopters and non-adopters groups were youthful farmers below the age of 35. This age group typically takes on labor-intensive roles in households, such as crop and livestock production. The older members often focus on decision-making and conflict resolution within the household. Warsame (2018) suggests that the dominance of the youthful age group is due to their involvement in herd management and decision-making, which applies to both adopters and non-adopters.

Education level plays a crucial role in adoption decisions. The data shows a significant difference between adopters and non-adopters regarding education level (t = 1.933). Higher education is associated with a greater likelihood of adopting improved technologies. Norris et al. (2007) found that a high number of uneducated individuals can affect a household's coping capacity and decision-making. The higher education level among adopters compared to non-adopters indicates that better-educated individuals are more informed about RWH technologies and their benefits, leading to a higher likelihood of adoption.

The average household size was 10, indicating larger households. In communities around Somaliland, family structures and cultural practices often result in larger families. Arouna and Dabbert (2009) suggest that as household size increases, the demand for water also increases, necessitating the use of RWH technologies to meet water needs. Mugerwa (2007) and Bunclark (2011) note that household size influences labor distribution for the preparation and rehabilitation of RWH techniques.

Regarding land usage, the majority of households (75.6%) practiced mixed crop and livestock production, rather than exclusive crop or livestock production or homestead purposes. This indicates a common practice of crop-livestock integration among both adopters and non-adopters.

Awareness of RWH technologies was high among both adopters and non-adopters, with no statistical difference between the groups (t = 0.283). This suggests that most respondents, regardless of their adoption status, had prior knowledge of RWH technologies.

Access to agricultural training was higher among adopters compared to non-adopters, with a significant difference in access. Respondents who had access to training were more likely to adopt RWH technologies as training provides knowledge about the technologies, their benefits, and how to use them. Recha *et al.* (2014) found that access to extension and training on RWH technologies led to benefits for respondents in Tharaka District, Kenya. The lack of training and awareness about RWH technologies results in lower rates of adoption.

By providing specific figures and avoiding generalized statements, the revised version provides more measurable and precise information about the socioeconomic characteristics of the respondents.

3.4.2 Sources of water used by adopters and non-adopters of RWH technologies

The adoption of RWH technologies aims to mitigate the effects of climate change by harnessing water for various purposes such as irrigation, domestic use, and livestock production. During floods, water is stored for use in dry seasons. One common technology used in arid areas for collecting water during the wet season is berkads, which are underground water tanks. Among adopters of RWH technologies, the exclusive use of berkads was the most commonly reported source of water (61.3%), as shown in Table 3.2.

Table 3.2: Sources of waters among adopters and non-adopters of RWH technologies

Main sources of water	**Adopters (n= 80)**	**Non-adopters (n= 100)**	**Pooled (n= 180)**
Berkad (Underground water tank)	61.3	19.0	37.8
Dams	2.5	0.0	1.1
Shallow well	1.3	0.0	0.6
Boreholes	0.0	0.0	0.0
Springs	0.0	0.0	0.0
Bae	35.0	81.0	60.6

Source: Survey Data (2020).

The study revealed that among adopters of RWH technologies, berkads (underground water tanks) were the most commonly used source of water (61.3%). This finding highlights the significance of berkads in water storage for use during the dry seasons. In contrast, among non-adopters of RWH technologies, only 19.0% reported using berkads. Instead, the majority of non-adopters relied on the Bae system (81.0%), which indicates a different water management approach.

It is interesting to note that shallow wells, boreholes, and springs were rarely used as water sources by households, both among adopters and non-adopters of RWH technologies. This finding contrasts with Warsame's (2018) study, which identified wells and boreholes as the most common water sources for domestic use and livestock production in the Qardho District of Somaliland. Our study suggests that boreholes and rainwater are more prevalent water sources for households in the present study area.

Water-related variables among adopters of RWH technologies are shown in Table 3.3. Access to water sources among adopters was predominantly restricted and controlled by groups or communities. The best practices for managing water resources included protecting water sources and regulating their frequency of use, as suggested by Warsame (2018). This management approach aligns with the cultural practices in the study area, where community elders hold authority in decision-making regarding water resources and other important matters.

Ahmed (2017) reported that traditional institutions, including elders, play a significant role in resolving conflicts and regulating access to resources like water, land, and pasture in Somaliland. Elders determine the frequency of access to water sources and assign roles related to maintenance and management. Disputes regarding water use and access are reported to the elders or relevant authorities for resolution. Gundel and Dharbaxo (2006) emphasize the importance of traditional institutions in establishing stable structures for governance, jurisprudence, and security in Somaliland communities, leading to reduced conflicts related to resource access and use.

Table 3.3: Access and management of water among adopters of RWH technologies

Variables	**Adopters (n= 80)**
Water access related Variables	
Access to water (% restricted access)	6.7
Access to clean water (% yes)	7.5
Experienced water shortage (% yes)	93.7
Access to information on water (% yes)	94.0
Water management variables	
Abide by water use agreement (% yes)	95.9
Control of water use (% elders)	77.5
Experienced water-related conflict (% yes)	2.2
Participation in technology maintenance (% yes)	91.3
Group-related variables	
Membership to water association (% yes)	88.8
Appointment of leaders (% elected)	2.8

Source: Survey Data (2020).

The Government of Somalia has been at the forefront in developing a national strategic plan for integrated water resource management (IWRM) by promoting the adoption of water sources and technologies like (rainwater harvesting (RWH), groundwater (GW), and shallow wells (SW). According to Oduor and Gadain (2007), the Water Act for Somaliland aimed at recognizing legitimatizing empowering, and endorsing Somaliland's customary laws as well as traditional institutions in administrative, fiscal, and judicial affairs relating to water use. Restriction of the water sources was mainly based on membership to the association and seasonality. Association members had privileged access to the water resources controlled by the association while non-members were restricted in terms of access and utilization to the water resources. Seasonality was also a factor that influenced restriction. During the wet season, there were fewer restrictions regarding the water sources as the water was readily available for use. However, scarcity during the dry season resulted in restrictions regarding access and use due to the unavailability of water. The restrictions put in place during the dry season are meant to regulate and control the use of the water to ensure the conservation of the resource because of the scarcity.

The majority of the adopters of RWH technologies (88.8 %) belonged to water associations. This shows that social capital among the adopters was very high. Membership to the water association/ group is deemed necessary as members benefit from information sharing, access to water resources, and usage through collective action. Members of water associations are provided with privileges such as access to water sources which was mainly restricted. Studies like Odendo *et al*. (2010) in Western Kenya and Zingiro *et al*. (2014) in Rwanda report that membership in groups plays a role in influencing adoption through collective action, which influences the adoption of new techniques. The existence of strong water associations and groups creates an avenue for information sharing and access to group-based training, extension, and water-related benefits.

Most of the leaders in the water association are elected to different positions by the members of the association and community members. Leadership structures are important in groups, especially on matters requiring decision-making. Leaders in the groups are elected to act as representatives and pursue interests that are beneficial to the other members. De Fraiture (2007) in his study on integrated water and food analysis at the global and basin level suggests that local people's participation in decision making and implementation of suitable strategies and institutions for water resource management is key in establishing resilient strategies. The elected leaders of the respective associations make decisions regarding access and use of the water restrictions as well as in conflict mediation and resolving when disputes regarding the water resources arise.

Very few respondents (2%) experienced water-related conflicts. Water-related conflicts generally involve issues relating to access, frequency of use, and time of access. The low cases of conflicts can be explained by the fact that management of the water resources is mostly determined by the authorities in charge such as elders in the community and authorities. This suggests the existence of clear dispute resolving mechanisms available to prevent conflicts as well as resolve conflicts arising from the access and use of the resources. Studies by Gundel and Dharbaxo (2006) and Ahmed (2017) in the Somaliland region have highlighted that conflict resolutions in communities are mostly carried out by traditional based institutions such as clan and elder-based leadership. The community’s role is the management of shared resources such as water and pasture through the resolution of conflicts by traditional institutions within the community. Flouting of the rules governing the access and use of the resources results in members being penalized by having their animals confiscated as a means of compensation.

