WATER USE AND CROP WATER PRODUCTIVITY IN FARMER MANAGED IRRIGATION SCHEMES ACROSS AGRO ECOLOGICAL ZONES OF USA RIVER CATCHMENT

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ABSTRACT

The Usa River Catchment is the potential area dealing with traditional irrigated agriculture. This study aims to estimate the amount of water abstracted for and yield that reflect water values to enhance crop water productivity. The main objective of this study was to assess water use and crop water productivity in farmer managed irrigation schemes across agro-ecological zones of Usa River Catchment. The specific objectives were: (a) to determine crop water productivity, (b) to determine factors causing the variation of crop water productivity, and (c) conveyance efficiencies in the traditional irrigation schemes in the Catchment. The secondary and primary data were collected and analysed using Statistical Package for Social Science (SPSS) and R-program. Consequently, the average productivity obtained were 2.3 kg/ha, 1.9 kg/ha, and 3.4 kg/ha of maize for downstream, midstream, and upstream zones respectively. Similarly, at twenty (20) furrows, the conveyances efficiency of the water channels was 72%, which reflects the water loss in the conveyances of 28% on average. However, the water abstractions were 3500 L/s more than the permitted amount of 2856.2 L/s, which was against the established water abstraction laws and regulations leading to water shortage in downstream of the catchment. Traditional irrigation infrastructure in this study contributed more water losses and low crop water productivity compared to global average water losses in the conveyance and crop water productivity in irrigation schemes. This study recommends weirs with water control structures intakes to be constructed, canal lining and improve irrigation water management.

DECLARATION

I, Humuri Khwantlay Haymale, do hereby declare to the Senate of the Nelson Mandela African Institution of Science and Technology that; this dissertation is my own original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

Humuri Khwantlay Haymale

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Nelson Mandela African Institution of Science and Technology a dissertation titled "*Water use and productivity in farmer-managed irrigation scheme across agro-ecological zones of Usa River Catchment, Arusha-Tanzania*" for the degree awards of Master of Science in Hydrology and Water Resource Engineering of Nelson Mandela African Institution of Science and Technology, Arusha-Tanzania.

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This dissertation is dedicated to my beloved late father Khwantlay Akonaay, my lovely wife, our children Joshua Haymale, Joel Haymale, and Gladness Haymale for their endless support in prayers and encouragement.

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LIST OF ABBREVIATION AND SYMBOLS

AEZ	Agro Ecological Zone
CO_2	Carbondioxide
DEM	Digital Elevation Model
EWP	Economic Water Productivity
EWPR	Economic Water Productivity Ratio
FAO	Food and Agriculture Organisation
GAP	Good Application Practice
GDP	Gross Domestic Product
GPS	Global Positioning System
GWP	Global Water Partner
MEWES	Material, Energy, Water, Environmental Engineering and Science
NM-AIST	The Nelson Mandela African Institution of Science and Technology
SPSS	Statistical Package for Social Sciences
SSA	Sub-Saharan Africa
UWAMAKIJUU	Umoja wa Watumia Maji Kikuletwa Juu'
USGS	United States Geological Survey
URT	The United Republic of Tanzania
URC	Usa Rivers Catchment
WP	Water Productivity
WUE	Water Use Efficiency
WUA	Water User Association
IWRM	Integrated Water Resource Management
PBWB	Pangani Basin Water Board
WRM	Water Resource Management

CHAPTER ONE

INTRODUCTION

1.1 Background of the Problem

Globally, rain-fed agriculture contribution to food production is about 60%; the irrigated agriculture supplements the other 40% (Clay, 2002). However, irrigation consumes a large amount of water about 70% of the available water (Global Water Partner [GWP], 2000). Irrigation efficiency in Sub-Saharan Africa (SSA) was 33% in the year 1998 and expected to improve to 37% in the year 2030 (Clay, 2002). The SSA irrigated agriculture is said to use less than 2% of the total renewable water resource to irrigate a land of six million hectares, which is equal to 6% of the entire irrigable area (Clay, 2002). Conversely, the Asia region uses 37%, and Latin America uses 17% of its total renewable water resource, which seems to be higher than SSA (Clay, 2002). Tanzania has a total of 1428 irrigation schemes where 1328 are smallholders, 85 are owned private sectors, and 15 are the government-owned schemes and the largest irrigation schemes are in Kilimanjaro, Arusha, Morogoro, Iringa and Mbeya (United Republic of Tanzania [URT], 2005). Irrigated agriculture in Tanzania consumes about 89% of the total water, compared to domestic use 9% and industrial water use 2% (URT, 2008). Simultaneously, farm water use efficiency is very low between 10%-20% contributing to major water loss in irrigated agriculture of Tanzania (URT, 2008). Irrigated farm performance is measured based on water productivity.

Molden *et al.* (2007) classified water productivity into physical and economical. Physical water productivity means the ratio of the mass of agricultural output to the amount of water used. Economic water productivity is the value derived per unit of water used (Molden *et al.*, 2007). The Usa River catchment is near Arusha town. It supports agricultural activities during the rainy season and irrigation during the dry season. Its climatic condition varies from the highland areas at the foot of Mount Meru to the lowlands which is assumed to affect the agricultural activities. Due to its vicinity, the Catchment has developed the water stress to the water use stakeholders resulted from excessive withdrawal surface water, underground water extraction, water pollution, and inefficient water use in agriculture. Water use and productivity are indicators of water resource utilization in the catchment by taking into account the external and internal factors. Therefore, this study will quantify water use and productivity across the agro-ecological zones in a farmer-managed irrigation schemes of the Usa River catchment.

1.1.1 Study Area

The Usa River Catchment (URC) is located in Meru and Arusha district in Arusha region between latitudes $3^0 15' 00''$ to $3^0 33' 00''$South and longitudes $36^0 45' 00''$ to $36^0 56' 00''$ East. The URC is in the eastern part of the Arusha Region and South of the foot of Mount Meru. It is among of the five sub-basins of Pangani Water Basin. The Catchment is at the upper Kikuletwa sub-basin at the foot of Meru Mountain, which covers 320 km^2. The URC became potential in irrigation because of land availability, water, location, and being near Arusha City as market outlet for farm produce.

1.1.2 Topography

The topography of the URC is generally categorized by a slightly rolling plain from the Mbuguni ward steepens towards the foot of Mountain Meru, where the rivers start. The average elevation is 1250 m above mean sea level, and the slope dissected by the permanent, perennial and seasonal streams found in the middle part of the catchment, which also recharges the rivers. The large area of the basin is exhausted by anthropogenic activities like agriculture, pastoralism, and habitats.

1.1.3 Geology and Hydrogeology

The land formation of the catchment is rocky, covered by a small layer of soil that supports the life of living things and agricultural activities. The URC is at the southern area where there is Arusha National Park, which is at the foot of Mount Meru and acts as the catchment during rainfall for recharge of the rivers found in an area. The presence of forest at the mountain helps to recharge through the infiltration of the surface water found in rivers. The hydrogeology of the catchment allows water movement in the ground to recharge rivers and the soil reserving moisture that makes irrigated agriculture possible. The available surface water is used for domestic use, animal drinking, fishing, and irrigated agriculture. However, due to good average of annual rainfall during the rainy season, the river causes flooding downstream, which is almost understandable and makes the rain-fed agriculture impossible. Moreover, the upstream area also practices rain-fed agriculture which does not give the acceptable yield due to high rainfall that affects the productivity. Therefore, the URC has great potential for the irrigated agriculture and the local market participation of tomatoes is (40%), onions (12.5%), and vegetables (11%) to the nearby City of Arusha (Sumari *et al.*, 2018).

1.1.4 Climate and Vegetation

The URC receives an average rainfall of 837 mm yearly. Therefore, the presence of rainfall and available forests at the upstream are essential for the recharge of rivers running from Meru Mountain to downstream of Pangani Basin for the irrigated agriculture and electricity generation. The URC has two rainfall seasons in a year; short rainy season starting from October to December and the long rainy season starting from March to May. The Catchment is at 1160 meters above the mean sea level, with an average temperature of 19.5^0C to 22^0C. The weather of the Catchment allows irrigation agriculture activities of different crops across the agro-ecological zones along the Usa Rivers. However, the climate varies from the foot of Meru Mountain downstream to the areas where river join.

1.1.5 Agro-ecological Zone

An agro-ecological zone is defined as land resource, in terms of climate, landform, soils, land cover, specific range of potentials and constraints for land use. The URC soil is fertile and suitable for irrigated agriculture during the dry season due to the availability of surface water from the number of existing perennial rivers. However, rain-fed agriculture is also exercised in the Catchment due to the availability of the vast land for agriculture during the rainy season. Moreover, the irrigated farming throughout the agro-ecological zones create the room for agribusiness for the produce. Similarly, catchment is connected with Arusha- Namanga’s main road to Nairobi City that stimulates agribusiness activities in the area. Subsequently, the presence of different landforms, soil type, insufficient irrigation water supply, however, the crop productivity enhancement is inevitable.

1.1.6 Land use

Land of the Catchment is used for agriculture, settlement, and recreation. However, the land’s population pressure and its potentiality have brought conflicts between the community and investors found in the watershed. Subsequently, irrigated agriculture takes the largest share of water for irrigation in the catchment as a result of shortage of water resource and brings conflict.

1.2 Statement of the Problem

Currently, irrigated agriculture is not focussed on insisting on water uses and productivity in several irrigation schemes (Walker, 1989). Inefficient water uses at different scales affect irrigated agriculture in farmer-managed irrigation schemes. Further, water uses in irrigated agriculture becomes the contentious and challenging issue because some of irrigation water is consumed by plant for growth, some is evaporated and some infiltrate into the ground. Similarly, traditional irrigation schemes are in forefront on inefficient of water use due to poor irrigation infrastructure. The Usa river catchment comprises several farmer-managed irrigation schemes which need assessment on water use and crop water productivity. For example, Lankford (2012) describes four fractions of water application to the irrigation field such as beneficial, non-beneficial, recoverable and non-recoverable to measure irrigation performance. Moreover, it was reported that irrigation efficiency (IE), water productivity (WP), and water use efficiency (WUE) were misused and aggravated water loss and waste in irrigation (Van Halsema & Vincent, 2012). Therefore, the study needed to assess traditional irrigation scheme performance across the agro-ecological zone of the Usa River catchment. Similarly, Knox *et al.* (2012) explained that it is better to understand the irrigation performance by asking irrigators to keep records of the amount of water used and the product obtained for accountability. Pereira *et al.* (2012) described terms used in determining the productivity and water use in irrigation scheme performance, such as consumptive use, non-consumptive use, water productivity (WP), water use efficient (WUE), economical water productivity (EWP) and economic water productivity ratio (EWPR). This study, therefore, intend to examine the performance of irrigation schemes' intakes, canals and waters uses to enhance crop water productivity across the agro-ecological zones of the Usa River catchment.

1.3 Rationale of the Study

About 75% of the mainstay of Tanzanian people are employed in agriculture, but productivity is among the lowest in Sub-Saharan Africa (URT, 2011). currently, in Tanzania irrigated agricultural land is still in small proportion (4%) of the existing irrigable area and most irrigated land (80%) is under smallholder farmers, usually considered by technocrat as their low inputs limiting productivity (URT, 2011). Furthermore, agriculture contributes 24.5% of Gross Domestic Product (GDP) of Tanzania, and 28.2% of the population is living below the poverty line, and the majority of them are staying in villages (URT, 2011). Similarly, in any 1% increase in agriculture yield/productivity, it translates 0.6% to 1.2% decrease in the percentage of absolute poverty level (Wani *et al.*, 2009). This study will help to enhance the water resources utilization in terms of social-economic improvement, water allocation issues, reduce conflict between the upstream and downstream water users, and contribute to advice policy makers on water-related matters and natural resource conservation.

1.4 Objective of the Study

1.4.1 Main Objective of the Study

This study's main objective was to assess water use and productivity in farmer-managed irrigation schemes across agro-ecological zones of Usa River catchment.

1.4.2 Specific Objectives

The specific objectives of this study were:

(i) To determine the water use and crop water productivity in farmer-managed irrigation schemes across the agro-ecological zones of the Usa River catchment.

(ii) Conveyance efficiencies in the farmer-managed irrigation schemes across the agro-ecological of the Usa River Catchment.

(iii) To determine the factors contributing to variations in crop productivity and conveyance efficiencies in farmers-managed irrigation schemes across agro-ecological zones of the Usa River catchment.

1.5 Research Questions

This research study was guided by the following research questions:

(i) How do water use, crop productivity and conveyance efficiencies in farmer-managed irrigation schemes differ across agro-ecological zones of the Usa River catchment?

(ii) What are the factors that determine the variations in crop productivity and conveyance efficiencies in farmers-managed irrigation schemes across the agro-ecological zones of the Usa River catchment?

1.6 Significance of the Study

The study's significance is a contribution to the knowledge on management of traditional irrigation schemes, pointing out the research gap that needs to be exhausted at catchment and provide awareness to stakeholders in water users and policy makers in decision making.

1.7 Delineation of the Study

Number of studies have been conducted in the URC; hence, this study will cover only conveyance efficiency and crop productivity across the agro-ecological zones of Usa River Catchment.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Water is the most important input required for the plant growth and production. In case of less rainfall, then the irrigation is used to supplement the water required by the plant. Vico and Porporato (2010) defined irrigation as the application of water to the soil to supplement natural precipitation/ soil moisture and provide an environment that is optimum for crop production. The application of the water to the farm is being done using various methods depending on technology which includes flooding, furrow, basin, trickle and drip irrigation methods. However, the increase of water scarcity and demand of agricultural production generate debate about improving the water use and productivity. Water used in irrigation is managed through irrigation scheme performance by determining water use efficiency (WUE), Irrigation Efficiency (IE) and water productivity (WP) (Van Halsema & Vincent, 2012).

Lankford (2012) describes four fractions of water uses diverted from the stream to the irrigation field and the water leaving the irrigation field. During transportation of water to the field, there are some amounts of water will be lost on the way and other in the farm during irrigation and others will be leaving the farm. These are non-recovered fraction (NRF) which includes evaporation, seepage and run-off (non-beneficial consumptive) and some of seepage and run-off can be recoverable to express the irrigation performance. However, the water losses in the traditional irrigation system do starts from point where the water is extracted.

Knox *et al.* (2012) describes clearly how the stakeholders perceive the efficient water use differently. For example, farmers think that water application to the farm is only meeting the agronomic demand and avoiding excessive water into the farm. Similarly, engineers focus on the efficiency of delivery water system into the farm while agronomists think of crop productivity. Further, policy makers focus on the utilization of water resources for food production. Therefore, it is better to understand the irrigation performance system which will help on utilization of water resource at field level (Knox *et al.*, 2012). This study intended to assess the traditional irrigation scheme performance in terms of productivity and conveyance efficiency in farmer managed irrigation schemes across agro ecological zone of Usa River catchment.

Pereira *et al.* (2012) described consumptive use, non-consumptive use, water productivity (WP), water use efficiency (WUE), economic water productivity (EWP) and economic water productivity ratio (EWPR) evaluating the irrigation scheme performance. Moreover, other terms are beneficial and non-beneficial water use for analysing the water productivity use efficiency. The study intended to understanding the irrigation schemes crop water productivity and conveyances efficiency to enhance utilisation of the water resource.