To regulate and monitor the use and access of the water resources, agreements are put in place to prevent conflicts that may arise as a result of access and utilization of the water resources. As shown in Table 3.3, the majority of the respondents (95.6 %) abided by the agreements regarding the use of water. The agreements (formal or informal) are deemed as an essential institution in regulating and controlling the access, utilization, and management of the crucial water resources available. Abiding by the water use agreement results in fewer conflicts that may arise. From the survey, it is also evident that access to clean water was a challenge as only 7.5 % of the respondents highlighted that they had access to clean water. In Sub Saharan Africa (SSA), access to clean water has been deemed a challenge, as households travel for long distances to access clean water, despite having access to water sources

3.4.3 Perceptions and knowledge regarding RWH technologies

Perceptions were provided for the RWH technologies among the adopters with the majority adopting *berkads* as good. Perception regarding shallow wells, boreholes, and springs was highest among the RWH technologies adopted, as they were perceived as excellent. This shows that in their view, the technologies were efficient in use and provided the best outcomes in terms of water harvesting, resulting in high perception. The use of the dam had relatively low perceptions among the adopters. This may be explained by the high costs required in the construction and maintenance of the technology.

Table 3.4: Perceptions regarding RWH technologies among adopters in Somaliland

	Perceptions regarding RWH technologies (%)				
	Very Poor	**Poor**	**Good**	**Very Good**	**Excellent**
Berkad	0.0	8.75	53.7	35.0	2.5
Shallow well	1.27	0.0	22.7	20.3	55.7
Borehole	1.28	0.0	10.3	26.9	61.6
Springs	0.0	0.0	6.4	16.7	76.9
Dam Water	15	22.5	35.0	27.5	0.0

Source: Survey Data (2020).

Information access is also critical in aspects regarding the adoption and utilization of the adopted technologies. More than 95 % of the respondents had access to access to information regarding water (see Table 3.1). Such information included aspects such as ownership of water resources, availability of water, water safety and sanitation, and access. The information accessed centered on water treatment, water catchment, climate change, and RWH technologies. Different sources were used to access the information regarding water-specific issues (Figure 3.1).

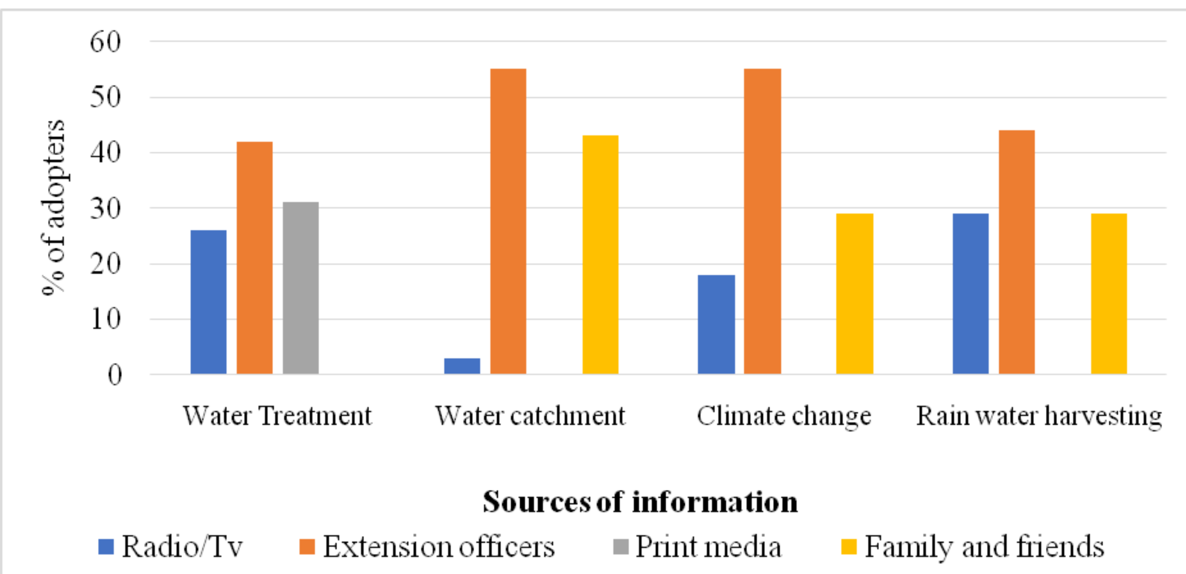

Figure 3.1: Information types and sources accessed by respondents

Source: Survey Data (2020).

The extension was the most relied upon source of information regarding water treatment, water catchment, climate change, and RWH. It plays a crucial role in providing relevant information regarding water-related aspects to farmers. Lack of extension limits information flow to farmers, and communities, resulting in low adoption of technologies such as RWH technologies. Recha *et al.* (2017) highlight the crucial role played by extension, especially regarding training on RWH technologies. The respondents relied on visits by government extension officers from NGOs as well as donor organizations for the services.

3.4 Conclusion and Policy Implications

Results from the study showed that education level and access to training had a statistical difference among adopters compared to non-adopters of RHW technologies. This shows that education and training influenced the adoption of RWH technologies, where, highly educated farmers and those who had accessed training were likely to adopt RWH technologies. The results also show that *berkad* was the main source of water for domestic and livestock use in the area. Water scarcity escalates conflicts among community members on water resources. Regulation of water usage, therefore, plays a big role in the sustenance of resilience to water scarcity.

Social capital and collective action were very high, owing to the large number of respondents who were members of water associations. The associations play a major role in regulating the water resources through restrictions and management of access and use. The elders play a critical role in regulating the water resources through the resolution of conflicts and disputes that arise from the access and utilization of the resources. Most of the adopters of the RWH technologies had positive perceptions (ranging from good to excellent) regarding the RWH technologies. This shows that the technologies served their purpose and were effective in ensuring the availability of water for the communities during seasons where water was scarce. The extension also played a critical role in providing information to the communities regarding important aspects such as climate change, water treatment, water catchment as well as RWH.

Based on these results, the government should develop permanent water sources like boreholes that are adequate for use by the communities. This can be done through collaboration with donor organizations and NGOs in the area. Through this, resources can be jointly mobilized and used to target interventions aimed at increasing water access by developing water sources for the communities. New water sources should be provided/developed for the communities to reduce conflicts arising from the shared use and utilization of the available water resources. Technical knowledge among community members can also be improved through training and extension services. Owing to the high social capital and collective action that exists through membership to water associations, group-based training can be prioritized as avenues to increase technical knowledge and boost information flow regarding RWH technologies. Local community participation in the management of the water resources is influenced by traditional and cultural beliefs. It is therefore important for government authorities and donor organizations to partner with local institutions such as elders to promote the necessary awareness to different clans as well as in developing and management of new water sources.

Policies and interventions by the government should target the promotion of water harvesting techniques through the provision of capital as well as equipment that can be used to facilitate water harvesting by the communities. There is also a need for a participatory approach to sensitize on aspects such as climate change, to enhance resilience to water scarcity.

CHAPTER 4

An Analysis of the Factors Influencing Adaptation and the Adoption Intensity of RWH Technologies in Odwayne District, Somaliland.

4.1 Abstract

Despite these efforts and the importance of the rain water harvesting technologies as alternatives to traditional water sources in the region, adoption has been very low. In addition, little empirical data exist on the adoption rate of RWH technologies in Somaliland and the factors influencing such adoption. Using data from 180 respondents, a binary logit model was used to assess factors influencing the adoption of RWH technologies and a Poisson regression model (PRM) was used to examine factors influencing the intensity of adoption. The results of the logit model show that household size and education have a significant effect on adoption. Country variables, such as size and institutions, and information variables, such as access to education and information, had a significant effect on the adoption of RWH technologies. The estimated PRM revealed that access to RWH information, water scarcity, overall farm income, and water adequacy all had a significant influence on the intensity of adoption. Based on the findings, there is a need to expand access to training to improve farmers' technical knowledge through group training in which participants can be instructed on RWH technology and its associated benefits.