2.2 Agro-Ecological Zones

The river naturally flows from the high altitude towards the lower land across different agro-ecological zones (AEZs). At a regional scale, AEZs are influenced by latitude, elevation, temperature, seasonality, rainfall, and water distribution during the growing season. Plant growth is being affected by the weather element, soil fertility, and seed heredity. Therefore, water abstraction and uses may differ from one intake to another along the rivers through agro-ecological zones. Specifically, AEZs of Arumeru District are well-drained, gently undulating to rolling plains and plateaux, altitude 500 − 1500 m developed on a gneissic rock with bimodal rainfall ranging 600 mm-1500 mm per annum (Kajembe *et al.*, 2005). The temperature ranges from 15ºC to 30ºC. Depletion of soil fertility, along with the related problems of weeds, pests, and diseases, is a major biophysical cause of low per capita food production in Africa (Characteristics-of-major-agro-ecological-zones-environmental). The particular parameters used in the definition focus attention on the climatic and edaphic requirements of crops and on the management systems under which the crops are grown. Each zone has a similar combination of constraints and potentials for land use and serves as a focus for the targeting of recommendations designed to improve the existing land-use situation, either through increasing production or by limiting land degradation. Given the full range of climates and types of soil around the globe, there are substantially different constraints to productivity from countries or sites to another (Adejumobi *et al.*, 2014).

2.3 Characteristics of Agro-Ecological Zones

In agriculture, the zone plays a significant role in productivity. Before policy makers can design appropriate policy responses, they need to have reliable indicators of how impacts will vary across the landscape. Farms in different Agro-Ecological Zones (AEZ) employ different farming practices. For example, depending on the AEZ location, each farmer will choose a specific farming type, irrigation, crop species, and livestock species that fit that AEZ (Seo *et al.*, 2008). The market demand drives the farmers in the agro-ecological zone to cultivate according to the demand needs. Subsequently, the difference in weather and soil fertility of the area dictates farmers what type of crop would be grown/cultivated. Further, the product's market value is also the driving force of the type of crop to be cultivated by the farmer. Different crops are grown at the high altitude, midstream and lower altitude of the Usa River Agro-ecological Zone. The productivity differences are caused either by soil fertility, weather and variable supply of water for the plant growth. The area close to the mountain has low temperature, resulting in prolonged duration of the plant to mature, so the water used for irrigation is not much because of more extended periods of rainfall and low evaporation. The AEZ of the Usa River runs from 934 m to 1350 m above mean sea level. The lowest area is the plain range where agriculture is possible, and the soil is fertile. Investment in high-potential areas generates more agricultural output and higher economic growth at a lower cost than in less-favoured areas (Fan *et al.*, 2000). The higher land is about 1350 m above sea level, the middle is 1100 m, and the downstream is 934 m above the sea level with cool and wet, moderately cold and arid and hot, respectively.

2.4 Water Conveyance in Irrigation

Irrigation agriculture means crop production by using water from the river or other sources. But intended irrigation farm field could be far away from the source of water as the results of infrastructure establishment that conveys water from source and within the farm. Similarly, the plants available in the farm also are scattered throughout the land necessitating the need for infrastructure to supply water within the farm. Water conveyance in irrigation system includes water intake structure, transportation and distribution, field application and drainage system. Irrigation intakes direct water from source of supply such as rivers, reservoir to the irrigation field through conveyance system. The conveyances system assures transport of water from the intakes to farm/field ditches. Further, field application system transport water within the field while drainage take away the excessive water from the irrigation field. Palanisami *et al.* (2009) explained that the water productivity in irrigation schemes varies at different scale of conveyances infrastructure and the type of irrigation system in practise. The conveyance and distribution of water in the irrigation schemes is the vital aspect that need to be highly considered for sustainability of the irrigated agriculture. Consequently, the canals transport water to the field, however they have different characteristics. The canals could be open or closed. Brouwer *et al.* (1985) explained that the canal is characterized by its shape of cross-section i.e., rectangular, triangular, trapezoidal, circular, parabolic and irregular or natural. Brouwer *et al.* (1985) in his manual describes the different control structures in the irrigation system, which helps in irrigation water management like control structures such as drop and chutes, division boxes, turnouts, checks, flumes, culverts and water measurement like weirs. Therefore, the irrigation scheme has four main types of structures which includes erosion, distribution, crossing and water measurement control structures (Brouwer *et al.*, 1985).

Moreover, conveyances infrastructure losses water before it reaches the farm field. Conveyance efficiency decreases with distance at an increasing rate, however major sources of conveyance loss are seepage and percolation (Chakravorty & Roumasset, 1991).

2.5 Irrigation Schemes

An irrigation scheme is a system of supplying (land) with water by means of artificial canals, ditches especially to promote the growth of food and other crops. Irrigation development in Tanzania, as in other countries in Sub-Saharan Africa, has taken place in stages and has been associated with large challenges (Mdemu *et al.*, 2017). In the early 1960s, Tanzania entered a phase of developing large irrigation schemes for commercial and food security which included infrastructure improvement, management in general, financing schemes, agricultural implement and machinery, transportation system improvement and access to profitable market (Mdemu *et al.*, 2017). Similarly, the government of Tanzania was involved in developing eleven (11) irrigation schemes since 1969. Through the Food and Agriculture Association (FAO) report to Tanzania Government the eleven (11) schemes were identified together with constraints and potential suitable areas for irrigation (URT, 1969). Subsequently, in 1980's the Sonjo people in North of Tanzania were practising irrigation under the farmer-managed irrigation system which were having poorly constructed infrastructures with stones and wooded to divert and convey water to their farms (Adams *et al.*, 1994). Farmer-Managed Irrigation

System (FMIS) means autonomous institutions whose community members are responsible for overall irrigation management including water appropriation, distribution, canal maintenance, and conflict management through collective action (Pradhan, 2003). Regmi (2008) explained that Farmer Managed Irrigation Schemes (FMIS) performed well in terms of agricultural productivity, water delivery and physical condition compared to Agency- Managed Irrigation System (AMIS).

2.6 Water User Associations

The issue of water resource management has become critical in different levels of administration. because of scarce water resources. Due to the food insecurity, irrigation is taking over responsibility to subsidize the deficit of agricultural productivity. Subsequently, quantity of water withdraws from the water sources became high and demand increased resulting to inefficient, unreliable and incomplete irrigation agriculture. The GWP (2000) narrated clearly the process which promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. Following the Dublin principles and implementation of Integrated Water Resource Management (IWRM), the government of Tanzania divided the water resource management system into water sheds governed by water boards. Further, Water User Associations (WUA) were formed following water policy as the lowest level of water management. The aim of WUAs establishment was to fulfil the three pillars of IWRM which are equity, efficiency and environmental sustainability. In line with Usa River Catchment the water user association was established to manage water for irrigation and domestic uses. The main objective of establishment was to manage the sustainable use of water resources, provide education and advice to stakeholders on water use, resolving various water use disputes, have joint management of water resources and conservation of water resource and the environment. However, twenty (20) furrow intakes of traditional irrigation schemes were established and joined a water user association called ’UWAMAKIJUU’ as shown in Fig. 1. A membership is granted after securing water permit from Pangani Basin Water Board (PBWB) to the group of farmers who extract water from the rivers found within the Usa River Catchment. Similarly, each member is needed to participate in regular and irregular maintenance of canal. The association faces difficulties of water allocation to the members, resolving disputes on water theft and member participation in canal maintenances. However, the members put in their article of association by-laws to handle their matters including aforementioned challenges.

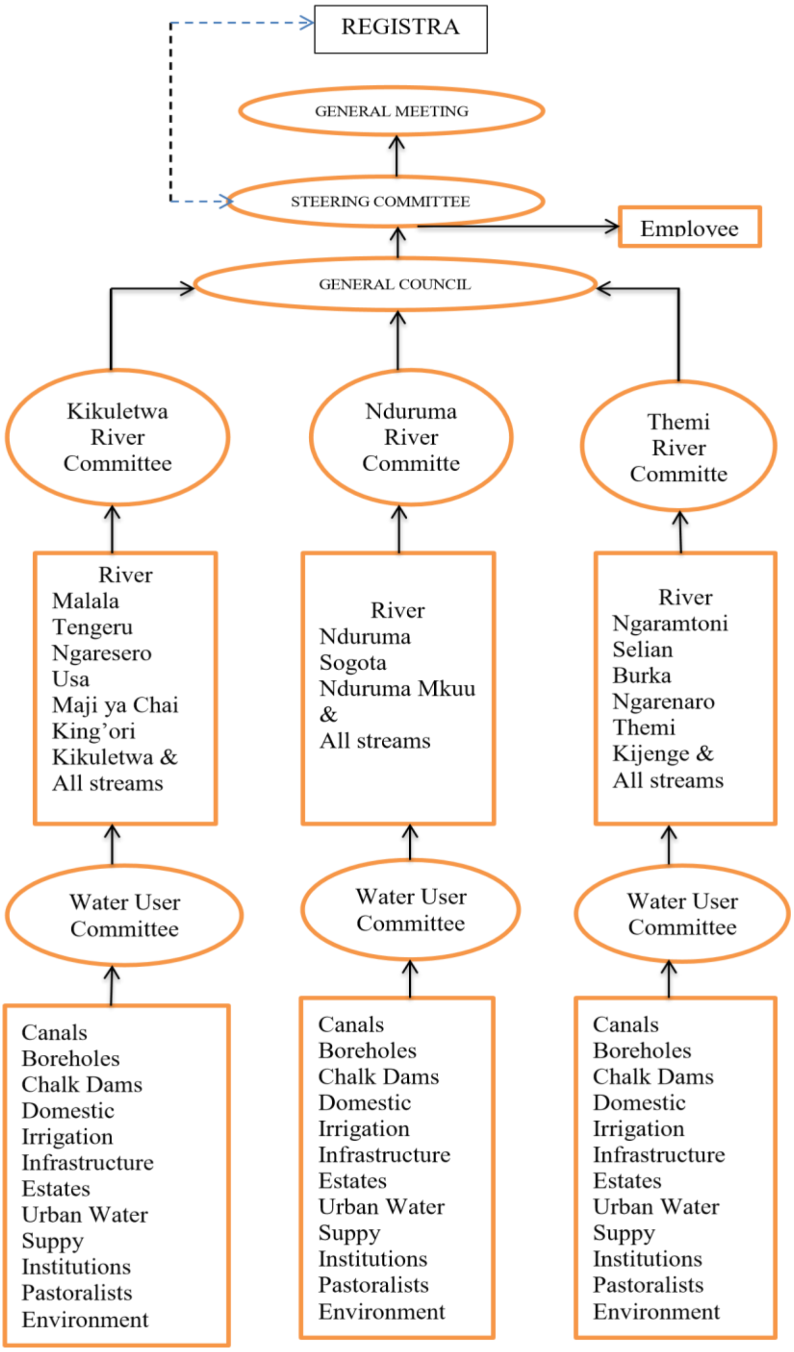


Figure 1: Organisational Structure of Upper Kikuletwa Water User Association

2.7 Water Management in Catchment

Water is the essential needs for human and plants for living. The Usa River Catchment has rivers and stream as the source of water. Irrigators, community, environment and policy makers are the stakeholders on sustainability of the available water resources. The Integrated Water Resource Management (IWRM) provided the key principles on how to manage this scarce resource for sustainable development. Furthermore, at national level the Ministry of Water and Irrigation prepared water policy and established river basin boards to manage water resources. The role and responsibilities of Pangani Water Board is to monitor the water resource, water allocation by issuing and managing water permits, strengthening community in Water Resource Management (WRM), coordinating WRM and development planning, quality monitoring and pollution control, water use conflict management, water resources protection and conservation (Parliament, 2012). Similarly, at the catchment level, water is being managed by asking water user to form their groups and prepare their article of association. Following the water act no.11 of 2009, the Upper Kikuletwa Water Association has established management system for smooth running of daily activities of water resource management and utilization as shown in Fig. 1. The organisation has six (6) levels of committee that starts from the bottom level as the best way of water resource utilization and monitoring. However, in the visited twenty (20) furrows intake, there were no water measurement structures like flumes that makes difficult for the water man to monitor the exact amount of water to be abstracted. This is because of over-abstraction and causes conflicts between the water user of upstream and downstream. Pangani basin is divided into two sub-basins; upper sub-catchment and lower sub-catchment. The upper sub-basin has three main rivers which includes Nduruma, Themi and Kikuletwa. This research based on Kikuletwa river and termed as Usa River Catchment in upper sub-catchment which consist of Malala River, Usa river, Tengeru river, Ngaresero river, Maji ya chai, King'ori and their streams led by catchment water committee. The government streamlined water management due to the growing water scarcity and increasing water competition across water-using sector that needs water serving and physical efficient use.

2.7.1 Conclusion

Generally, in the catchment water abstraction for agriculture is subject to crop water requirement and command area for irrigation. However, the irrigation infrastructures inefficiency causes over-abstraction, water conflicts and difficulties in water allocation management.

2.8 Conveyance Efficiency

The water diverted to the farm is conveyed through the channel to the destined farm plot. In traditional irrigation, water channels are found in natural soil and are human-made. Similarly, water diverted from the source to farm field travels a long way from the source to the farm area where is believed to get lost through canal seepage, evaporation, and even improper management of the water use (Perry *et al.*, 2009; Wallace, 2000). The conveyance efficiency (Ec) is defined as the ratio between the actual volume of water diverted through the channel for a specific purpose and the volume delivered or derived from a supply source for that same purpose (Perry *et al.*, 2009). Economic viability and environmental sustainability enhancement in irrigated agriculture water-efficient practices are inevitable (Levidow *et al.*, 2014). When water is supplied to the farm or field, and some is 'lost,' they may return to the aquifer or stream and reused if the quality has not deteriorated beyond acceptable limits (Wallace, 2000). In determining the efficiency, the mathematical concept of the fraction was used whereby the denominator and numerator were executed. From the definition, the water is being transported from the source through the channel to the farm. Water losses through the traditional irrigation infrastructure is difficult to manage and the challenging issue. The available water resources become scarce, and more emphasis is given to the efficient use of irrigation water for maximum economic return and water resources sustainability (Irmak, 2011). The loss of water in the channel has two boundaries: Losses occurring above the water surface caused by the weather as evaporation and water losses occurring below the channel bed, such as seepage and deep percolation. Due to these losses, the water diverted from the source, denoted as the denominator, becomes higher than the water reaches farm denoted as the numerator as equation below expresses:

$$Ec = \frac{Qoutflow}{Qinflow} \times 100\% \qquad (1)$$

Where:

E_c = Conveyance Efficiency

$Q_{out\ flow}$ = Water flow measured at the outlet of channel(end)

Q_{inflow} = Water flow measured at the inlet of channel (Head)

The varying volumes indicate the performance of the conveyance is measured in percentage. When the conveyance efficiency is high, then the lost water is low; hence, the channel's performance is excellent. However, the conveyance efficiency depends typically on soil type, length of the canal, material, and methods of construction. Moreover, the water losses in the canal need proper water management from a source that may help the significant utilization of the scarce resource. Subsequently, monitoring irrigation schemes through water control from the source to the destination is inevitable in order to rescue or serve the water available as irrigation takes a large share of freshwater in the World. Similarly, the economy at various levels in a country harms the implementation of irrigation infrastructure projects in terms of technology, material to be used in construction, and finance to invest hence making the infrastructure efficiency low. Further, efficiencies in agriculture are divided into different types depending in the area of application. Machibya *et al.* (2004) in the draft of irrigation efficiency and productivity manual described these phenomena of efficiencies in various areas of water uses and application such as conveyance efficiency, field application efficiency, and irrigation system efficiency.

2.9 Crop Productivity

Productivity is regarded as a ratio of the output to input concerning land, labour, capital, and overall resources employed in agriculture. Water productivity is the ratio of output (physical, economic, or social) to the amount of water depleted in producing the output (Machibya *et al.*, 2004). Water productivity is classified into two; pure physical productivity defined as the quantity of the product in weight (Kg) divided by the quantity of the input/water in (M^3) during production and economic productivity is the gross or net present value of the product divided by the value of the water diverted or depleted, which can define in terms of its opportunity cost in the highest alternative use (Kijne, 2003; Molden *et al.*, 2007; Heydari, 2014). Water productivity varies within each climatic zone (Brauman *et al.*, 2013). Further, Ali and Talukder (2008) highlighted the factors affecting crop productivity, which included water application into the farm and techniques used to improve the water use efficiency for productivity. However, agronomic management and engineering factors should consider highly to improve the crop productivity (Ali & Talukder, 2008).