Keywords: RWH technologies, adoption, information access, training.

4.2 Introduction

Agricultural production in many Sub-Saharan African (SSA) countries is reliant on rainfed agriculture (Biazin *et al.*, 2011; Qadir *et al.*, 2012). However, there is a high variability of renewable sources in arid and semi-arid areas like Somaliland. Dependence on rainfed agriculture is therefore susceptible due to variations in climate, which has negative impacts on livelihoods as well on food production (Biazin *et al.,* 2011)

The economy of Somaliland is much dependent on the environment, in the relation to the livestock sector. However, small-scale agro-pastoral farmers face challenges enhancing water productivity from rainfed agriculture through the adoption of new technologies of rainwater harvesting. Previous studies like Postel (2000) and Rockstrom (2003) identified increasing water productivity as a vital strategy due to limitations in water supply in dryland areas. This results in the need to promote alternative sources of water supply, in face of dwindling water resources and climate variability. Rainwater harvesting is aimed at significantly increasing water productivity, thereby mitigating the scarcity of agricultural water and increasing agricultural productivity (Biazin *et al*., 2011). Dean *et al.* (2012) note that rainwater harvesting is common in many parts of the world and can be a practical, economical, sustainable, and clean source of water if implemented correctly.

Government agencies and NGOs are working to support community-based rainwater harvesting projects to help pastoralists and agro-pastoralists in Somaliland better cope with frequent droughts and improve their food security. In particular, dams, shallow wells and salt ponds have been constructed in the Togdheer region. However, rainwater harvesting has not received sufficient attention in Somaliland's policy documents. Therefore, the government should provide evidence-based information when developing rainwater harvesting plans and projects. The use of different water harvesting technologies should also be evaluated to determine the best options that are ecologically sustainable and can provide better living conditions for communities, and to guide future actions. It is therefore important to know to what extent technologies have been adopted and what socioeconomic differences exist between users and non-users, so that measures can be taken to improve the use of these technologies.

Studies have been conducted on the adoption and impact of RWH technologies in several African countries: see Nkegbe et al. (2014), Zingiro *et al.* (2014), Recha *et al.* (2015) and Mangisoni *et al.* 2014 However, few studies accept empirical evidence on the use of RWH in Somaliland. This study aims to fill this gap by examining the factors influencing the adoption and implementation of RWH in the Odwayne region of Somaliland. It will complement existing knowledge by understanding adoption levels and socio-economic differences between users and non-users, which is important for identifying interventions to improve the use of these technologies.

4.3 Materials and Methods

4.3.1 Research design

Primary data was collected using semi-structured questionnaires. Respondents were interviewed on aspects relating to adoption, perceptions, and knowledge regarding rainwater harvesting techniques, management by community and utilization levels, and benefits to the community were also discussed. Participatory rural appraisal techniques were used to collect qualitative data for the study. This supplemented the primary data from the survey. This research design was important in bringing out the differences brought about by the different types of respondents.

4.3.2 Sampling and data collection

Key informant interviews (KIIs) and focus group discussions (FGDs) were conducted to collect qualitative data. Interviews were conducted to gain a better understanding of rainwater harvesting and to incorporate the different perspectives of various stakeholders, including key farmers, farm workers, village elders, government officials and NGOs. Focus group discussions (FGDs) were conducted with selected participants from the farming community, village elders, and government and NGO representatives to collect data on perceptions and knowledge of rainwater harvesting practices, levels of management and use by the community, and benefits to the community. The information obtained was used to refine the questionnaire used for data collection; the FGD data was analyzed and used to validate the descriptive results of the study.

A three-stage sampling approach was used to select respondents. In the first stage, Odwayne district in Somaliland, one of the regions where RWH technology promotion activities are conducted, was selected as the study area. The district also has a large number of agro-pastoralists practicing small-scale agriculture. In the second phase, villages were selected based on their level of adoption of RWH technology. To illustrate the differences in adoption rates, high and low adoption villages were selected. Respondents were divided into two groups: users and non-users of RWH technology. Respondents were then randomly selected from both strata (adopters and non-adopters).

2.2.1 Sample size determination

The study adopted a random sampling procedure in obtaining the respondents for the survey. The sample frame of the study included a representative sample of the individuals living in the community. The calculated sample was based on Anderson *et al.*, 2011) stated below:

$$N= Z^2 (1-P) P/e^2 = [0.5(1-0.5) (1.96) 2 / (0.0703)2] = 194 \quad (1)$$

Where,

N = sample size, Z = degree of confidence 1.96 %, e = error 0.0703, *p*-value= 0.05

4.3.3 Empirical analysis

4.3.3.1 Factors influencing adoption of RWH technologies in Odwayne District, Somaliland

Modeling farmers' decisions regarding the adoption of technology constitute a discrete decision on whether or not to take up the technology and continuous decisions regarding the intensity of adoption (Wale and Yallew, 2007). The implementation model is based on the assumption that people can choose between alternatives and that their choice depends on identifiable technical characteristics (Pindyck and Rubinfeld, 1997). Therefore, the dependent variable has two options: to adopt or not to adopt the RWH technology. Adoption is thus modeled as a decision between two options: to adopt or not to adopt. Adoption is thus a dichotomous variable that takes the value 1 if the farmer adopts the RWH technology and 0 if he does not adopt it.

Empirically, the dependent variable was defined as follows.

$$Y_i\{1 \; if \; adopt \; 0 \; if \; otherwise \qquad (2)$$

In these cases, the logit or probit model is usually used. In this study, the logit model was used because of its mathematical simplicity and the binary logit model because of the discrete nature of the dependent variable.

According to Greene (2003), the probability of an individual adopting a given technology is defined in a simplified form.

$$Prob\left[Y_{ij} = 1\right] = \frac{exp\, B' X_1}{1+} = \Lambda B' X_1 \qquad (3)$$

where i and j represent the farmer's acceptance status [1 = accepted, 0 = otherwise] and the vector is a vector of farmer explanatory variables (including socioeconomic and institutional factors) and unobservable errors.

The probability of an individual adopting the RWH technology can be estimated empirically as follows.

$$Pr[Y_i = 1] = B'X_1 + e_i \qquad (4)$$

where X is a vector of socio-economic and institutional characteristics that are assumed to influence the probability of respondents adopting the technology or not.

is the vector of parameters to be estimated and the statistical conditions of the survey are random? Table 4.1 presents the factors assumed to influence farmers' adoption of WSS technologies.

Marginal effects were estimated to examine the direct effect of changes in explanatory variables on the probability of knowledge, holding all other explanatory variables constant. Following Anderson and Newell (2003), marginal effects were calculated as follows.

$B_m = \left[\frac{\delta(B'X_1 = e_i)}{\delta B'X_1}\right] B_i$ for continuous independent variables (5)

Or $B_m = P_r[Y_i = 1] - P_r[Y_i = 0]$ for dummy variables (6).

Table 4.1: Description of variables influencing the adoption of RWH technologies

Variable	Description of the variable	Sign
Age	Age of the respondents (1= 35 years and below; 0= Above 35 years)	+/-
Household size	Number of members in a household	+
Farm usage	Activity in the farm (1= Agricultural-related; 0= Otherwise)	+/-
Main Income source	The main source of household income (1= Agriculture; 0= Otherwise)	+
Total farm income	Total household income (USD)	+
Access to training	Access to training on RWH (1= Yes; 0= No)	+
Education	The education level of the respondent (1= Primary school and above; 0= below primary school)	+
Gender	Sex of the respondent (1= Male; 0= Female	+/-
Total land size	Size of land owned (acres)	+/-

Source: Survey Data (2020).

The variance inflation factors (VIFs) were used to test for multicollinearity between the variables used in the model:

$$VIF_i = \frac{1}{1 - R_i^2} \qquad (7)$$

Since all VIF values were below the critical value of 10 (Gujarati and Porter, 2009), no multicollinearity was found in the sample data (see Appendix 1).

4.3.3.2 Determinants of intensity of adoption of RWH technologies in Odwayne District

A data collection model was used to analyze the intensity of SCP adoption in Odwayne District, Somaliland. The dependent variable (intensity of technology adoption by respondents) was measured as the number of CSP technologies adopted by respondents. Since it is a count variable with a Poisson distribution, it can be estimated using a Poisson model. Therefore, a Poisson regression model (PRM) was used in this study.

A PRM was used to estimate the intensity of adoption of RWH technologies in Odwayne District, Somaliland. The intensity was measured as the number of technologies one had adopted for use (Table 4.4).

PRM assumes that the dependent variable yi has a Poisson distribution under a vector of predictors Xi The probability density function yi on Xi is given in its entirety by.

conditional mean $E(y_i|x_i = \lambda_i)$ and its uniform distribution $Var(y_i|x_i) = \lambda_i$ (7).

Therefore, the IPD density function is given (Greene 2008).

$$f(y_i|x_i) = \frac{e^{-\lambda(x)}\lambda_i(x)^y}{\Gamma(1+y_i)} \qquad (8)$$

where.

$\lambda_i =$ exp ($\alpha + X'\beta)$ and $y_i = 0,1,\ldots,i$) is the number of RWH methods used by the respondents.

X is a vector of explanatory variables and $\propto$ and β is the parameter to be estimated (Greene 2008). According to Wooldridge (2002) and Greene (2008), the expected number of events (number of technologies adopted) is:

$$E\ (y_i|x_i) = \text{Var}[y_i|x_i] = \lambda_i = \text{Exp}(\alpha + X'\beta) \text{for i} = 1,2, \dots, n \qquad (9)$$

where X′ is a vector of explanatory variables (Table 4.2). The PRM estimated in this study are defined as follows. *Intensity of adopting RWH* = f (irrigation frequency + access to information + water scarcity + sanitation + farm income + maintenance participation + access to resources + group membership + water adequacy + ε) (10).

The marginal effects for the PRM model were interpreted as the change in the unit in the intensity of adoption as a result of a change in the explanatory variable (Cameron and Trivedi, 1998). The marginal effects in the PRM are determined by:

$$\frac{\partial E(x_i)}{\partial x_i} = \lambda_i \beta \qquad (11)$$

The VIF was also used to test the variables included in the PRM for multicollinearity:

$$VIF_i = \frac{1}{1 - R_i^2} \qquad (12)$$

Since all VIF values were below the threshold value of 10, there was no evidence of multicollinearity in the sample data (see Appendix 2).

Table 4.2: Description of variables influencing the adoption of RWH technologies

Variable	Description of the variable	Expected Sign
Fetching frequency	Frequency of fetching water (1= Daily; 0= Otherwise)	+/-
Information access	Access to RWH-related information (1= Yes; 0= No)	+
Water shortage	Experienced water shortage (1= Yes; 0= No)	-
Sanitation	Have water sanitation measures in place (1= Yes; 0= No)	+
Farm income	Total household income (USD)	+
Participate in maintenance	Participate in the maintenance of an RWH technology (1= Yes; 0= No)	+
Access to resource	Access to a water resource (1= Open access; 0= Restricted)	+
Group membership	Membership to a water association (1= Yes; 0= No)	+
Water adequacy	Perception regarding adequacy of water supply (1= Adequate; 0= Otherwise)	+/-

Source: Survey Data (2020).

4.3.4 Data handling and analysis

The data from FGD and KIIs were qualitatively analyzed with their insights used to refine the survey questionnaires and validate the results for the study. The data from the questionnaire was captured using the Statistical Package for Social Sciences (SPSS) Version24. The STATA version 14 software was used in computing descriptive statistics and estimating the regression models. The results were presented using tables and graphs.

4.4 Results and Discussion

4.4.1 Factors influencing adoption of RWH technologies

Table 4.3 highlights the factors hypothesized to influence farmers' probability of adopting RWH technologies. These variables were used in the binomial Logit model. It was hypothesized that a farmer's probability of being adopting RWH technologies is a function of a set of factors that included age, household size, the usage of the farm, main income source, total farm income, access to training, education level, gender, and the total land size.

Household size positively influenced the adoption of RWH technologies at a 10 percent level of significance ($P = 0.049$). Farmers with larger household sizes were more likely to adopt RWH technologies, compared to households with smaller household sizes. Large household sizes create increased demand for water for household use, thus pressure on available water resources. The likelihood of adoption of RWH technologies in such situations is high as households will resort to diversifying their water sources to increase the availability of water, especially in seasons where water is scarce. Studies by Mugerwa (2007) working in Kiboga and Masaka Districts of Uganda and Bunclark (2011) in Botswana respectively, report that the number of household members is a crucial element in the distribution of labor. This is important in the preparation and rehabilitation of RWH techniques. Gupta and Dubey (2006) also assert that in most rural areas where, a large family is representative of social insurance This gives an incentive to adopt, owing to the provision of unpaid labor by family members or the skills relevant for technology adoption.

At a 10 percent level of significance (P= 0.056), access to training positively influenced the adoption of RWH technologies. Farmers who accessed training were more likely to adopt RWH technologies compared to those who lacked access to training. Training on aspects related to water harvesting and related technologies provides farmers with technical knowledge as well as relevant information on rainwater harvesting and the benefits of adopting the technologies. The information thus increases the likelihood of adoption. Prackash, (2011) also reports that rainwater harvesting training offers instructions on the concept and technology of rainwater harvesting for domestic use thus increasing adoption. Recha *et al*. (2014) in their study in the Tharaka region of Kenya found that respondents accrued benefits resulting from access to extension and training, specifically on RWH technologies.

Table 4.3: Factors influencing adoption of RWH technologies in Odwayne District

Variable	**Coef.**	**Std. Error**	**Significance *(P-value)***	**Marginal Effects (dy/dx)**
Age	-.002	.329	0.995	-.001
Household size	.661	.873	0.049*	-.144
Farm usage	-.216	.377	0.566	-.0472
Main Income source	.318	.680	0.640	.069
Total farm income	.058	.346	0.868	.0125
Access to training	.857	.449	0.056*****	.187
Education	1.067	.468	0.023******	.233
Gender	-.599	.417	0.151	-.131
Total land size	-1.205	.414	0.004*******	-.263
Constant	1.081	1.111	0.331	
Log-likelihood		-112.729		
R-squared		0.18		
Prob > Chi^2		0.009		

Note: ***, **, and * denote significance levels at 1, 5, and 10 percent respectively.

Source: Survey Data (2020).

Education level positively influenced the adoption of RWH technologies at a 5 percent level of significance (p= 0.023). Farmers who had formal education (primary level of education and above) were more likely to adopt RWH technologies compared to those who lacked any formal education (no schooling). The intellectual capacity of farmers is expected to be high as a result of access to education, thus influencing the level of understanding of technologies as well as their attitudes towards the technologies. Highly educated farmers are expected to understand the benefits of RWH technologies, therefore, are more likely to adopt the technologies compared to those without access. Studies like Ramji *et al*. (2002) in Dhading district of Nepal and Tassew (2004) focusing on 15 Districts of Ethiopia have also found that households/ individuals that have attained higher education levels have a higher probability of adopting new technologies, compared to the less-educated households.

Land size, however, negatively influenced the adoption of RWH technologies at a 1 percent level of significance (p = 0.004). Farmers with smaller land sizes were less likely to adopt RWH technologies compared to farmers with large land sizes. Large land sizes provide adequate space and permit owners to set up technologies aimed at harnessing rainwater for use. Land in most communities in the region is communally owned and comprises large land parcels. This facilitates the setting up of RWH technologies that are beneficial to the communities, which increases the likelihood of adoption. Smaller land sizes are mostly owned by individuals who are limited in terms of the number of enterprises to set up on the land thus limiting adoption. In a study conducted in the rain shadow area of the Zomba Rural Development Project in Southern Malawi, Mangisoni *et al*. (2019) also found that land size negatively influenced the adoption of RWH technologies.