Moreover, Molden *et al.* (2010) explained various factors to consider in improving the water use and productivity under biophysical and socio-economic environments across the irrigation areas and basin at large. However, there are factors which affect crop productivity far from water availability to the plant growth. Subsequently, crop water productivity is being affected by both external factors and internal factors. The vulnerability of the external factor prominently interacts with the plant, soil, and environment, including climatic, edaphic, biotic, physiographic, and social-economic factors. The internal factors depend on the heredity of the genotype of the crop/plant, which may either be productive, resistant to drought, and pests. Moreover, the climate of an area affects crop productivity by 50% compared to the other factors. These include precipitation, temperature, solar radiation, wind velocity, and atmospheric gases (Sharma & Arora, 2015). The different precipitate which is prominent across the agro-ecological zones the plant types to cultivate is affected in terms of intensity and maturity (Sharma & Arora, 2015). Further, temperature also affects light energy intensity for plant growth development, gas exchange within plants and in the soil, and proper mineral absorption by plants.

2.9.1 External Factors

During plant growth, some factors contribute the productivity positively. However, external factors that need to be considered to enhance the water productivity of a particular farm in climatic condition. Climate is one of them which affects plant growth. Climate variation tend to affect the crop growth since without temperature, the plants could not grow and produce. Temperature helps the plant to manufacture biomass through photosynthesis in the presence of carbon dioxide. Similarly, the accumulation of biomass is effective in plant leaves in presence of carbon dioxide through stomata, water through plant roots and light. At a time, plants take in carbon dioxide through leaves stomata while the roots take in nutrients from the soil (Fig. 2). The climate contributes to the escapement of water molecules from the surface of leaves or plants and the open land. The combination of transpiration and evaporation is called evapotranspiration, which is the function of the surface cover of the plant leaves and energy (Fig. 2). The risks of climate change in irrigated agriculture are inevitable. The increase in temperature, rainfall conditions changes, and increased CO_2 content in the air are the major climatic factors affecting crop production. Temperature rise leads to losses of soil moisture hence increases the crop water demand. The amount and availability of water stored in the soil will be affected by changes in both the precipitation in seasonal and annual evapotranspiration regimes. Changes in atmospheric carbon dioxide concentration can cause uncertainty in crop yields. Solar radiation also has a considerable effect on photosynthesis and crop yield (Neenu *et al.*, 2013).

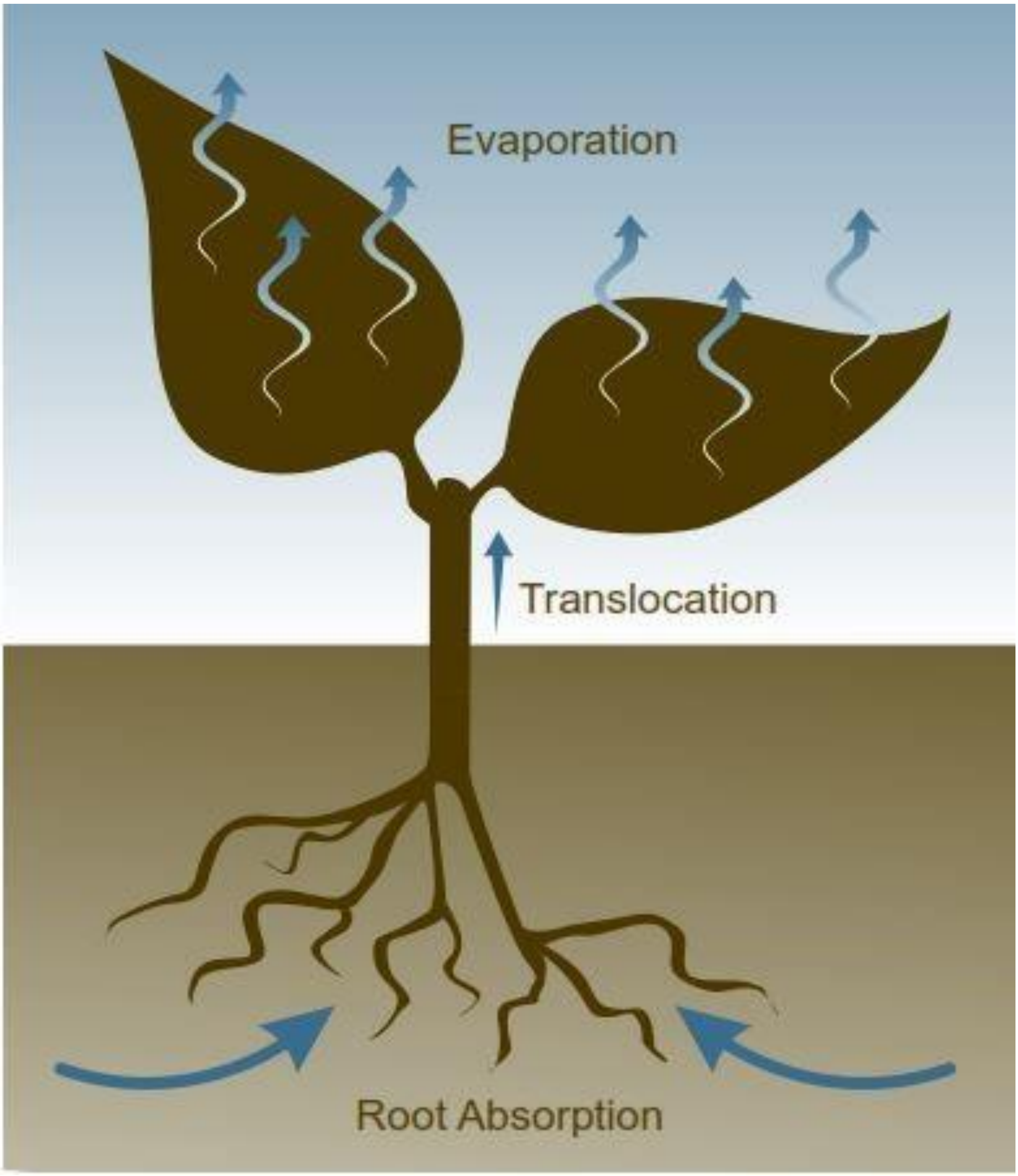


Figure 2: Plant absorption and transpiration of water

2.9.2 Internal Factors

Crop productivity depends on genetic that governs the development of plant growth. According to the research done early, 21st century suggests that yield of a crop drops while the population increases that invites the necessity of improving the phenotype of the crop to meet the demand (Miflin, 2000). However, catchment also is not isolated from the weather changes, which affects plant growth. Since the environment changes according to geography and season, a given variety will perform differently from place to place and season to season (Miflin, 2000). Furthermore, improved grain quality and disease resistance are demanded more by farmers and consumers than improving drought resistance (Richards, 1992). Subsequently, it is difficult to measure the degree of effects of the genetic of the crop; however, farmers claim much on that issue. Similarly, most plant growth developments tend to change according to weather of a particular area resulting in effect yield. Generally, crops gene can either be productive or not at various agricultural irrigation practices. Furthermore, irrigation agriculture is well affected by water availability which, unfortunately, this resource sustainability is under threat of climate change and uses. Therefore, it understood that crop productivity is affected by the internal factor that the farmer cannot control; however, irrigation water shortage also affects the productivity.

2.10 Irrigation Scheduling

Water management includes planning the use and utilization of resources in agriculture. Irrigation means the application of water into the soil to reduce the plants or crop stress and facilitate nutrient absorption in solution form. Similarly, the excessive water during irrigation in the farm is removed through drainage in order for a plant not be suffocated. The irrigation schedule has to meet the plant water requirement. Irrigation scheduling means the process of determining when to irrigate, how much water to apply, based upon measurements or estimates of soil water or water used by the plant, application rate and how often to irrigate (Hunsaker *et al.*, 2007). Since the irrigation schedule is affected by the soil type, growth stage development, and climatic condition of an area, it varies accordingly. The climatic condition of the Usa River Catchment across the agro-ecological zone is different, resulting in varying crop water requirements. The amount of water available in the catchment affects irrigation water management in terms of water allocation. Further, inefficient irrigation scheduling can cause stress to plants as the reduction in crop productivity. Similarly, crop water requirement is due to climatic factors such as temperature, solar radiation, humidity, and wind from the environment. Subsequently, the total evapotranspiration, includes transpiration accounting 90%, which is the function of canopy cover of plants and evaporation as an open space account 10% (Allen *et al.*, 1998).

2.11 Plant Density

Plant spacing is described as the number of crops planted in a unit area, distance from the plant to one another, row to row in the peace of land for utilizing the area. However, plant spacing is crucial in crop production because it increases the number of plants in an area resulting in productivity. The study on plant row spacing and density of maize done by Farnham (2001) highlighted the increase of productivity governed by the plant row spacing concerning hybrid of maize. Moreover, when the plants are planted very near to each other, it means that plant density is high which affects growth development and yield. The maize grain yield improvements result in advanced production practices, such as higher soil fertility, better weed control, increased plant densities and narrow row spacing, and the use of genetically superior hybrids (Sangoi, 2001).

2.12 Traditional Irrigation Infrastructure

Traditional irrigation means the local, application of water to the farm to supplement the unsatisfied moisture for crops in a farm while infrastructure means ways through water is abstracted, conveyed and transported to the destined farm. Therefore, if this statement became one, its local methods of conveying and applying water to the farm using local infrastructure. Subsequently, the irrigation system refers to the physical infrastructure provided to obtain water resources and to deliver, apply, and remove excess water for agricultural purposes (Makin, 2016). Irrigation agriculture, in other words, is one of the methods of agricultural water management. Similarly, irrigation infrastructure is essential for the sustainability of water resources and crop production for food security because rain-fed does not suffice the supply (Makin, 2016).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the Study Area

The Usa River Catchment (URC) is located in Meru District in Arusha region. The catchment has an area of 320 km^2 in the Pangani basin called upper Kikuletwa sub-basin with 3892 m as the highest point and 934 m as the lowest point above the sea level. The URC collects water from various streams and rivers to the main stream called Kikuletwa. These streams/rivers include Maji ya chai, Tengeru, Malala, Makumira, Ngaresero, Usa, and Mogadirisho. People in the catchment practice subsistence farming and commercial farming, which includes rain-fed and irrigated farming. The catchment is located at latitude $3^0\,15'00''$ to $3^0\ 32.5'\ 00''$ S and longitude $36^0\ 45'\ 00''$ to $36^0\ 57.5'\ 00''$ E (Fig. 3). Moreover, the catchment has two rainy seasons which begins from October to December termed as short rainy and March to May as long rainy seasons each year.

3.2 Methodology

In research, methodology is the leading tool towards the collection of desirable and reliable information to achieve the main objective. Consequently, the methodology does answer how the data are collected and analysed. In this research, visitation of the field, water flow, and distance measurement and laboratory experiment were done to collect the information regarding the catchment. In so doing, the obtained data were presented in tables, figures, and established catchment maps using geographical information systems (GIS).

3.3 Catchment Establishment

The catchment map was established by using ArcSwat Software after downloading the Digital Elevation Model (DEM) of the area with 30 m × 30 m resolution from the United States Geological Survey (USGS) data of 1995 to 2015. Irrigated agriculture is practised along rivers from upstream to the downstream that define the agro-ecological zone of the catchment. The selected plots were Mbuguni as downstream, Lakitatu area as a middle stream, and an area above the Arusha –Moshi (Ngurudoto area) road as upstream as shown in Fig. 3.

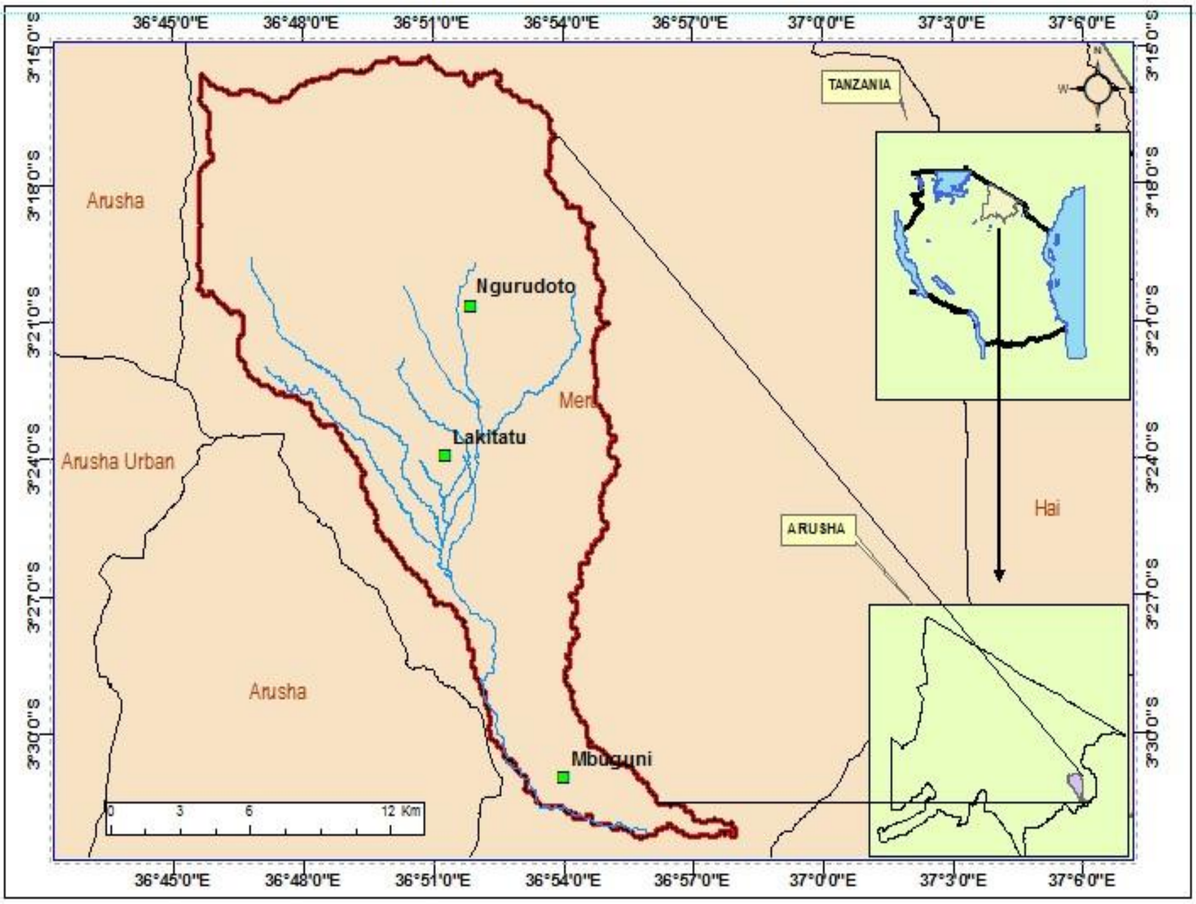


Figure 3: The Map of Usa River Catchment showing Rivers, Study Area and Boundaries

3.4 Water Flow Measurement

3.4.1 Irrigation Water Intake

The Usa River Catchment runs from uphill of Meru Mountain up to the lower area of Mbuguni village where many streams converge and form one river called Kikuletwa with vast land. Further, the furrow water intakes were visited and water flows were measured using current meter (SEBA Universal Current Meter F1 with propeller 125 mm and 300 mm pitch) and intake names were located using GPS (Garmin 60s) in the map (Fig. 4).

Figure 4: Water flow measurement using current meter

The measurement was taken at one point where the current meter propeller was placed at 0.6 m equal to 60% of actual depth from the bottom of the channel while the propeller directed opposing the water flow direction. The instrument was further shifted across the channel. The overall width decided the distance interval from one point of the measurement to another across the channel starting from the bank, but to some cases there were 0.1 to 0.2 meters, as shown in the recording sheet in Table 1. Further, water flow in m^3/s obtained by putting the reading, i.e., pulse, seconds, width, and depth into calibrated formulae of the respective current meter as shown in Table 1.