4.4.2 Determinants of the intensity of adoption of RWH technologies in Odwayne District, Somaliland

The frequency of fetching water positively influenced the intensity of the adoption of RWH technologies at a 1 percent level of significance (P = 0.000). Households that fetched water frequently (daily) were more likely to adopt more technologies compared to those who did not fetch water regularly. Fetching frequency relates to the demand for water, meaning that households that fetch water frequently have higher water demand compared to those that do not fetch water daily. This creates the incentive to adopt multiple technologies to increase water supply and availability, hence a higher intensity.

Access to information regarding RWH technologies hindered the intensity of adoption at a 1 percent level of significance (P = 0.001). Individuals with access to information regarding RWH technologies and related technologies were more likely to adopt fewer technologies hence a lower intensity of adoption, compared to those who lacked information. This was contrary to studies by Sturdy *et al.* (2008) in Bergville District of South Africa who concluded that information positively influences the adoption of technologies. Individuals with information access know the benefits, advantages, and disadvantages of the technologies, hence can make rational choices regarding the technologies and select those technologies that are more efficient in use. Individuals with less information are likely to adopt multiple technologies as they lack the knowledge to select the more efficient and better technologies, hence higher intensity of adoption. Some of the farmers also relied on sources that inadequately disseminated appropriate messages regarding RWH adoption (Baguma and Loiskandl, 2010).

At a 5 percent level of significance (*P* = 0.022), water shortage had a positive effect on the intensity of adoption of RWH technologies. Individuals who had experienced water shortages were likely to adopt more technologies hence a higher intensity of adoption, compared to those who had not experienced water shortages. Water shortages result in increased demand for water thus straining the available and existing water resources. This creates the need for alternative sources of water to meet the increased demand. Individuals are therefore more likely to adopt multiple technologies to increase water availability thus higher adoption intensity. Similar results were reported by Onwonga *et al*. (2013) working in the semi-arid Yatta District of Kenya who found that the experience of water shortage positively influences the rate of adoption of water harvesting techniques.

Table 4. 4: Factors influencing intensity of adoption of RWH technologies

Variables	**Coef.**	**Std. Error**	**Significance *(P-value)***	**Marginal Effects (dy/dx)**
Fetching frequency	1.249	.336	0.000***	.612
Information access	-4.752	1.451	0.001***	-2.463
Water shortage	2.904	1.269	0.022**	1.452
Sanitation	1.448	.859	0.922	.609
Farm income	-.925	.480	0.054*	-.593
Participate in maintenance	2.426	1.259	0.054*	1.726
Access to resource	-.355	.801	0.658	.010
Group membership	.093	1.037	0.928	-.168
Water adequacy	-2.491	1.222	0.042**	-1.029
Log-likelihood		-129.159		
R-squared		0.063		
Prob > Chi^2		0.044		

Note: ***, **, and * denote significance levels at 1, 5, and 10 percent respectively.

Source: Survey Data (2020).

Water adequacy hindered the intensity of adoption of RWH technologies at a 5 percent level of significance (*P = 0.042*). Individuals who had access to adequate water supply were likely to adopt fewer technologies hence a lower intensity of adoption, compared to those who did not have access to the adequate water supply. Adequate water supply results in lower demand for water as the water supply is readily available. Farmers/ individuals with inadequate water supply are more likely to adopt more RWH technologies due to increased demand for water. This creates the need for alternative sources of water to meet the increased demand. Individuals are therefore more likely to adopt multiple technologies to increase water availability thus higher adoption intensity.

At a 10 percent level of significance ($P = 0.054$), farm income negatively influenced the intensity of adoption of RWH technology. Farmers with high incomes were likely to adopt fewer technologies hence a higher intensity of adoption compared to farmers with lower incomes. Conventionally, farm income, a proxy for household capital endowment positively influences adoption and intensity of adoption. However, in this study, farmers with high income (more capital endowment) were likely to adopt fewer RWH technologies. Herath and Takeya (2003) focusing on smallholder rubber farmers from five major rubber-growing regions in Sri Lanka noted that the role of farm income on the decision to adopt is unclear. For this study, the results can be explained by the fact that individuals with high income are likely to use capital-intensive sources of water as alternative sources and measures to get water, rather than relying on RWH technologies. This results in their low adoption intensity. Similarly, individuals with low farm incomes (less capital endowment) are more likely to adopt more RWH technologies as sources of water due to a lack of adequate capital.

Participation in the maintenance of RWH technologies had a positive effect on the intensity of adoption of RWH technologies at a 5 percent level of significance ($P = 0.054$). Individuals who participated in the maintenance of an RWH technology were more likely to adopt more RWH technologies, compared to individuals who did not participate in the maintenance. Participation in the maintenance of the technology creates a sense of ownership and acts as an incentive to adopt more RWH technologies to increase the water supply. This, therefore, translates to increased intensity of adopting RWH technology.

4.5 Conclusions and Policy Implication

The findings of the study have important policy implications for promoting the adoption and intensity of adoption of rainwater harvesting (RWH) technologies. Firstly, it is crucial to ensure access to relevant information about RWH technologies. This can be achieved by implementing programs that recruit and deploy extension officers to disseminate information to farmers.

Providing farmers with the right information will enable them to make informed decisions and adopt fewer, yet more efficient, technologies.

Education and training also play a significant role in the adoption of RWH technologies. To enhance technical knowledge among farmers, it is recommended to increase access to training programs. Group training sessions, leveraging existing social networks, can effectively educate farmers about RWH technologies and their benefits, ultimately driving higher adoption rates.

Targeting larger households and individuals with higher education levels is another key recommendation. These groups have shown a greater propensity for adopting RWH technologies, and policymakers should develop tailored interventions and incentives to further promote adoption among them.

Addressing land-related challenges is essential. Land size has been identified as a significant factor influencing adoption. Policymakers should formulate policies that tackle issues such as land fragmentation, which can hinder the adoption of RWH technologies.

Given the positive influence of water shortage experiences on the intensity of adoption, strategies should be directed toward addressing water scarcity and promoting the widespread use of efficient RWH technologies. These efforts will help meet the increased demand for water and encourage farmers to adopt multiple technologies to improve water availability.

Finally, it is important to recognize the diversity of practices among farmers in different locations. Promotional strategies should account for this diversity and customize interventions to meet the specific needs and preferences of individuals in each location.

In conclusion, these policy implications and recommendations aim to bridge information gaps, enhance technical knowledge, target specific groups, address land-related challenges, and tackle water scarcity issues. By implementing these recommendations, policymakers can effectively promote the adoption and intensity of adoption of RWH technologies, leading to more sustainable water management practices.

CHAPTER FIVE

Influence of rainwater harvesting (RWH) systems on irrigation water quality in Odwayne District, Somaliland

5.1 Abstract

There is crucial need to understand irrigation water quality for sustainable land use and increased production at lower environmental foot print. This study aimed at evaluating the key attributes of irrigation water from different rain water harvesting technologies; dams, berkads (underground water tanks), and shallow wells in Somaliland's Odwayne District during the dry and wet seasons of September 2019 to March 2020. The irrigation water quality parameters underwent analysis of variance (ANOVA) in STATA 16 statistical software, with mean separation performed using LSD at a 5% level of probability for significant F-values, considering the location and season as experimental factors. Water samples were collected from the RWH techniques and analyzed for pH, temperature, electrical conductivity (EC), sodium adsorption ratio (SAR), chlorine (Cl^-), sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^+), and total dissolved solids (TDS)**.** Significant differences were measured at ($p<0.05$). SAR levels was higher in shallow and lower in the dams' samples at 0.76 and 0.14 me/l, respectively. Chloride levels were higher across all the RWH technologies whilst EC ranged from 0.3 to 0.7 dS/m while the TDS was highest in shallow wells (542 mg/l) across all locations. The pH ranged from 7.62 to 7.74 indicative that the water is slightly alkaline. The drier season had higher EC as to the mid and rainy season. In-situ water quality aspects are mainly affected by the inherent aspect of the parent material thus site experiences dryland salinity. The study therefore, recommends dam and *berkads* technologies for irrigation water during rainy periods.

Keywords: Irrigation water quality, water quality, soil quality, Water harvesting technologies

5.2 Introduction

In recent years, the available water sources have been inadequate to meet the growing water demand. The scarcity has been on the rise due to the shifting weather patterns in recent years (Mbayaki and Kinama, 2022). Irrigation systems can play an important role in food security, especially in developing countries, as water scarcity is linked to food security (Kamal *et al.* 2022). Smallholder farmers in Somaliland face the challenge of reducing the annual dry spell and increasing water productivity in rainfed agriculture through rainwater harvesting systems.

Rainwater harvesting is considered an effective solution to water scarcity. Rainwater harvesting includes collecting rainwater from rooftops and other planned catchments, artificial land, natural reservoirs, and rocky areas for domestic, industrial, agricultural, and environmental uses (Vohla and Barry, 2009; Kahinda and Taigbenu, 2011). According to Denison and Wotshela (2009), earthen dams, ponds, weirs, and spillways are examples of common rainwater harvesting practices in south-central and parts of northwest Somaliland. Other regions, including the southern basin, benefit from flooding, particularly in the Juba and Shabelle river basins (Sebhat and Wenninger, 2014).

In Somaliland, rainwater harvesting and management falls into three categories: crop production systems, livestock production systems, and domestic water supply systems (Kassahun et al., 2008; Jirde et al., 2021). In crop production, captured runoff is collected and stored in reservoirs for later use or direct rainfall is used to retain soil moisture in situ, while in livestock production, surface runoff is used and groundwater or runoff is collected and stored in natural or artificial reservoirs such as ponds (Swartley and Toussaint, 2006; Petersen, 2012). In other parts of Somaliland, rainwater from roofs and rocks is collected and stored in underground concrete tanks called *Berkad guri*.

Water management for long-term productivity requires knowledge of irrigation water quality (Uhlenbrook *et al.,* 2022). On the other hand, agricultural production in arid and semi-arid areas is totally dependent on irrigated agriculture (Chen *et al.*, 2022). In this case, farmers are forced to use irrigation water with high dissolved salt content, which inevitably leads to lower yields of most crops. This means that the water must not contain soluble salts that are harmful to crops or affect soil continuity and thus cannot meet the water requirements of all crops (Foster and Chilton, 2003; Minhas and Sharma, 2003); Ravindiran *et al.,* 2022). To overcome this obstacle, irrigation water testing is strongly recommended (Coelho et al., 2022).

Water quality indicators can be divided into physical, chemical, and microbiological properties, which vary greatly depending on the water source, storage conditions, or methods (Dean and Mitchell, 2022; Dutta *et al.*, 2022). Physical properties of water quality include color, odor, turbidity, taste, temperature, and conductivity, while chemical properties include the amount of carbonate, sulfate, chloride, fluoride, nitrate, and metal ions in solution (Laskar *et al.*, 2021; Keli, 2022). The suitability of the water for irrigation is then determined based on these water quality parameters. The objective of this study is to compare some water harvesting technologies that are expected to have similar water quality characteristics for irrigation, such as dams, *Berkads* (underground reservoirs) and shallow wells. This will provide knowledge on the benefits of using free rainwater to improve household water supply and integrated water management at the community level, and provide a framework for stakeholders to act on agricultural policies for sustainable small-scale irrigation development in the region.

5.3 Materials and methods

5.3.1 Description of the study site

The study was conducted in Odwayne District of Somaliland. The area is mainly characterized by dry climatic conditions and receives mean annual precipitation of 474 mm which occurs in two seasons, long rains from March to May referred to as '*Gu*', and short rains periods called '*Dayr*' that occur in August to October. The mean annual temperature is 27 °C with a range of 23.8 ° and 30.1°C (MoA, 2017). Seasonal rivers are the most important sources of surface water, especially during the rainy season. Diurnal temperatures vary with the colder months having a range of approximately 15 - 26°C and the summer averaging 26 - 32°C, though temperatures do fluctuate, reaching 0° in the highlands during colder months (December to February) and climbing to 45°C. The most prevalent land use in this region is agro-pastoral characterized by small-holder farmers with very small average landholdings (Tessema *et al*., 2013). The types of livestock reared in this region are goats, sheep, and camels. Goats are the preferred species of livestock followed by camels due to their adaptability, milk yield, and meat production.

Figure 5.1: Map of Odwayne District, Somaliland

5.3.2 Sampling and analysis of water

Water samples were collected during the dry, mid, and wet seasons (September 2019 to March 2020). The water samples (approximately 500 ml) were collected in triplicates at three sampling points in each of the RWH technology (dam, *berkads,* and shallow wells) using PVC bottles. The water samples were kept at 4°C in a cool box until analyses were done at the Hydrology and Watershed Laboratory in the University of Nairobi. The water samples were analyzed for pH, temperature, electrical conductivity (EC), sodium adsorption ratio (SAR), chlorine (Cl^-), sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), and total dissolved solids (TDS) following the methods described by Katerji *et al.*, (2003).

5.3.3 Statistical analysis

The irrigation water quality parameters were subjected to analysis of variance (ANOVA) using STATA 16 statistical software. Mean separation was done using LSD at a 5 % level of probability where the *F*-values were significant. The location and season were considered as experimental factors.

5.4 Results and discussion

5.4.1 Irrigation water quality as affected by location and seasons in Odwayne District of Somaliland

The irrigation water analysis across the locations and seasons are shown in Table 1. Significant differences ($P<0.05$) were observed for all the parameters except pH ($P = 0.292$) in the different locations. Seasonal differences were only noted for temperature and pH ($P<0.001$).

The pH ranged from 7.62 - 7.74 indicative that the water is slightly alkaline for all locations. The normal pH range is 6.5 - 8.4 and thus the water from the sources is safe for irrigation. Significant difference in pH ($P<0.001$) was noted through the seasons with dry season having a higher mean value (7.90) compared to samples collected in the mid (7.67) and rainy season (7.43). The higher values reported during the dry season are as a result of the high salt content and lesser permeability that may results from minimal solubility compared to the rainy and mid seasons. When leached with a low salt water, especially during the rainy season some saline soils tend to disperse resulting in low permeability to water and air (FAO, 2022). The effect of pH in water during the dry season may be linked to the soil surface charge. As the pH of variable-charge in soils approaches the point of zero net charge (PZNC), the net surface charge decreases resulting in flocculation as a result of high-water infiltration and saturation (Nakagawa and Ishiguro, 1994). The pH is an essential parameter for the identification of acidity or alkalinity in water bodies. In crop production, such pH could not harm the plant growth directly but affects the efficiency of the coagulation and flocculation process (Tahir *et al.,* 2003; Kahlown *et al.,* 2006). A high pH implies that the water has higher hardness which could result in the dissolution of carbonates, hydroxides, phosphates, bicarbonates (Pandey *et al.,* 2020; Anoop *et al.,* 2022). The study area falls under a large folded Tertiary clastic sedimentary rock (geology) and this may be the reason for increased pH (Yin and Harrison, 2000; Jolly and Lonergan, 2002).

The potassium levels ranged from 3.73 - 8.27 mg/l across the locations (dams, *berkads* and shallow wells) which is above the usual range for irrigation (0 - 2 mg/l) (Ayers and Wescot, 1994). The *berkads* had a higher average of 6.01 mg/l followed by the dams, 4.42 mg/l and the shallow wells with 3.91 mg/l.