Table 1: Calculation Excel sheet for One Point Section of Irrigation Channel

Distance(cm)	Depth (cm)	Depth (0.6m)	Revs (N)	time (s)	rev/sec	vel.point(m/s)	Av.vel (m/s)	AreaSect (m^2)	Qsect(m^3/s)	Qcum.(m^3/s)
0	0	0	0	40	0	0	0.05	0.005	0	0
10	10	0.06	7	40	0.18	0.071	0.10	0.0155	0.002	0.002
20	21	0.126	17	40	0.43	0.124	0.19	0.0215	0.004	0.006
30	22	0.132	39	40	0.98	0.255	0.24	0.0225	0.005	0.011
40	23	0.138	33	40	0.83	0.217	0.35	0.0235	0.008	0.019
50	24	0.144	76	40	1.9	0.49	0.47	0.025	0.012	0.031
60	26	0.156	70	40	1.75	0.452	0.50	0.025	0.013	0.044
70	24	0.144	86	40	2.15	0.554	0.52	0.023	0.012	0.056
80	22	0.132	75	40	1.88	0.484	0.37	0.02	0.007	0.063
90	18	0.108	40	40	1	0.261	0.24	0.0175	0.004	0.067
100	17	0.102	33	40	0.83	0.217	0.22	0.0175	0.004	0.071
110	18	0.108	36	40	0.9	0.236	0.24	0.0135	0.003	0.074
125	0	0	0	40	0	0	0.00	0	0	0.074

During field work, twenty (20) irrigation water intakes were determined, which justified the irrigation agriculture practiced in the catchment. However, the Pangani water office was also visited to get the water permit number of the respective furrow intake as shown in Table 6.

3.4.2 Conveyances Efficiency Measurement

The water infrastructure of the traditional irrigation schemes was not in good order. The water was extracted from the river through locally constructed intakes and designed intakes. The implication of this was that irrigation water demand was rising all the time due to the need of food supply and market of the horticultural products. However, water is transported through the earthen canal over a longer distance depending on the location of farm. It is believed that open earthen canal loses much water through seepage, evaporation and overflow. The water flow measurement using current meter (SEBA Universal Meter F1 with propeller 125 mm and 300 mm pitch) was used at the intake point and section with large amount of water. However, in a section with small amount of water and small depth, the pigm type current meter was used. In this study, the measurement of water flows in the canals at different points/junctions along the water channels was done. Conversely, in case of proper demonstration in this research, Kammama irrigation scheme was used as illustrated in Fig. 5. Since the aim was to determine the performance of conveyance, water flows in terms of volume using calibrated formulae of current flow meter were measured at every junction of the canals, and the difference between inflow (head) and outflow(tail/end) was determined. However, the measurements were recorded in the excel form sheet with a calibrated formulae used to determine the water flow rate in litres per second as shown in Table 1. Similarly, the difference between the outlet water flow and inlet water flow divided by inlet water flow determines the conveyance efficiency. The distance of channel was determined using the global positioning system (GPS) with an accuracy of ±3 m.

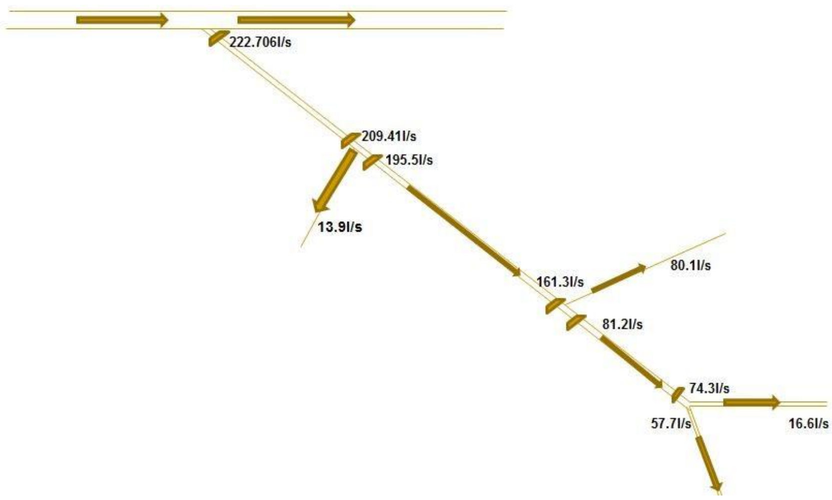


Figure 5: Sketched Water flow Measurement along Irrigation Canal

The task involved measurement of irrigation water flows to determine the amount of water abstraction, inflow (head) and outflow (tail) along the canals to determine the conveyance efficiency of the canals' sections of the traditional irrigation systems. Furthermore, the calculation of efficiency was done as in equation 2, 3 and 4 and presented in the Table 10, Table 11 and Table 12.

$$Q_{Dischargeloss} = Q_{head} - Q_{tail} \qquad (2)$$

Where:

$Q_{Dischargeloss}$; means the quantity of water lost in a channel in L/s

Q_{head}; means the quantity of water at the head (inflow) in L/s

Q_{tail}; means the quantity of water at the end of the channel (outflow) L/s

Discharge loss in percentage (Q%)

$$QLoss\% = \frac{Qinflow - Qoutflow}{Qinflow} \times 100\% \quad (3)$$

Where:

Qinflow; water quantity at the channel head (L/s)

Qoutflow; Water quantity at the channel tail (L/s)

Conveyance Efficiency

$$Ec = \frac{Qoutflow}{Qinflow} \times 100\% \quad (4)$$

Where:

E_c = Conveyance Efficiency

Q_{inlow} = Water quantity at the channel head (L/s) Q_{out}
$_{flow}$ = Water quantity at the channel tail (L/s)

3.5 Factors Causing Variation in Conveyance Efficiency and Crop Productivity

In this objective, the structured questionnaires were administered to the farmers of different levels to seek answers to the research questions. The catchment divided into three agro-ecological zones along the streams that demonstrate different social-demographic characteristics of the farmers. Four hundred (400) questionnaires were administered to farmers throughout the agro-ecological zones of the catchment from upstream to downstream. The data collected from the respondents were analysed using statistical package of social science (SPSS).

3.5.1 Social Demographic Characteristics

The Usa River Catchment community was categorized into gender, age, level of education and experience in irrigation agriculture. The total weighted respondent throughout the catchment were 400 in which it was divided into three zones such as upstream, middle stream and downstream. The weighted respondent indicated that 141 (35.3%) were female and 259.8 (64.8%) were male. The age group of 15-29 years were 52 (13%), 30-44 years were 195

(48.8%), 45-55 years were 75 (18.8%) and above 56 were 78 (19.5%). Similarly, 25 (6%) haven't gone to school at all, 221 (55.3%) they got primary education and 155 (38.8%) secondary education. Furthermore, community has an experience of irrigation agriculture from 0-1 year were 28 (7%), 2-5 years were 26 (6.5%), 6-10 years were 129 (32.3%) and above 10 years were 217 (54.3%) as shown in Table 5.

3.5.2 Crop Productivity Variation

Questionnaires were administered to the respondents to collect data about factors contributing to the variations in crop productivities across agro-ecological zones of the Usa River Catchment. Data collected were analysed using Statistical Package for Social Science (SPSS) software. However, the scale measure of the crop productivity/ yield determined were through agroecological zones such that upstream, midstream and downstream. The results are shown in Table 7. Crop productivity can be explained as yield of grains in kilogrammes obtained in a given piece of land. The area cultivates multiple crops such as maize and cassava as the staple food and horticulture products as agribusiness. Since agro-ecological zone characteristics dictate the crop productivity resulted from climatic parameters then productivity will vary as well. In determination of the causes of crop variation fifteen (15) items were analysed. The results are shown in Table 7.

3.5.3 Conveyances Efficiency Variation

Regarding this item, a total of 392 questionnaires were administered to determine the factors causes the variation of conveyance efficiency in three agro-ecological zones of the catchment. In order to get differences through the agro-ecological, the common possible factors were used in administering questionnaires. The responses from the respondents revealed that water losses along the channel is attributed to many factors which caused different conveyance efficiencies in the upstream, midstream and downstream. However, the factors were determined in respective to the zones. Furthermore, the questionnaires were administered using the common variable factors and analysed using R-program and results presented in Table 13, Table 14 and Table 15 for upstream, midstream and downstream respectively.

3.6 Soil Sampling and Preparation

Soil samples were collected from the catchment farms at the selected three plots at a profile of 10 cm, 30 cm, and 50 cm and stored in a plastic bag. Then, the samples were taken to the Selian Agricultural Research Institute (SARI) laboratory for analysis. The collected soil samples were air-dried, grounded to small particles, and a small portion weight 500 gm was put into the well-labelled A5 envelope ready for the analysis. The prepared soil sample of 10 gm was taken from the envelope and placed into the 250 mL beaker filled with distilled water of 150 mL. The wet soil samples were boiled to the temperature of 90^0C to remove the organic matter while pouring hydrogen peroxide (H_2O_2) for some minutes until there was no more thawing from the sample. The sample were cooled and transferred into the 1000 mL measuring cylinders, and more distilled water was added. The 10 mL of sodium hexametaphosphate (Calgon) was added to the solution to separate the stick together particles and mixed thoroughly for five minutes ready for sieving.

3.6.1 Wet Sieving Sand Fraction

The wet sample of 50 gm was sieved through the sieve no.140 (106µm) and passing liquid with some particles were captured through the funnel. The retained particle was sand fraction and was transferred to the container for drying. Oven was used to heat the samples at 107^0C for some hours to dry out the water in the sample and weighed as the sand fraction in grams as shown in Table 2.

Table 2: Sand Fraction Calculation

S/No.	Wt Beaker	Wt (Beaker+Sand)	Wt Sand
1	33.29	33.97	0.68
2	29.85	30.35	0.5
3	28.49	29.2	0.71
4	31.94	32.5	0.56
5	31.88	32.54	0.66
6	31.76	32.28	0.52
7	31.89	32.59	0.7
8	31.93	32.7	0.77
9	31.1	32.33	1.23
10	32.63	34.11	1.48

3.6.2 Pippete Silt and Clays

The passed fraction through sieve no. 140 (106 µm) consisted of silt and clay. The sample was transferred into measuring cylinder of 1000 mL, then distilled water was added to reach the volume of 1000 mL. In getting a fraction of silt and clay, the sample was disturbed, and a pipette of 25 mL was used to take the sample at a depth of five (5 cm) and put into the beaker for drying in an oven at a temperature of 107^0C. The obtained dried sample was silt and clay in grams. Then, the sample in the cylinder was left to settle to get the clay fraction. The viscosity of the water is affected by the temperature, which also affects the particle's settling velocity. The temperature of the mix was measured to determine the second round of clay sample to be taken using the pipette of 25 mLs. The minimum temperature of the sample was 19^0C and maximum temperature was 25^0C which ranges from 3.5 to 4¾ hours of taking clay sample from the cylinder using pipette after being rinsed using distilled water. Then, the fraction of clay in solution was dried in the oven at a temperature of 107^0C. After that, to obtain the fraction of silt, the difference between the silt and clay was determined. Thereafter, the equation 3.4 to 3.9 were used to determine the soil fraction to obtain a portion of sand, silt and clay in sample as shown in Table 3. The Equations used were as follows:

$$B - A = C \tag{5}$$

$$C - E = D \tag{6}$$

$$F = 40E \tag{7}$$

$$I = H - G \tag{8}$$

$$K = I - J \tag{9}$$

$$L = 40K \tag{10}$$

Where:

A, G; Weight of beaker

B; Weight of beaker+silt+clay+calgon

C; Weight of silt+clay+calgon

D, I; Weight of clay+calgon

E; Weight of silt in 25 mLs

F; Weight of silt in 1000 mLs

H; Weight of beaker+clay+calgon

J; Weight of calgon

K; Weight of clay in 25 mLs

L; Weight of clay in 1000 mLs

Table 3: Silt and Clay Fraction Determination

A	B	C	D	E	F	G	H	I	J	K	L
31.97	32.19	0.22	0.12	0.1	4	33.29	33.41	0.12	0.001	0.119	4.76
32.17	32.39	0.22	0.11	0.11	4.4	29.85	29.96	0.11	0.001	0.109	4.36
32.24	32.45	0.21	0.12	0.09	3.6	28.49	28.61	0.12	0.001	0.119	4.76
31.71	31.92	0.21	0.11	0.1	4	31.94	32.05	0.11	0.001	0.109	4.36
31.98	32.2	0.22	0.12	0.1	4	31.88	32	0.12	0.001	0.119	4.76
31.79	32	0.21	0.12	0.09	3.6	31.76	31.88	0.12	0.001	0.119	4.76
31.67	31.89	0.22	0.13	0.09	3.6	31.89	32.02	0.13	0.001	0.129	5.16
31.82	32.04	0.22	0.11	0.11	4.4	31.93	32.04	0.11	0.001	0.109	4.36
31.75	31.96	0.21	0.12	0.09	3.6	31.1	31.22	0.12	0.001	0.119	4.76

Further, the percentages of soil type in terms of sand, silt and clay were determined using equation 11 to 13 and the result are shown in Table 4.

$$Sand\ \% = \frac{Weight\ Sand}{Total\ Weight} \times 100\% \qquad (11)$$

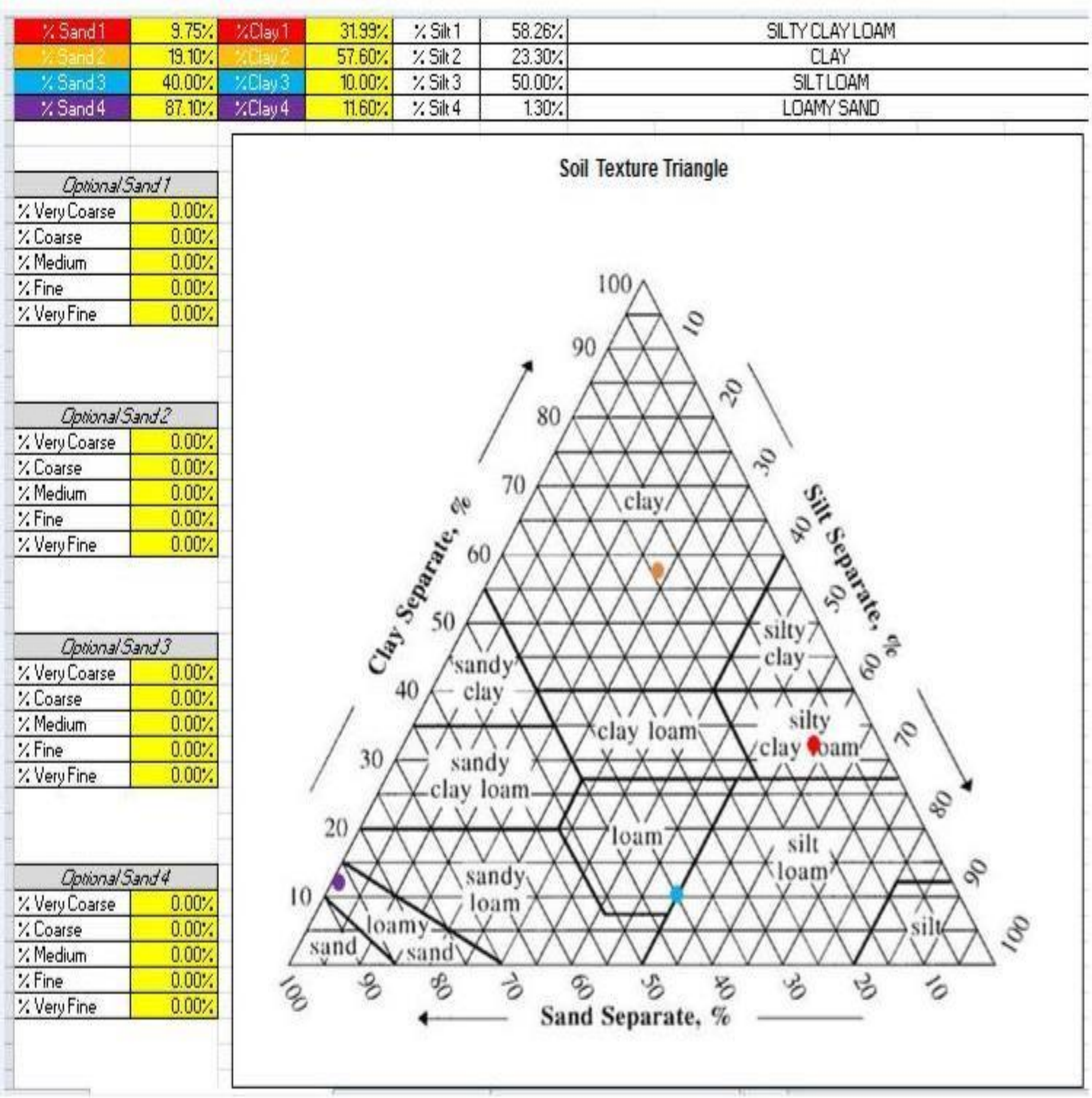
$$Silt\ \% = \frac{Weight\ Silt}{Total\ Weight} \times 100\% \qquad (12)$$

$$Clay\ \% = \frac{Weight\ Clay}{Total\ Weight} \times 100\% \qquad (13)$$

Table 4: Sand, Silt and Clay Percentage Determination

Wt Sand	Wt Si 1000 mls	Wt C 1000 mls	Total Wt	% Sand	% Silty	% Clay
0.68	4	4.76	9.4	7.2	42.4	50.4
0.5	4.4	4.36	9.3	5.4	47.5	47.1
0.71	3.6	4.76	9.1	7.8	39.7	52.5
0.56	4	4.36	8.9	6.3	44.8	48.9
0.66	4	4.76	9.4	7	42.5	50.5
0.52	3.6	4.76	8.9	5.9	40.5	53.6
0.7	3.6	5.16	9.5	7.4	38.1	54.5
0.77	4.4	4.36	9.5	8.1	46.2	45.8
1.23	3.6	4.76	9.6	12.8	37.5	49.6
1.48	4.4	3.56	9.4	15.7	46.6	37.7

Thereafter the portion of sand, silt and clay in percentage was imported into the soil textural triangle to get the soil texture of particular farm in the Catchment as shown in Fig. 6. Using a soil texture triangle (Fig. 6) the obtained percentage of sand and clay were filled in the yellow highlighted cells (optional Sand 1) and the texture calculator gave the texture of the soil. The texture of the soil obtained at a selected farms for downstream, midstream and the upstream was of different.



% Sand 1	9.75%	%Clay 1	31.99%	% Silt 1	58.26%	SILTY CLAY LOAM
% Sand 2	19.10%	%Clay 2	57.60%	% Silt 2	23.30%	CLAY
% Sand 3	40.00%	%Clay 3	10.00%	% Silt 3	50.00%	SILT LOAM
% Sand 4	87.10%	%Clay 4	11.60%	% Silt 4	1.30%	LOAMY SAND

Optional Sand 1	
% Very Coarse	0.00%
% Coarse	0.00%
% Medium	0.00%
% Fine	0.00%
% Very Fine	0.00%

Optional Sand 2	
% Very Coarse	0.00%
% Coarse	0.00%
% Medium	0.00%
% Fine	0.00%
% Very Fine	0.00%

Optional Sand 3	
% Very Coarse	0.00%
% Coarse	0.00%
% Medium	0.00%
% Fine	0.00%
% Very Fine	0.00%

Optional Sand 4	
% Very Coarse	0.00%
% Coarse	0.00%
% Medium	0.00%
% Fine	0.00%
% Very Fine	0.00%

Figure 6: Triangle Soil Texture Calculator

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

The primary data, analysis, discussion, and observation of the study is presented to assess the traditional irrigation scheme water use and crop productivity. These contribute to the sustainable use of water resources, food security, and household income of the catchment and nation as a whole at the basin level. Similarly, this chapter presents the surveyed irrigation water intakes, water resource abstraction, water flow measurement, and soil texture determination for traditional irrigation schemes sustainability to the livelihood of Usa River Catchment farmers.

4.2 Demographic Characteristics

Table 5 indicated that the household characteristics have an implication to social and economic status of crop productivity under the traditional irrigation scheme in the catchment. Household composition affects crop production process because 48% (30-44) years can participate in the farm activities. Moreover, 55% and 39% were primary and secondary education levers respectively who can be trained in irrigated agriculture in areas of water resource utilization, and proper irrigation practices, according to the findings in Table 5.

Table 5: Demographic Characteristics of the Catchment in Agro-Ecological Zones

Variable	Upstream	M-stream	D-stream	Mean	Total	2
Gender						34.810*
Female (*n*, %)	55, 32.9	41, 34.7	45, 39.1	47	141, 35.3	
Male (*n*, %)	112, 67.1	77, 65.3	70, 60.9	86.33	259, 64.8	
Age						122.000*
15-29(*n*, %)	21, 12.6	16, 13.6	15, 13.0	17.33	52, 13.0	
30-44(*n*, %)	80, 47.9	57, 48.3	58, 50.4	65	195, 48.8	
45-55(*n*, %)	32, 19.2	25, 21.2	18, 15.7	25	75, 18.8	
above56 (*n*, %)	24, 20.9	20, 16.9	24, 20.9	22.67	78, 19.5	
Level of Education						153.785*
No education (*n*, %)	8, 7.0	8, 6.8	8,4.8	8	24, 6.0	
Primary school (*n*, %)	60, 52.2	69, 58.5	92, 55.1	73.67	221, 55.3	
Secondary	47, 40.9	41, 34.7	67, 40.1	51.67	155, 38.8	
Experience						253.940*
0-1(*n*, %)	8, 7.0	9, 7.6	11, 6.6	9.33	28, 7.0	
2-5(*n*, %)	8, 7.0	12, 10.2	6, 3.6	8.67	26, 6.5	
6-10(*n*, %)	43, 37.4	34, 28.8	52, 31.1	43	129, 32.3	
above 10(*n*, %)	56, 48.7	63, 53.4	98, 58.7	72.33	217, 54.3	

Note: Statistical level test, *-statistically significant at 0.05, ns-not significant

It has been revealed that the working-age population (WAP) threshold as per the International Labour Organisation ranges from 15 years and above. The community composition helps to enhance the irrigated agriculture in Usa River Catchment hence crop productivity for food security, sustainable agriculture and water resource utilization. Conversely, irrigation agriculture in the catchment is one of the socio-economic activities. The assessed demographic characteristics in Catchment indicated satisfactory workforce for irrigated agriculture productivity hence economic development.

4.2.1 Gender

The analysis presented in Table 5 shows that female participating in irrigated agriculture were 35.2% among the respondents throughout the Usa River Catchment. These results suggest that irrigated agriculture needs capital and is energy-intensive which do not favour majority of female in the Catchment.

4.2.2 Production Age Group

The crop production and socio-economic activities in the Catchment need energetic people. The findings shown in Table 5 indicate that 48.8% (195) of the respondent were aged from 30 −44 years, which falls in the age of the active economic group. The average number of years throughout the Catchment is 41 years, while the average years of the nation is 39.9 years (NBS, 2002). Further, above 56 years who usually are less productive and dependant were (78) equal to 19.5%.

4.2.3 Education Level

The level of education in the catchment is important for the community to be aware of good agricultural practises (GAP). The results indicated that 55.3% (221) of the respondent attended primary education and 38.8% (155) attended secondary education. In this case, many farmers can learn, use, and adopt new appropriate technology of irrigation to enhance crop productivity and water uses. Those reached secondary level were helped by the government's effort in providing free secondary education to the community. Moreover, the analysed data of group in education has an impact as the significant value is less than 0.05 ($p < 0.05$) tested using chi-square as shown in Table 5.

4.2.4 Experience in Irrigation Agriculture

The farmer's experience in irrigation contributes in crop production, hence food security. The experience was grouped 0−1 year, 2−5 years, 6−10 years, and above 10 years. The analysed results in Table 5 indicate that 54.3% (217) of the respondents have more than 10 years of experience in irrigation agriculture in the Catchment. Years of experience have implication in agriculture such as they help to understand proper irrigation schedules, cropping calendar, market demand, and type of crop to cultivate concerning soil fertility. The significant factor that contributes to crop productivity in the respective area or scheme is irrigation scheduling.

4.3 Water Abstraction and Compliances for Irrigation

In the catchment, 3500 L/s of water is abstracted from the river sources for irrigation relative to permitted amount of 2856.14 L/s from twenty (20) furrows. Therefore, the abstraction exceeded the permitted amount by 23% which means no compliances with laws and regulation set for sustainable water use in the catchment, nation and the world at large (Table 6). Moreover, twelve (12) equal to 60% abstract more water due to crop water demand and unavailable control and regulating structures.

Table 6: Irrigation furrows, water Abstraction and water permits in September, 2017

S/N	Furrow	Permit No.	Quantity Permitted(L/s)	Quantity	% 0f	River source	Status Intake
1	Shamima	140236	200	189	95	Kikuletwa	With gate
2	Star	140616	68	70	103	Kikuletwa	Without gate
3	Mbukita	140237	200	151	76	Kikuletwa	Without gate
4	Orbuso	2285	200	215	108	Kikuletwa	With gate
5	TPL	3156	280.3	130	46	Kikuletwa	With gate
6	Mapama	140550	300	242	81	Kikuletwa	With gate
7	Kammama	140040	200	204	102	Kikuletwa	With gate
8	Valestika	3727	142.2	130	91	Kikuletwa	Without gate
9	Kipilipili	3151	14.16	147	1038	Kikuletwa	O/gate/repair
10	Kwa Ugoro	4761	113.28	150	132	Kikuletwa	Without gate
11	Dolly/BCW	1765	84.96	224	264	USA	With gate
12	Kaanani	1110055	200	135	68	Malala	Without gate
13	Kitamaka	140014	200	138	69	Malala	With gate
14	Elia	140046	20	69	345	Malala	Without gate
15	Mkindi	140047	100	83	83	Tengeru	with gate
16	Ngolo	14007	100	115	115	Tengeru	Without gate
17	Humalu	1.1E+07	50	55	110	Malala	Without gate
18	Mimako	140191	85	227	267	Tengeru	With gate
19	Furrow No.1	1.1E+07	100	453	453	USA	Without gate
20	Makiba	3143	198.24	373	188	Kikuletwa	Without gate

4.4 Crop Yield Variation

Crop yield is assumed to vary from one place to another. Table 8 and Table 9 show the distribution of respondent according to the farm size and yield, respectively. The results indicated that an average of (35%) of farmers practice small scale irrigation farming having land size ranges from 0.5−1 hectares throughout the Usa River Catchment (Table 8). This is because the large area of the Catchment is covered with settlements. Similarly, crop yield varied according to the zones. Consequently, the average yield was 23.5, 19, and 34.1 bags per hectare in downstream, midstream, and upstream, respectively. These results indicated that the community practices traditional irrigation due to a low supply of water, lack of technical know-how of using new irrigation technology, land size, climatic condition and preferably not using recommended seeds by agronomists. In addition, improper water management at the level of intakes, traditional conveyances systems, and water application at farm level contributed to crop productivity variation as well as sizes of farmland cultivated.

4.4.1 Factors Causing Variation in Crop Productivity

Table 7 highlighted fourteen (14) factors which causes the variation in productivity on a particular area. Crop productivity as an output under the variable items can affect yield positively or negatively, but identifying more affecting item is important. Following the finding in Table 7, the obtained odds ratio indicated that some were less than one and others more than one as presented in Table 7. These results implies that when the odds ratio is less than one, it negatively affects the end value (productivity), which affects the coefficient (β) to a negative value, hence reduces productivity. Similarly, if the odds ratio is more than one affects the coefficient (β) positively as the result of increasing productivity as highlighted in Table 7. For example, the use of inorganic fertilizer, farmers' participation in canal maintenance, and weed control; their odds ratio is less than one that reduces the output (productivity) through the negative value of coefficient (β) hence reduces the output/productivity. The rest variables in Table 7 describe the same trends in both agro-ecological zones from upstream to downstream. However, the variable that causes negative changes need to be taken into more consideration in crop production.

Table 7: Factors Causes Crop Productivity Variation

Variable	Upland of stream		Middle of stream		Lowland stream	
	Coefficient (β)	Odds ratio	Coefficient (β)	Odds ratio	Coefficient (β)	Odds ratio
Training in Irrigation	0.792	2.208	-0.497	0.609	0.271	1.312
Regular soil fertility	0.366	1.442	-0.11	0.896	0.234	1.263
Irrigation scheduling	0.769	2.158	0.651	1.918	-0.062	0.94
Crop water requirement	0.133	1.142	0.035	1.035	-0.103	0.903
Irrigation Crops start to dry	0.084	1.088	-0.255	0.775	-0.111	0.895
Use of Crop calendar	0.233	1.263	0.13	1.138	-0.277	0.758
Plants space as per agronomic	0.229	1.258	0.469	1.599	0.114	1.121
Inorganic Fertilizer application	-21.661	0	-0.877	0.416	-0.06	0.942
Weed control by herbicides	-0.848	0.428	0.416	1.516	1.316	3.728
Recommended Seed	0.841	2.319	-0.016	0.984	-0.017	0.984
System of water distribution	0.019	1.019	0.129	1.137	-0.265	0.767
Irrigation drainage system	0.314	1.368	0.424	1.527	0.001	1.001
Traditional infrastructure works	0.19	1.209	0.581	1.788	-0.551	0.577
Participation in canal maintenance	-0.768	0.464	1.494	4.457	0.822	2.275

Table 8: Size of Farm Plot in Zones

Zone	Hectares	Frequency	Percent	Cumulative
downstream	0-0.5	5	3.0	3.0
	Total	167	100.0	
midstream	0-0.5	12	10.2	10.2
	1.5 above	39	33.1	100.0
	Total	118	100.0	
upstream	0-0.5	8	7.0	7.0
	Total	115	100.0	

Table 9: Statistics of Yield in Zones

Zone			Yield	Size
downstream	N	Valid	167	167
		Sum	3917	
midstream	N	Valid	11818.99	118
		Median	15.00	
		Sum	2241	
upstream	N	Valid	115	115
		Sum	3922	

4.5 Conveyance Efficiency

Table 10, Table 11 and Table 12 highlighted that water diverted from the downstream, midstream and upstream intakes were lost before reaching at the farm. The calculation done revealed that there were water losses within the conveyances during the transportation. The amount of water lost during the irrigation on transportation system was 28% and 72% were found to reach at the farm for irrigation. Therefore, the conveyance efficiency of the traditional irrigation canals was 72% which implies the water losses in the canals is high and unproductive.