Table 5.1: Water quality parameters as affected by location and seasons in Odwayne, Somaliland

	Water Quality Parameters							
	K (mg/l)	**Mg (mg/l)**	**Na (mg/l)**	**Ca (mg/l)**	**SAR (me/l)**	**Cl^- (mg/l)**	**EC (dS/m**	**TDS (mg/l)**
Location								
TalaboYar dam	5.80^{abc}	6.5^{a}	1.2a	1.30^{a}	0.167^{ab}	6.2^{a}	0.300^{ab}	237^{ab}
Odwayne dam	3.73^{ab}	9.9^{ab}	2.9^{a}	3.80^{bc}	0.167^{ab}	13.2^{ab}	0.300^{ab}	273^{ab}
Gatitalay dam	3.73^{ab}	7.5^{ab}	1.2^{a}	2.47^{ab}	0.100^{a}	7.7^{a}	0.300^{ab}	187^{a}
Gatitalay *berked*	6.57^{bc}	5.4^{a}	1.9^{a}	1.53^{ab}	0.167^{ab}	12.2^{ab}	0.300^{ab}	253^{ab}
Galolay *berked*	3.20^{a}	14.8^{abc}	6.1^{ab}	2.77^{ab}	0.300^{abc}	14.8^{ab}	0.467^{bc}	347^{b}
Qalocato *berked*	8.27^{c}	6.0a	1.4^{a}	2.60^{ab}	0.100^{a}	14.8^{ab}	0.267^{a}	240^{ab}
Odwayne SHW1	3.83^{ab}	28.0^{bc}	24.1^{c}	7.33^{d}	0.967^{d}	20.4^{bc}	0.700^{d}	508^{c}
Odwayne SHW2	4.03^{ab}	30.1^{c}	17.4^{bc}	5.17^{cd}	0.633^{bcd}	27.2^{bc}	0.700^{d}	597^{c}
Odwayne SHW3	3.87^{ab}	23.3^{c}	16.0^{bc}	6.30^{d}	0.667^{cd}	20.8^{c}	0.633^{cd}	523^{c}
Seasons								
1 - Rainy	4.21	13.6	9.2	3.81	0.378	12.6	0.433	339
2 - Mid - season	4.63	12.4	8.8	3.08	0.422	16.4	0.400	327
3 - Dry	5.50	17.7	6.0	4.20	0.289	16.8	0.489	388
Mean	**4.78**	**14.6**	**8.0**	**3.70**	**0.363**	**15.3**	**0.441**	**352**
Location	**0.045**	**0.017**	**0.008**	**< .001**	**0.012**	**0.025**	**< .001**	**< .001**
Season	0.330	0.461	0.621	0.224	0.604	0.346	0.201	0.318

***Note: SHW** - Shallow well; Different letters within the column indicate significant differences at 95% CI*

Magnesium levels of the waters ranged between 6.5 - 30.1 mg/l (0.53 - 2.48 me/l) with shallow wells, 27.1mg/l (2.23 me/l), *berkad* 8.7 mg/l (0.72 me/l) and the dams at 7.97 mg/l (0.66 me/l) indicative of good levels (<5 me/l) (Ayers and Wescot, 1994; Bauder *et al*., 2014).

The sodium levels increased in shallow wells, average of 19.17 mg/l (0.83 me/l) while < 3.2 mg/l (0.14 me/l) in the dams and < 2 mg/l (0.09 me/l) in the *berkads.* The sodium levels in the water from the different sources were safe as they are less than the recommended value of <40 me/l (Ayers and Wescot, 1994; Bauder *et al*., 2014).

The calcium levels ranged between 1.3 - 7.3 mg/l (0.06 - 0.37 me/l) which is considered for irrigation (<20 me/l) (Ayers and Wescot, 1994; Bauder *et al*., 2014). The shallow wells had a higher average of 6.27 mg/l (0.31 me/l), whereas the dams and *berkeds* had 2.52 mg/l (0.13 me/l) and 2.31 mg/l (0.11 me/l), respectively.

Sodium adsorption ratio is a measure of the amount of sodium (Na) relative to calcium (Ca) and magnesium (Mg) in the water and dictates the suitability of water for use in agricultural irrigation (Wilcox, 1955; Obiefuna and Sheriff, 2011; Zaman *et al*., 2018). The SAR levels ranged between 0.1- 0.97 me/l with shallow wells > *berkad* > dam) of 0.76, 0.19 and 0.14 me/l, respectively.

The chloride levels ranged between 6.2 - 27.2 mg/l (0.17 - 0.77 me/l) with shallow wells> *berkad* >dam). The levels were below 70mg/l which is generally safe for all plants (Bauder *et al*., 2014). The EC for the water samples was between 0.3 - 0.7 dS/m, which offer no restriction in use for irrigation (< 0.7 dS/m) (Bauder *et al*., 2014). The EC values ranged as shallow wells (0.68 dS/cm), 0.34 dS/m and 0.30 dS/m for *berkads* and dams, respectively. Electrical conductivity is a useful guideline for measuring the water salinity hazard.

TDS values vary from shallow wells (542 mg/l) > *Berkeds* (280 mg/l) > Dam (232 mg/l); concentrations below 450 mg/l in Dam and *Berkeds* indicate no use limitation, while shallow wells show moderate to low use limitation (450 - 2000 mg/l). The higher TDS levels in the shallow wells are due to mineral-rich water sources, carbonation, saline precipitation, and seawater intrusion (Albu *et al.,* 2012). The higher the salinity, the more energy plants must consume to take up fertilizer and nutrients dissolved in soil water (Awan *et al.,* 2022).

The temperature range for all plots was 23-270°C. Significant temperature differences were observed between seasons ($P<0.001$), with the mean temperature during the wet season (26.030°C) being higher than that of samples collected during the mid-season (24.50°C) and dry season (23.010°C). The temperature difference between the mid-wet season and the dry season is primarily determined by humidity and saturated vapor pressure difference, i.e., as humidity increases, the vapor pressure difference decreases and, consequently, so does the temperature. Since the absence of saturated vapor pressure causes the atmosphere to be dry, an increase in saturated vapor pressure causes a corresponding increase in temperature, especially in semi-arid regions, and explains the difference between wet and dry seasons (Mbayaki and Kinama, 2022). The taste, viscosity, solubility, odor, and chemical composition of water also depend on temperature, as do the biosorption processes of heavy metals dissolved in water. This is why many people find water at 10-15°C more pleasant.

5.5 Conclusion and Policy Implications

The low permeability of calcareous soils, low rainfall in dry areas, transpiration of vegetation, and high summer evaporation lead to salt accumulation in the rhizosphere. In the future, "salinity in drylands" should play an important role in public debate and policy, but as this study has shown, the focus should be exclusively on salinity in shallow aquifers and wells. Therefore, there is a need for salinity control strategies in drylands in order to achieve sustainable management in the context of climate change and to increase the agricultural productivity of these areas.

CHAPTER SIX

SUMMARY, CONCLUSIONS, AND POLICY IMPLICATIONS

6.1 Summary and Conclusions

The results show that there are statistical differences in the level of education and access to education between RWH supporters and non-supporters. They also show that *Berkads* is the main source of water for domestic water and livestock in the region. Water scarcity exacerbates conflicts between local people over water resources. Thus, regulating the frequency of water use plays an important role in maintaining resilience to water scarcity.

Social capital and collective action are high, as many respondents are members of water associations. Associations play an important role in water supply and use through mitigation and management; most RWH users have a positive (good or excellent) attitude toward RWH technology. Advocacy has also played an important role in providing communities with information on climate change, water treatment, water harvesting and hot water.