Table 10: Downstream Conveyance Efficiency Calculations

Furrow Name	Canal Section	Q(L/s) H/Sec	Q(L/s) E/ Sec	L (m)	Q (L/s)	Q L/s/m	L %	Eff % (Ec)
Shamima	Section 1	189	105	1902	84	0.044	44.4	55.6
	Section 2	83	53	891	29	0.033	35.5	64.5
Star	Section 1	70	41	1183	29	0.025	41.4	58.6
Mbukita	Section1	72	53	716	19	0.027	26.4	73.6
Orbuso	Section 1	209	152	3648	57	0.016	27.3	72.7
	Section 2	100.5	98	273	3	0.011	2.5	97.5
TPL	Section1	153.3	136.1	2251	17	0.008	11.2	88.8
Makiba	Section 1	373	221	846	152	0.18	40.8	59.2
			Average	1463.8	48.8	0.043	28.7	71.3

Table 11: Midstream Conveyance Efficiency Calculation

Furrow Name	Canal Section	Q (L/s) H/Sec	Q(L/s) E/ Sec	L (m)	Ql(l/s) (L/s)	Q(l/s) L/s/m	L %	Eff % (Ec)
Mapama	Section1	429	162	3924	267	0.068	62.3	37.7
Kammama	Section 1	223	209	864	13	0.015	6	94
	Section 2	196	161	202	34	0.168	17.5	82.5
	Section 3	81	74	454	7	0.015	8.5	91.5
	Section 4	71	58	1148	13	0.011	18.8	81.2
Valestika	Section 1	152	87	2270	65	0.029	42.8	57.2
	Section 2	48	30	873	18	0.021	37.5	62.5
Kipilipili	Section 1	447	297	2228	150	0.067	33.5	66.5
	Section 2	132	125	262	7	0.027	5	95
	Section 3	54	43.3	1109	11	0.01	20.4	79.6
Kwa Ugoro	Section 1	448	82.5	3128	365	0.117	81.6	18.4
	Section 2	46	26	1781	20	0.011	43.1	56.9
Dolly/BCW	Section 1	257	221.7	1357	35	0.026	13.6	86.4
	Section 2	132	123	898	9	0.01	7.1	92.9
	Section 3	81	27	2546	54	0.021	66.8	33.2
Kaanani	Section 1	198	120.9	1457	77	0.053	38.8	61.2
	Section 2	99	19.7	830	79	0.095	80.1	19.9
Kitamaka	Section 1	41	39	20	2	0.1	4.9	95.1
Elia	Section 1	22	8	672	15	0.022	65.4	34.6
Mkindi	Section 1	37	33.9	345	3	0.009	9.1	90.9
Ngolo	Section 1	143	100	1215	43	0.035	30.1	69.9
			Average	1313.5	61.3	0.044	33.00	67

Table 12: Upstream Conveyance Efficiency Calculation

Furrow Name	Canal Section	Q (L/s) H/Sec	Q(L/s) E/ Sec	L (m)	Q(l/s) (L/s)	Q(l/s) L/s/m	L %	Eff % (Ec)
Humalu	Section 1	48	40	504.5	8	0.016	16.7	83.3
	Section 2	32	24	69	8	0.116	25	75
Mimako	Section 1	94	90	634	4	0.006	4.4	95.6
	Section 2	58	48	931	10	0.011	17.5	82.5
	Section 3	42	35	463	7	0.015	16.7	83.3
Furrow No.1	Section 1	440	415	1452	25	0.017	5.7	94.3
	Section 2	335	330	975	5	0.005	1.4	98.6
	Section 3	310	271	1321	39	0.03	12.5	87.5
	Section 4	82	45	531	37	0.07	45.1	54.9
			Average	764.5	15.9	0.032	16.1	83.9

4.6 Factors Affecting Conveyance Efficiency

The application of water into the farm involves infrastructure. One of the facilities is conveyance canal that transport water from the intake to the destined field. Traditional irrigation schemes believed to have poor infrastructure and inefficient, which includes conveyance canals. According to the analysis done and the variable used to test indicated that there are different values of the coefficient obtained. In linear regression relationship that presented in the (Table 13, Table 14 and Table 15) shows conveyance efficiency increases as the coefficient (β) is positive value and decrease as the coefficient (β) is negative in upstream, midstream and downstream respectively. When the coefficient value (β) is positive affect the dependent variable/conveyance efficiency positively, which increases the efficiency. It implies that less amount of water is lost then determines the good performance of conveyances. Similarly, when the value of coefficient (β) is negative affects the dependant variable/conveyance efficiency negatively which means amount of water is lost by that value of independent variable (β) (Table 13, Table 14 and Table 15). The respondents' answers relating to seven variables with different magnitudes as shown in Table 13. The magnitudes of their differences executed varied throughout the agro-ecological zones. However, the three agro-ecological zones results show insignificant ($p > 0.05$) variation of conveyance efficiency as shown in (Table 16).

Similarly, the comparison of average values for the conveyance efficiency across agro-ecological zones is well illustrated in Fig. 7.

Table 13: Factors Causing Variation in Conveyance Efficiency in Upstream

S/No	Variable	Upstream	
		Coefficient (β)	P-Values
1	Water challenges Tradition Irrigation System	-0.20066	0.6343
2	Importance of irrigation conveyance	-0.93408	0.1627
3	Improvement of Traditional Irrigation System	-0.02542	0.9666
4	Reduction of losses in conveyances	-0.39392	0.6029
5	Participation in canal maintenance	-2.67416	0.133
6	Water distribution structures in schemes	-0.18091	0.8851
7	Traditional infrastructure working	2.67147	0.0488 *

Table 14: Factors Causing Variation in Conveyance Efficiency in Midstream

S/No	Variable	Midstream	
		Coefficient (β)	P-Values
1	Water challenges Tradition Irrigation System	0.2267	0.543
2	Importance of irrigation conveyance	0.02584	0.973
3	Improvement of Traditional Irrigation System	-1.12587	0.102
4	Reduction of losses in conveyances	-0.42784	0.484
5	Participation in canal maintenance	4.56447	0.019 *
6	Water distribution structures in schemes	-0.45165	0.704
7	Traditional infrastructure working	-0.96667	0.437

Table 15: Factors Causing Variation of Conveyance Efficiency in Downstream

S/No	Variable	Downstream	
		Coefficient (β)	P-Values
1	Water challenges in Tradition Irrigation System	0.41797	0.266
2	Importance of irrigation conveyance	-0.69433	0.182
3	Improvement of Traditional Irrigation System	0.02707	0.937
4	Reduction of losses in conveyances	-0.69144	0.283
5	Participation in canal maintenance	-1.34259	0.482
6	Water distribution structures in schemes	-1.02746	0.367
7	Traditional infrastructure working	0.34421	0.773

Table 16: Conveyance efficiency across the agro-ecological zones

AGZ	Mean	Sd	P-value
Upstream(n=9)	83.89	±13.21	
Midstream(n=21)	67	± 25.51	0.155
Downstream(n=8)	71.31	± 15.12	

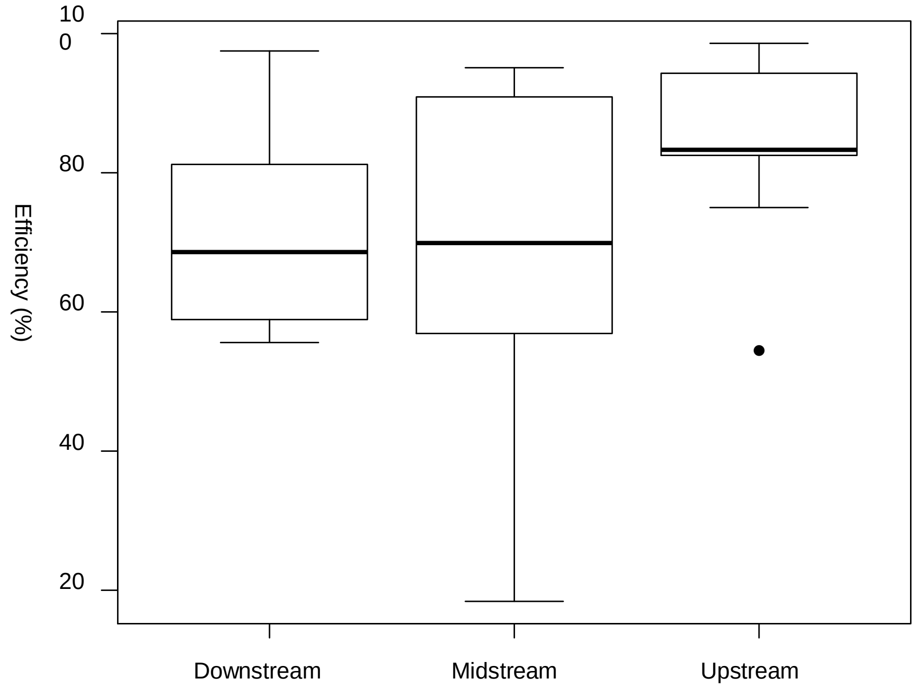


Figure 7: Agro-Ecological Zones vs Average Conveyance Efficiency

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study was conducted to evaluate traditional irrigation infrastructure which is inefficient in supplying irrigation water. Furthermore, the traditional irrigation system has a shortfall, which needs to be solved to enhance irrigation water management, crop productivity, and water resource utilization for environmental sustainability adherence. Based on the research findings, the catchment exercises traditional irrigation under small scale farming of land size ranging from 0.5−1 hectares for downstream equal to (32.3%), midstream equal to (36.4%) and upstream equal to (34.8%). Similarly, across the catchment the result of crop productivity obtained were varying as 2.3 t/ha for downstream, 1.8 t/ha for midstream and 3.4 t/ha for upstream. Furthermore, variations of crop productivity were caused by not following irrigation scheduling, no plant spacing, inefficient water distribution system, absence of training and varying soil fertility. Subsequently, irrigated agriculture contributes significantly to food security, household income, and employment in the Catchment. However, irrigation subsidizes the food shortage at the catchment, but water losses in the conveyance canals obtained in this research was 28% equal to 72% conveyance efficiency on average. Conversely, water extraction from the river exceeded the permitted amount by 23%. The amount of extracted water measured during this research was 3500 L/s while the permitted amount was 2856.14 L/s at Usa River Catchment, which is against water management laws and regulations of Tanzania. Similarly, despite food security contribution, employment, and household income, the traditional irrigation system is restricted by poor infrastructure, inadequate irrigation water management, water allocation, and inferior border field, which results to unsustainable water resources and irrigated agriculture.

5.2 Recommendations

The study recommends that irrigation water intakes to be constructed and provided with watergates in order to abstract permitted amount with irrigation command area to proportionate and allocate water as per crop water requirement in the catchment. Similarly, the study recommends irrigators to improve water utilization and scheme performance at the catchment level and basin by incorporating water user association to cultivate the valuable crops. Subsequently, farmers' frequent training on good agricultural practice is needed to enhance irrigation agriculture sustainability. Furthermore, irrigators association should enforce by-laws and laws regularly in regard to cleaning and maintenance of irrigation channels in terms of participation. In addition, the policy and decision makers should put a clause in water permit that enforces water users' association to maintain a certain water use and conveyances efficiency.

Subsequently, on crop productivity the study recommended that farmers should control weeds, regular canal maintenance to reduce water losses, regular farmers training, maintaining irrigation scheduling, following of crop calendar, use seeds recommended by agronomist and maintaining soil fertility.

Moreover, the study recommends further research on water use efficiency to ascertain the amount of water abstracted and yield/grains to the abstracted water produces across agro-ecological zones in the catchment and basin at large.

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APPENDICES

Appendix 1: Research Questionnaire

Introduction

The purpose of this questionnaire is to collect research data regarding the ***factors contributing to the variations in water productivity and conveyance efficiencies in farmer initiated irrigation schemes across agro-ecological zones of Usa River catchment.*** The aims are only for research and create awareness' on water resource utilization for sustainable irrigation and development. You have chosen to give your thoughtful in regard to the water resource utilization for irrigation. Further, be assured that the information you provide will be used and trusted for the purpose of this study only.

These questionnaires are closed ended type; please kindly **tick** [√] statement/ phrase that answer the question clearly.

A. General Question

1. Date of Interview..
2. Respondent Gender: Male [ ] Female [ ]
3. Age of the respondent (in years)
   (i) Age between 18- 30 [ ] (ii) Age between 30-50 [ ] (iii) Age between 50-55 [ ]
4. Level of Education
   (i) Primary education [ ] (ii) Secondary education [ ] (iii) Diploma in agriculture [ ] (iv) Degree in agriculture [ ]
5. Experience in irrigation agriculture practice in years
   (i) Between 0-1years [ ] (ii) Between 1-2 [ ] (iii) Between 2-3 years [ ]
   (iv) Between 3-4 [ ] (v) Between 5 years and above [ ]
6. All irrigators are the members of water user association (i) Yes [ ] (ii) No [ ]

B: **Strategies employed to enhance irrigation agriculture practice**

Indicate the level of practising irrigation agriculture for productivity. Put [√] against statement that you agree or disagree

NO	Statement	Yes	No
1	Do you have training on irrigation		
2	The regular determination of soil fertility		
3	Proper use of irrigation schedule		
4	Water requirement with crop type		
5	Irrigation is done when crop start to dry		
6	Following the planting date/ Crop calendar		
7	Planting space to consider the plant density		
8	Application of inorganic fertilizer during growth development		
9	Weed control(herbicides) during growth development stages		
10	Seed used is according to the agronomic recommendation		
11	Established zones and Irrigation blocks in relation to crop type		

C: Understanding Irrigation Infrastructure

NO	Statement	YES	NO
1	Designed Constructed intake/weir		
2	Water flow measurement structures		
3	Lined water conveyance channel		
4	Water distribution structures available		
5	Availability of water drainages systems		
6	Available infrastructures works properly		
7	Irrigation infrastructure needs improvement & constructed		
8	Irrigation water channel are permanent		
9	Participation in maintaining the irrigation canals		

D: OTHERS

1. What is your normal irrigation schedule?
   i. When the plants starts to dry [ ]
   ii. Determining soil moisture [ ]
   iii. Planned irrigation schedule [ ]
   iv. No regular schedule, whenever water is available [ ]

2. How long do you take to irrigate per events
   (i) 1-2 hours (ii) 2-3 hours (iii) 3-4 hours (iv) 4-6 hours (v) Above

3. Do you irrigate different amount frequency of water based on crop type (specify)..

4. The size of irrigation land/field is as follows;
   (i) 0-0.5 hectare [ ] (ii) 0.5-1hectare [ ] (iii) 1-1.5hectare [ ] (iv) 1.5 hectare and above [ ]

5. The yield obtained in season is as follows
   (i) 0.5 hectare............... (ii) 1 hectare.................. (iii) 1.5 hectare.............
   (iv) 1.5 hectare and above [ ]

6. What type of crops do you grow?..........................., ...

7. How do you find the productivity of the past and now days?
   (i) Low (ii) Average (iii) high

8. Do you apply pesticides at your crops?YES/NO [ ]. If Yes...............How much?..

9. Does water satisfy irrigation farming in this area?YES/NO [ ] If no what should be done...

10. What type of crops(s) do you grow for the case of scarce water? Mention...

11. Where do you abstract water for irrigation?
    (i) River [ ] (ii) Borehole [ ] (iii) Spring [ ] (iv) Dam [ ] (v) Irrigation canal []

The following crops are grown in an area. (i) Cereal crops [ ] (ii) Vegetables crops [ ] (iii) root crops [ ] (iv) all of the above [ ]

12. Give your opinion regarding the water productivity in traditional irrigation system...

13. Give your opinion regarding importance of irrigation conveyances in system...

14. Give the water challenges in traditional irrigation system
....

15. What is your opinion on water allocation for irrigation along the stream?
....
....

16. What do you think should be done to reduce the water losses through the conveyance?...
....

17. What should be done to improve traditional irrigation system in the catchment?..

18. Does your soil have high Ec or contain salt? YES [ ] NO [ ]

19. IF answer no.18 is YES What is the effects in crops/plant growth?
....

20. What do you do with the straws(mabua) after harvesting?..
Do you know the advantages of living straws into the farm?
....
....

21. Does your whole area of farm get water during irrigation?..(i) Yes [ ] (ii) No [ ]

22. If answer Q21 is No what do you think is reason?..

23. What is the average yield in your farm (bags per acre) during dry season and wet season...

24. What was the previous year's yield in the same field (bags per acre) during dry season [ ] and wet season [ ]

Thank you, for your time God blesses you.

Appendix 2: Water flow Excel sheet data

		Doly/WCB Furrow- End Section 2							**Date; 29/02/2018**			
Source name; Usa River												
Distance	**Sounded Depth**	**revised depth**	**Revs. (N)**	**time (s)**	**revs per**	**vel. At point**	**mean**	**mean**	**Area of section**	**discharg e in**	**Discharg e accum.**	
0.00	20.0	0.120	0	40	0.00	0.000		0.9579	0.0195	0.019	0.019	
10.00	19.0	0.114	225	40	5.63	1.437	1.44	1.4083	0.018	0.025	0.044	
20.00	17.0	0.102	216	40	5.40	1.380	1.38	1.3543	0.0185	0.025	0.069	
30.00	20.0	0.120	208	40	5.20	1.329	1.33	1.2589	0.0195	0.025	0.094	
40.00	19.0	0.114	186	40	4.65	1.189	1.19	1.1541	0.0175	0.020	0.114	
50.00	16.0	0.096	175	40	4.38	1.119	1.12	0.5596	0.0155	0.009	0.123	
60.00	15.0	0.090	0	40	0.00	0.000	0.00	0.0000	-0.045	0.000	0.123	
0.00	0.0	0.000	0	40	0.00	0.000	0.00	0.0000	0	0.000	0.123	
0.00	0.0	0.000	0	40	0.00	0.000	0.00	0.0000	0	0.000	0.123	
0.00	0.0	0.000	0	40	0.00	0.000	0.00	0.0000	0	0.000	0.123	
	0.0	0.000	0	40	0.00	0.000	0.00	0.0000	0	0.000	0.123	
										0.000	**0.123**	**m3/s**
											122.5	**l/s**

			Doly/BCW- Head Section					**Date;**				
Source name; Usa River												
Distance	**Sounde d**	**revise d**	**Revs . (N)**	**tim e (s)**	**rev s**	**vel. At**	**mea**	**mean**	**Area of**	**dischar g**	**Dischar g**	
0.00	20.0	0.120	0	40	0.00	0.00		0.640	0.026	0.017	0.017	
10.00	32.0	0.192	150	40	3.75	0.96	0.96	0.944	0.032	0.030	0.047	
20.00	32.0	0.192	145	40	3.63	0.92	0.93	0.947	0.036	0.034	0.081	
30.00	40.0	0.240	151	40	3.78	0.96	0.97	0.979	0.044	0.043	0.124	
40.00	48.0	0.288	155	40	3.88	0.99	0.99	1.023	0.048	0.049	0.173	
50.00	48.0	0.288	165	40	4.13	1.05	1.06	1.055	0.037	0.039	0.212	
60.00	26.0	0.156	165	40	4.13	1.05	1.06	1.061	0.025	0.027	0.239	
70.00	24.0	0.144	167	40	4.18	1.06	1.07	0.982	0.017	0.017	0.256	
80.00	10.0	0.060	140	40	3.50	0.89	0.90	0.448	0.004	0.002	0.257	
84.00	10.0	0.060	0	40	0.00	0.00	0.00	0.000	-0.042	0.000	0.257	
	0.0	0.000	0	40	0.00	0.00	0.00	0.000	0	0.000	0.257	
										0.000	**0.257**	**m3/**
											257.3	**l/s**

			Doly/BCW Furrow-End Section 3						**Date; 28/02/2018**			
Source name; Usa River												
Distance	**Sounded**	**revised**	**Revs. (N)**	**time (s)**	**revs per**	**vel. At point**	**mean**	**mean**	**Area of section**	**discharg e in**	**Discharge accum.**	
0.00	0.0	0.000	0	40	0.00	0.000		0.1657	0.005	0.001	0.001	
10.00	10.0	0.060	38	40	0.95	0.248	0.25	0.2707	0.011	0.003	0.004	
20.00	12.0	0.072	45	40	1.13	0.293	0.29	0.3089	0.012	0.004	0.008	
30.00	12.0	0.072	50	40	1.25	0.325	0.32	0.3438	0.011	0.004	0.011	
40.00	10.0	0.060	56	40	1.40	0.363	0.36	0.3756	0.0105	0.004	0.015	
50.00	11.0	0.066	60	40	1.50	0.388	0.39	0.3883	0.0115	0.004	0.020	
60.00	12.0	0.072	60	40	1.50	0.388	0.39	0.3724	0.0115	0.004	0.024	
70.00	11.0	0.066	55	40	1.38	0.357	0.36	0.3184	0.0095	0.003	0.027	
80.00	8.0	0.048	43	40	1.08	0.280	0.28	0.1624	0.00375	0.001	0.028	
85.00	7.0	0.042	2	40	0.05	0.045	0.04	0.0223	-	-0.001	0.027	
	0.0	0.000	0	40	0.00	0.000	0.00	0.0000	0	0.000	0.027	
										0.000	**0.027**	**m3/s**
											27.0	**l/s**

			Doly/BCW Furrow-Head						**Date; 28/02/2018**			
Source name; Usa River												
Distance (cm)	**Sounded Depth (cm)**	**revised depth of obs.**	**Revs. (N)**	**time (s)**	**revs per**	**vel. At point (m/s)**	**mean vel. In**	**mean vel**	**Area of section (m2/s)**	**discharge e in section**	**Discharge accum. (m3/s)**	
0.00	0.0	0.000	0	40	0.00	0.000		0.2377	0.009	0.002	0.002	
10.00	18.0	0.108	55	40	1.38	0.357	0.36	0.3724	0.021	0.008	0.010	
20.00	24.0	0.144	60	40	1.50	0.388	0.39	0.4201	0.024	0.010	0.020	
30.00	24.0	0.144	70	40	1.75	0.452	0.45	0.5027	0.027	0.014	0.034	
40.00	30.0	0.180	86	40	2.15	0.554	0.55	0.5186	0.03	0.016	0.049	
50.00	30.0	0.180	75	40	1.88	0.484	0.48	0.4709	0.023	0.011	0.060	
60.00	16.0	0.096	71	40	1.78	0.458	0.46	0.4391	0.0155	0.007	0.067	
70.00	15.0	0.090	65	40	1.63	0.420	0.42	0.4201	0.015	0.006	0.073	
80.00	15.0	0.090	65	40	1.63	0.420	0.42	0.4042	0.015	0.006	0.079	
90.00	15.0	0.090	60	40	1.50	0.388	0.39	0.1942	0.0075	0.001	0.081	
100.00	0.0	0.000	0	40	0.00	0.000	0.00	0.0000	0	0.000	0.081	
										0.000	**0.081**	**m3/s**
											80.6	**l/s**

		Doly/WCB Furrow- Head Section 2							**Date; 29/02/2018**			
Source name; Usa River												
Distance (cm)	**Sounded Depth**	**revised depth of obs.**	**Revs. (N)**	**time (s)**	**revs per**	**vel. At point (m/s)**	**mean vel. In**	**mean vel in**	**Area of section (m2/s)**	**discharge in section**	**Discharge accum.**	
0.00	20.0	0.120	0	40	0.00	0.000		0.7037	0.0195	0.014	0.014	
10.00	19.0	0.114	165	40	4.13	1.056	1.06	1.0715	0.018	0.019	0.033	
20.00	17.0	0.102	170	40	4.25	1.087	1.09	1.1318	0.0185	0.021	0.054	
30.00	20.0	0.120	184	40	4.60	1.176	1.18	1.1318	0.0195	0.022	0.076	
40.00	19.0	0.114	170	40	4.25	1.087	1.09	1.1032	0.0175	0.019	0.095	
50.00	16.0	0.096	175	40	4.38	1.119	1.12	0.9761	0.0155	0.015	0.110	
60.00	15.0	0.090	130	40	3.25	0.833	0.83	0.7855	0.015	0.012	0.122	
70.00	15.0	0.090	115	40	2.88	0.738	0.74	0.6933	0.0145	0.010	0.132	
80.00	14.0	0.084	101	40	2.53	0.649	0.65	0.4614	0.00475	0.002	0.134	
85.00	5.0	0.030	42	40	1.05	0.274	0.27	0.1370	-	-0.003	0.132	
	0.0	0.000	0	40	0.00	0.000	0.00	0.0000	0	0.000	0.132	
										0.000	**0.132**	**m3/s**
											131.6	**l/s**

Gauging station; USA									Date: 28 February 2018			
			Doly/BCW Furrow-End									
For Currentmeters												
Distance (m)	**Sounded Depth (m)**	**revised depth of obs. (m)**	**Revs. (N)**	**time (s)**	**revs per sec.**	**vel. At point (m/s)**	**mean vel. In**	**mean vel in**	**Area of section (m2/s)**	**discharge in section (m3/s)**	**Discharge accum. (m3/s)**	
0.00	0.51	0.004	0	40	0.0000	0.000		0.512	0.052	0.026	0.026	
0.10	0.52	0.420	220	40	5.5000	0.768	0.768	0.769	0.052	0.040	0.066	
0.20	0.52	0.432	221	40	5.5250	0.771	0.771	0.779	0.052	0.041	0.107	
0.30	0.52	0.432	226	40	5.6500	0.788	0.788	0.791	0.053	0.042	0.149	
0.40	0.54	0.426	228	40	5.7000	0.794	0.794	0.786	0.054	0.042	0.191	
0.50	0.54	0.408	223	40	5.5750	0.778	0.778	0.389	0.053	0.020	0.212	
0.60	0.51	0.408	0	40	0.0000	0.000	0.000	0.000	-0.153	0.000	0.212	
				40	0.0000	0.000	0.000	0.000	0.000	0.000	0.212	
				40	0.0000	0.000	0.000	0.000	0.000	0.000	0.212	
				40	0.0000	0.000	0.000	0.000	0.000	0.000	0.212	
				40	0.0000	0.000	0.000	0.000	0.000	0.000	0.212	
				40	0.0000	0.000	0.000	0.000	0.000	0.000	0.212	
				40	0.0000	0.000	0.000	0.288	0.035	0.010	**0.222**	**m3/s**

		Kammama-End						Date;		
Source name; Kikuletwa River										
Distance	**Sounded**	**revised**	**Revs.**	**tim**	**rev**	**vel. At**	**me**	**me**	**Area of**	**discharg e**	**Discharg**
0.00	0.0	0.00	0	40	0.0			0.28	0.02	0.00	0.006
10.00	40.0	0.24	65	40	1.6	0.4	0.4	0.40	0.04	0.01	0.022
20.00	40.0	0.24	60	40	1.5	0.3	0.3	0.40	0.03	0.01	0.038
30.00	39.0	0.23	64	40	1.6	0.4	0.4	0.43	0.03	0.01	0.055
40.00	40.0	0.24	70	40	1.7	0.4	0.4	0.43	0.04	0.01	0.072
50.00	40.0	0.24	65	40	1.6	0.4	0.4	0.21	0.01	0.00	0.074
55.00	0.0	0.00	0	40	0.0	0.0	0.0	0.00	0	0.00	0.074
				40	0.0	0.0	0.0	0.00	0	0.00	0.074
				40	0.0	0.0	0.0	0.00	0	0.00	0.074
				40	0.0	0.0	0.0	0.00	0	0.00	0.074
				40	0.0	0.0	0.0	0.00	0	0.00	0.074
Kamama Intake-Head Section 4										0.00	**0.074**
											74.2 l

		Kamama End						Date;		
Source name; Kikuletwa River											
Distance (cm)	**Sounded Depth**	**revised depth**	**Revs. (N)**	**time (s)**	**revsp**	**vel. At poi**	**mean vel.**	**mean vel**	**Area of section**	**discharge in secti**	**Discharge accum.**
0.00	0.0	0.00	0	40	0.0	0.0		0.43	0.0	0.00	0.004
10.00	19.0	0.11	10	40	2.5	0.6	0.6	0.65	0.0	0.01	0.017
20.00	19.0	0.11	10	40	2.5	0.6	0.6	0.66	0.0	0.01	0.029
30.00	19.0	0.11	10	40	2.6	0.6	0.6	0.66	0.0	0.01	0.042
40.00	19.0	0.11	10	40	2.5	0.6	0.6	0.66	0.0	0.01	0.055
50.00	19.0	0.11	10	40	2.6	0.6	0.6	0.33	0.0	0.00	0.058
60.00	0.0	0.00	0	40	0.0	0.0	0.0	0.00	0	0.00	0.058
				40	0.0	0.0	0.0	0.00	0	0.00	0.058
				40	0.0	0.0	0.0	0.00	0	0.00	0.058
				40	0.0	0.0	0.0	0.00	0	0.00	0.058
				40	0.0	0.0	0.0	0.00	0	0.00	0.058
										0.00	**0.058**
											57.7 l/

		Kamama Furrow-Head Section 2							**Date; 29/10/2017**			
Source name; Kikuletwa River												
Distance	**Sounded Depth**	**revised depth of**	**Revs. (N)**	**time (s)**	**revs per**	**vel. At point**	**mean**	**mean**	**Area of section**	**discharg e in section**	**Discharg e accum.**	
0.00	0.0	0.000	0	40	0.00	0.000		0.4919	0.0175	0.009	0.009	
10.00	35.0	0.210	115	40	2.88	0.738	0.74	0.7378	0.035	0.026	0.034	
20.00	35.0	0.210	115	40	2.88	0.738	0.74	0.7474	0.035	0.026	0.061	
30.00	35.0	0.210	118	40	2.95	0.757	0.76	0.7569	0.035	0.026	0.087	
40.00	35.0	0.210	118	40	2.95	0.757	0.76	0.7315	0.035	0.026	0.113	
50.00	35.0	0.210	110	40	2.75	0.706	0.71	0.7061	0.035	0.025	0.137	
60.00	35.0	0.210	110	40	2.75	0.706	0.71	0.6902	0.035	0.024	0.162	
70.00	35.0	0.210	105	40	2.63	0.674	0.67	0.6647	0.035	0.023	0.185	
80.00	35.0	0.210	102	40	2.55	0.655	0.66	0.3276	0.035	0.011	0.196	
100.00	0.0	0.000	0	40	0.00	0.000	0.00	0.0000	0	0.000	0.196	
				40	0.00	0.000	0.00	0.0000	0	0.000	0.196	
										0.000	**0.196**	
											196.3	**l/s**

Gauging station; USA RIVER									Date: 27 February 2015			
		Kamama Furrow-End Section 1										
For Currentmeters												
Distance	**Sounded Depth**	**revised depth of**	**Revs. (N)**	**time (s)**	**revs per**	**vel. At point**	**mean**	**mean**	**Area of section**	**discharg e in section**	**Discharg e accum.**	
0.00	0.00	0.000	0	40	0.0000	0.000		0.223	0.023	0.005	0.005	
0.20	0.23	0.138	90	40	2.2500	0.335	0.335	0.368	0.049	0.018	0.023	
0.40	0.26	0.162	110	40	2.7500	0.402	0.402	0.423	0.060	0.025	0.049	
0.60	0.34	0.210	123	40	3.0750	0.445	0.445	0.471	0.073	0.034	0.083	
0.80	0.39	0.240	139	40	3.4750	0.498	0.498	0.483	0.075	0.036	0.119	
1.00	0.36	0.204	130	40	3.2500	0.468	0.468	0.468	0.067	0.031	0.151	
1.20	0.31	0.198	130	40	3.2500	0.468	0.468	0.438	0.059	0.026	0.176	
1.40	0.28	0.174	112	40	2.8000	0.408	0.408	0.385	0.052	0.020	0.196	
1.60	0.24	0.144	98	40	2.4500	0.362	0.362	0.334	0.034	0.011	0.208	
1.80	0.10	0.120	82	40	2.0500	0.306	0.306	0.153	0.010	0.002	0.209	
2.00		0.000	0	40	0.0000	0.000	0.000	0.000	0.000	0.000	0.209	

			0	40	0.0000	0.000	0.000	0.000	0.000	0.000	0.209	
			0	40	0.0000	0.000	0.000	0.000	0.000	0.000	**0.209**	**m3/s**
											209.3069	**l/s**