This study also assessed the determinants of RWH technologies as well as the intensity of adoption and its determinants. A binary Logit model and a count data model (PRM) were used to check for the factors influencing adoption and the intensity of adoption. Results from the logit model showed that household size, education, land size, access to training and information were also found to significantly influence the adoption of RWH technologies. From the PRM to estimate the factors that influenced the intensity of adoption of RWH technologies, variables such as access to RWH information, frequency of fetching water, water shortage, total farm income as well as the adequacy of water significantly influenced the intensity of adoption.

6.2 Policy Implications

Governments need to develop permanent water sources suitable for community use. This can be done in cooperation with donor agencies and local NGOs. New water sources should be constructed or developed for communities to reduce conflicts over sharing existing water sources. Group trainings can also be organized to increase the technical knowledge of the local population and facilitate the flow of information on RWH technologies.

It is therefore important for government agencies and donor organizations to work with local institutions, such as elders, to raise awareness among different tribes about the need to develop and manage new water sources. Government policies and actions should aim to promote community-based water harvesting technologies by providing capital and equipment. Based on the empirical results, information played a crucial role in influencing adoption. This implies that adoption could be enhanced if farmers could have access to relevant information. This can be done through programs aimed at recruiting and deploying extension officers to disseminate information regarding RWH technologies and their benefits. The results highlight the need to increase access to training to increase the technical knowledge of the farmers. This can be done through group training, where participants are educated on the methods and benefits of RWH to increase their acceptance.

The study also recommends that "salinity in drylands" be the focus of public and political debate, but based on the results of this study, it focuses only on salinity caused by shallow groundwater and shallow wells in particular. Strategies to increase the use of such salinity control in drylands for sustainable management and productivity of dryland agriculture in the context of climate change.

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APPENDICES

Appendix 1: Variance Inflation Factors (VIF) for variables in the binary logit model

Variable	VIF	1/VIF
Gender	1.07	0.933
Total farm income	1.07	0.936
Household size	1.06	0.944
Main income	1.06	0.944
Access to training	1.06	0.947
Education	1.05	0.951
Farm usage	1.04	0.959
Total land size	1.03	0.969
Age	1.03	0.974
Mean VIF	**1.05**	

Source: Survey Data (2020).

Appendix 2: Variance Inflation Factors (VIF) for variables in the PRM

Variable	VIF	1/VIF
Group membership	2.88	0.346
Participate in maintenance	2.82	0.354
Information access	1.73	0.577
Access to resource	1.63	0.612
Water adequacy	1.53	0.654
Water shortage	1.36	0.734
Sanitation	1.22	0.821
Farm income	1.18	0.847
Fetching frequency	1.09	0.918
Mean VIF	**1.72**	

Source: Survey Data (2020).

Appendix 3: Guidelines for interpretations of water quality for irrigation

Parameter	Units	Degree of restriction on use		
		None	**Slight to moderate**	**Severe**
EC	dS/m	< 0.7	0.7 – 3.0	> 3.0
TDS	mg/l	< 450	450 – 2000	> 2000
Na	SAR	< 3	3 – 9	> 9
Cl	me/l	< 4	4 – 10	> 10
N	mg/l	< 5	5 – 30	> 30
HCO3	me/l	< 1.5	1.5 – 8.5	> 8.5
Ca	me/l	40 -100		
Mg	me/l	30 - 50		
pH		Normal Range 6.5 – 8.4		

Appendix 4: Agropastarolists Survey Questionnaire

Introduction:

My names are Mustafe, a student from the University of Nairobi. As a requirement of my Master's Degree in Land and Water Management. I am carrying out a study on Rainwater Harvesting Technologies and their utilizations in this area. The survey is voluntary and you can choose or not take part. The information that you give will be confidential and will be used for the economic purpose only; it will not include any specific names. Could you please spare 15-20 minutes for the interview and kindly answer the following questions?

SECTION A: BASIC INFORMATION: No. ( )

1. Date……………. Name of Enumerator ……………………
2. Respondent Name…………….. Tell …………………. Location ……………………………… Age ……… Sex; Male [ ] Female[ ]
3. What is the highest education level completed? (Parents F [ ] M [ ] children C [ ])

	M	F	C
A) Never wanted to school			
B) Lower primary school			
C) Upper primary school			
D) Secondary			
E) Certificate			
F) Diploma			
G) University			
H) Others (specify)			

4. How many household members?

____

5. What is the size of your farm (specify units)?
   A. Less than a hector
   B. 1-2 Hector
   C. 2-4 Hector
   D. 4-8 Hector
   E. 8 Hector or More than
6. What is used for the farm?
   A. Crop production
   B. Livestock production
   C. Homestead
   D. Others (specify) …………………………………

7. Where do you get information to assist in the management of your farm?
    A. Radio
    B. Newspapers
    C. Friends
    D. Extension Officers
    E. Internet
    F. Television
    G. Others (Specify) …………………………………
8. Is farming your main source of income?
    A. Yes
    B. No
9. If No (in 8 above), what are your other sources of income?
    A. Business
    B. Remittance from family members
    C. Pension/retirement benefits
    D. Others (Specify) …………………………………
10. What is your income (USD) per annum?
    I. From farming:
    A. 0-50]
    B. 50-200
    C. 200-400
    D. 400-1000
    E. Over 100
    F. Others (specify) …………………………………
    II. From other sources
    A. 0-500
    B. 500-2000
    C. 2000-4000
    D. 4000-10000
    E. Over 10000
    F. Others (specify) …………………………………
11. Did you get any training?
    A. Yes
    B. No

SECTION A: BASIC INFORMATION: Rainwater Information

1. Are you aware rainwater harvesting?
    A. Yes
    B. No
2. If Yes (in 1 above), how many technologies you are aware of?

Technologies	Remarks
1.	
2.	
3.	

4.	
5.	
6.	
7.	
8.	
9.	
10.	

3. What is your main source of water?
   A. Berkad
   B. Dam
   C. Shallow wells
   D. Poreholes
   E. Others (specify) …………………………………
4. Is the water harvested enough for your household need?
   I. Yes
   II. No
5. If the water harvested is not enough, what amount do you need in order to sufficiently meet your household needs?

___

___

6. What means do you or other community members use to access water from the community watering point?
   A. Donkey drawn carts
   B. Pickups
   C. Lorries
   D. Household labour
   E. Others (specify) …………………………………
7. What you use for water from those technologies?
   A. Livestock
   B. Crop Production
   C. Domestic use
   D. Both domestic and livestock
   E. Both livestock and domestic
   F. Others (specify) …………………………………
8. If its crop (in 7 above), which crops you practice?

___

___

9. How many crops you used to grow before the technologies and how many now?

No	Crops before	No	Crops after

10. How many Kg of yield you used to harvest for one particular crop and now how many Kg?

No	Crop	Kg before	Kg after
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			

11. Is the water harvested clean enough for drinking?
    I. Yes
    II. No
12. If No (in 11 above), what kind of treatment do you use to improve water to be cleaned for drinking?

    ____

    ____
13. How often you fetch water?
    A. Every day
    B. After 1-2 days
    C. After 2-3 days
    D. After 3-4 days
    E. After 5days
14. Have you ever experienced water shortage?
    A. Yes
    B. No
15. If yes (in 14 above), when and for how long did you experience the water shortage?

    ____

    ____
16. Which month(s) of the year is water shortage usually severe in this area (please tick the month or months reported?

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

17. How do you cope with periods of water shortage? Please explain with respect to water for domestic use, livestock needs and Agricultural activities?

18. Who controls?
    A. Elders
    B. Men
    C. Women
    D. Youth
19. In general, what are the factors influencing and/or affecting adoption of water harvesting techniques among households in this region?
20. A. Are there organizations/institutions helping your community in the setting up of water harvesting techniques?
    I. Yes
    II. No
    III. Have no idea
21. If yes in (20 above), name the organizations and the water harvesting techniques being promoted?

Organization/Institution	Water harvesting technique being promoted	How received by the community

22. A. Are there any conflicts among farmers on water use?
    A. Yes
    B. No
    C. Can't tell
23. If yes (in 22 above), specify the nature of the conflicts?