Gauging station; USA RIVER — Date: 25 February 2015

Kamama Furrow-Head Section 1

For Currentmeters

Distance	**Sounded Depth**	**revised depth of**	**Revs. (N)**	**time (s)**	**revs per**	**vel. At**	**mean**	**mean**	**Area of section**	**discharg e in section**	**Discharg e accum.**	
0.00	0.00	0.000	0	40	0.0000	0.000		0.268	0.025	0.007	0.007	
0.10	0.49	0.294	110	40	2.7500	0.402	0.402	0.400	0.049	0.020	0.026	
0.20	0.49	0.294	109	40	2.7250	0.398	0.398	0.400	0.049	0.020	0.046	
0.30	0.49	0.294	110	40	2.7500	0.402	0.402	0.408	0.049	0.020	0.066	
0.40	0.49	0.294	114	40	2.8500	0.415	0.415	0.416	0.049	0.020	0.086	
0.50	0.49	0.294	115	40	2.8750	0.418	0.418	0.407	0.049	0.020	0.106	
0.60	0.49	0.294	108	40	2.7000	0.395	0.395	0.397	0.049	0.019	0.126	
0.70	0.49	0.294	109	40	2.7250	0.398	0.398	0.403	0.049	0.020	0.145	
0.80	0.49	0.294	112	40	2.8000	0.408	0.408	0.405	0.049	0.020	0.165	
0.90	0.49	0.294	110	40	2.7500	0.402	0.402	0.400	0.049	0.020	0.185	
1.00	0.49	0.294	109	40	2.7250	0.398	0.398	0.397	0.049	0.019	0.204	
1.10	0.49	0.294	108	40	2.7000	0.395	0.395	0.197	0.047	0.009	0.213	
1.20	0.45	0.270	0	40	0.0000	0.000	0.000	0.288	0.035	0.010	**0.223**	**m3/s**
											223.4802	**l/s**

Gauging station; USA RIVER — Date: 27 February 2015

Kamama Furrow-Head Section 3

For Currentmeters

Distance (m)	**Sounded Depth (m)**	**revised depth of obs. (m)**	**Revs. (N)**	**time (s)**	**revs per sec.**	**vel. At point (m/s)**	**mean vel. In vert.**	**mean vel in section**	**Area of section (m2/s)**	**discharg e in section (m3/s)**	**Discharg e accum. (m3/s)**
0.00	0.00	0.000	0	40	0.0000	0.000		0.154	0.025	0.004	0.004
0.10	0.50	0.300	60	40	1.5000	0.230	0.230	0.283	0.050	0.014	0.018
0.20	0.50	0.300	90	40	2.2500	0.335	0.335	0.337	0.050	0.017	0.035
0.30	0.50	0.300	91	40	2.2750	0.338	0.338	0.370	0.050	0.018	0.053
0.40	0.50	0.300	110	40	2.7500	0.402	0.402	0.400	0.050	0.020	0.073
0.50	0.49	0.294	109	40	2.7250	0.398	0.398	0.400	0.049	0.020	0.093
0.60	0.49	0.294	110	40	2.7500	0.402	0.402	0.378	0.049	0.019	0.111
0.70	0.49	0.294	96	40	2.4000	0.355	0.355	0.310	0.049	0.015	0.126
0.80	0.49	0.294	70	40	1.7500	0.265	0.265	0.280	0.049	0.014	0.140
0.90	0.49	0.294	79	40	1.9750	0.295	0.295	0.266	-0.221	-0.059	0.081

	0.00	0.000	62	40	1.5500	0.237	0.237	0.119	0.000	0.000	0.081	
			0	40	0.0000	0.000	0.000	0.000	0.000	0.000	0.081	
			0	40	0.0000	0.000	0.000	0.000	0.000	0.000	**0.081**	**m3/s**
											81.40235	**l/s**

Gauging station; USA RIVER			Kipilipili Furrow- Head Section 1					Date: 25 February 2018				
For Currentmeters												
Distance (m)	**Sounded Depth (m)**	**revised depth of obs. (m)**	**Revs. (N)**	**time (s)**	**revs per sec.**	**vel. At point (m/s)**	**mean vel. In vert.**	**mean vel in section**	**Area of section (m2/s)**	**discharg e in section (m3/s)**	**Discharg e accum. (m3/s)**	
0.00	0.00	0.000	0	40	0.0000	0.000		0.026	0.022	0.001	0.001	
0.20	0.22	0.132	4	40	0.1000	0.039	0.039	0.143	0.055	0.008	0.008	
0.40	0.33	0.198	65	40	1.6250	0.247	0.247	0.341	0.075	0.026	0.034	
0.60	0.42	0.252	120	40	3.0000	0.435	0.435	0.468	0.092	0.043	0.077	
0.80	0.50	0.300	140	40	3.5000	0.501	0.501	0.498	0.103	0.051	0.128	
1.00	0.53	0.318	138	40	3.4500	0.495	0.495	0.491	0.110	0.054	0.182	
1.20	0.57	0.342	136	40	3.4000	0.488	0.488	0.480	0.114	0.055	0.237	
1.40	0.57	0.342	131	40	3.2750	0.471	0.471	0.480	0.114	0.055	0.292	
1.60	0.57	0.342	136	40	3.4000	0.488	0.488	0.476	0.115	0.055	0.347	
1.80	0.58	0.348	129	40	3.2250	0.465	0.465	0.456	0.114	0.052	0.399	
2.00	0.56	0.336	124	40	3.1000	0.448	0.448	0.405	0.082	0.033	0.432	
2.20	0.26	0.156	98	40	2.4500	0.362	0.362	0.181	0.026	0.005	0.437	
2.40	0.00	0.000	0	40	0.0000	0.000	0.000	0.288	0.035	0.010	**0.447**	**m3/s**
											446.5939	**l/s**

			Kipilipili Furrow-Head Section					**Date; 25/02/2018**			
Source name; Kikuletwa River											
Distance (cm)	**Sounded Depth (cm)**	**revised depth of obs. (m)**	**Revs. (N)**	**time (s)**	**revs per sec.**	**vel. At point (m/s)**	**mean vel. In vert.**	**mean vel in section**	**Area of section (m2/s)**	**discharg e in section (m3/s)**	**Discharg e accum. (m3/s)**
0.00	0.0	0.000	0	40	0.00	0.000		0.3012	0.0045	0.001	0.001
10.00	9.0	0.054	70	40	1.75	0.452	0.45	0.6171	0.0095	0.006	0.007
20.00	10.0	0.060	122	40	3.05	0.782	0.78	0.8554	0.0085	0.007	0.014
30.00	7.0	0.042	145	40	3.63	0.928	0.93	1.0079	0.008	0.008	0.023
40.00	9.0	0.054	170	40	4.25	1.087	1.09	1.1032	0.0095	0.010	0.033
50.00	10.0	0.060	175	40	4.38	1.119	1.12	1.1668	0.0095	0.011	0.044
60.00	9.0	0.054	190	40	4.75	1.214	1.21	1.0715	0.009	0.010	0.054
70.00	9.0	0.054	145	40	3.63	0.928	0.93	0.4642	0.00135	0.001	0.054
73.00	0.0	0.000	0	40	0.00	0.000	0.00	0.0000	0	0.000	0.054

	0.0	0.000	0	40	0.00	0.000	0.00	0.0000	0	0.000	0.054	
	0.0	0.000	0	40	0.00	0.000	0.00	0.0000	0	0.000	0.054	
										0.000	**0.054**	**m3/s**
											54.4	**l/s**

			Kipilipili Furrow-End						**Date; 28/02/2018**			
Source name; Kikuletwa River												
Distance (cm)	**Sounded Depth (cm)**	**revised depth of obs. (m)**	**Revs. (N)**	**time (s)**	**revs per sec.**	**vel. At point (m/s)**	**mean vel. In vert.**	**mean vel in section**	**Area of section (m2/s)**	**discharg e in section (m3/s)**	**Discharg e accum. (m3/s)**	
0.00	0.0	0.000	0	40	0.00	0.000		0.0439	0.007	0.000	0.000	
20.00	7.0	0.042	6	40	0.15	0.066	0.07	0.1002	0.018	0.002	0.002	
40.00	11.0	0.066	19	40	0.48	0.135	0.13	0.1693	0.029	0.005	0.007	
60.00	18.0	0.108	31	40	0.78	0.204	0.20	0.2485	0.038	0.009	0.016	
80.00	20.0	0.120	45	40	1.13	0.293	0.29	0.2866	0.04	0.011	0.028	
100.00	20.0	0.120	43	40	1.08	0.280	0.28	0.2644	0.042	0.011	0.039	
120.00	22.0	0.132	38	40	0.95	0.248	0.25	0.1242	0.034	0.004	0.043	
140.00	12.0	0.072	0	40	0.00	0.000	0.00	0.0000	0.018	0.000	0.043	
170.00	0.0	0.000	0	40	0.00	0.000	0.00	0.0000	0	0.000	0.043	
		0.000	0	40	0.00	0.000	0.00	0.0000	0	0.000	0.043	
	0.0	0.000	0	40	0.00	0.000	0.00	0.0000	0	0.000	0.043	
										0.000	**0.043**	**m3/s**
											43.3	**l/s**

			Kipilipili Furrow-Head Section 2						**Date; 28/02/2018**			
Source name; Kikuletwa River												
Distance	**Sounded Depth**	**revised depth of**	**Revs. (N)**	**time (s)**	**revs per**	**vel. At point**	**mean**	**mean**	**Area of section**	**discharg e in section**	**Discharg e accum.**	
0.00	0.0	0.000	0	40	0.00	0.000		0.2038	0.02	0.004	0.004	
20.00	20.0	0.120	47	40	1.18	0.306	0.31	0.3565	0.041	0.015	0.019	
40.00	21.0	0.126	63	40	1.58	0.407	0.41	0.4105	0.036	0.015	0.033	
60.00	15.0	0.090	64	40	1.60	0.414	0.41	0.4233	0.029	0.012	0.046	
80.00	14.0	0.084	67	40	1.68	0.433	0.43	0.4773	0.034	0.016	0.062	
100.00	20.0	0.120	81	40	2.03	0.522	0.52	0.4963	0.045	0.022	0.084	
120.00	25.0	0.150	73	40	1.83	0.471	0.47	0.4582	0.049	0.022	0.107	
140.00	24.0	0.144	69	40	1.73	0.445	0.45	0.3978	0.047	0.019	0.125	
160.00	23.0	0.138	54	40	1.35	0.350	0.35	0.2265	0.03	0.007	0.132	
180.00	7.0	0.042	13	40	0.33	0.103	0.10	0.0514	0.0035	0.000	0.132	
190.00	0.0	0.000	0	40	0.00	0.000	0.00	0.0000	0	0.000	0.132	
										0.000	**0.132**	**m3/s**
											132.4	**l/s**

			Kipilipili Furrow- End Section 2						Date; 28/02/2018			
Source name; Kikuletwa River												
Distance	**Sounded Depth**	**revised depth of**	**Revs. (N)**	**time (s)**	**revs per**	**vel. At point**	**mean**	**mean**	**Area of section**	**discharg e in**	**Discharg e accum.**	
0.00	0.0	0.000	0	40	0.00	0.000		0.3436	0.018	0.006	0.006	
20.00	18.0	0.108	80	40	2.00	0.515	0.52	0.6234	0.038	0.024	0.030	
40.00	20.0	0.120	114	40	2.85	0.731	0.73	0.7632	0.045	0.034	0.064	
60.00	25.0	0.150	124	40	3.10	0.795	0.80	0.6806	0.04	0.027	0.091	
80.00	15.0	0.090	88	40	2.20	0.566	0.57	0.5313	0.032	0.017	0.108	
100.00	17.0	0.102	77	40	1.93	0.496	0.50	0.4519	0.032	0.014	0.123	
120.00	15.0	0.090	63	40	1.58	0.407	0.41	0.2037	0.01125	0.002	0.125	
135.00	0.0	0.000	0	40	0.00	0.000	0.00	0.0000	0	0.000	0.125	
		0.000		40	0.00	0.000	0.00	0.0000	0	0.000	0.125	
		0.000		40	0.00	0.000	0.00	0.0000	0	0.000	0.125	
		0.000		40	0.00	0.000	0.00	0.0000	0	0.000	0.125	
										0.000	**0.125**	
											125.2	**l/s**

Computed by Haymale

			Kipilipili Furrow-End						Date; 28/02/2018			
Source name; Kikuletwa River												
Distance (cm)	**Sounded Depth (cm)**	**revised depth of obs. (m)**	**Revs. (N)**	**time (s)**	**revs per sec.**	**vel. At point (m/s)**	**mean vel. In vert.**	**mean vel in section**	**Area of section (m2/s)**	**discharg e in section (m3/s)**	**Discharg e accum. (m3/s)**	
0.00	0.0	0.000	0	40	0.00	0.000		0.0580	0.018	0.001	0.001	
20.00	18.0	0.108	10	40	0.25	0.087	0.09	0.2376	0.044	0.010	0.011	
40.00	26.0	0.156	60	40	1.50	0.388	0.39	0.6266	0.054	0.034	0.045	
60.00	28.0	0.168	135	40	3.38	0.865	0.86	0.9158	0.058	0.053	0.098	
80.00	30.0	0.180	151	40	3.78	0.967	0.97	0.9317	0.066	0.061	0.160	
100.00	36.0	0.216	140	40	3.50	0.897	0.90	0.8332	0.072	0.060	0.220	
120.00	36.0	0.216	120	40	3.00	0.770	0.77	0.5472	0.073	0.040	0.260	
140.00	37.0	0.222	50	40	1.25	0.325	0.32	0.2485	0.072	0.018	0.278	
160.00	35.0	0.210	26	40	0.65	0.172	0.17	0.1722	0.06	0.010	0.288	
180.00	25.0	0.150	26	40	0.65	0.172	0.17	0.1849	0.045	0.008	0.296	
200.00	20.0	0.120	30	40	0.75	0.198	0.20	0.0988	0.00725	0.001	0.297	
205	9	0.054	0	40	0	0	0	0.0000	-0.09225	0.000	**0.297**	**m3/s**
											297.1	**l/s**

Gauging station; Date: 25 February 2017

Orbuso Furrow-End Section 2

For pigm 50.447

Distance (m)	Sounded Depth (m)	revised depth of obs. (m)	Revs. (N)	time (s)	revs per sec.	vel. At point (m/s)	mean vel. In vert.	mean vel in section	Area of section (m2/s)	discharge in section (m3/s)	Discharge accum. (m3/s)	
0.00	0.00	0.000	0	40	0.0000	0.000		0.146	0.008	0.001	0.001	
20.00	8.00	4.800	133	40	3.3250	0.220	0.220	0.267	0.021	0.006	0.007	
40.00	13.00	7.800	200	40	5.0000	0.315	0.315	0.349	0.030	0.010	0.017	
60.00	17.00	10.200	248	40	6.2000	0.383	0.383	0.394	0.030	0.012	0.029	
80.00	13.00	7.800	264	40	6.6000	0.406	0.406	0.417	0.033	0.014	0.043	
100.00	20.00	12.000	280	40	7.0000	0.428	0.428	0.425	0.043	0.018	0.061	
120.00	23.00	13.800	275	40	6.8750	0.421	0.421	0.408	0.045	0.018	0.079	
140.00	22.00	13.200	256	40	6.4000	0.394	0.394	0.390	0.043	0.017	0.096	
160.00	21.00	12.600	250	40	6.2500	0.386	0.386	0.193	0.011	0.002	0.098	
170.00	0.00	0.000	0	40	0.0000	0.000	0.000	0.000	0.000	0.000	0.098	
				40	0.0000	0.000	0.000	0.000	0.000	0.000	0.098	
				40	0.0000	0.000	0.000	0.000	0.000	0.000	0.098	
				40	0.0000	0.000	0.000	0.000	0.000	0.000	0.098	
				40	0.0000	0.000	0.000	0.000	0.000	0.000	0.098	
				40	0.0000	0.000	0.000	0.000	0.000	0.000	0.098	
				40	0.0000	0.000	0.000	0.000	0.000	0.000	0.098	
				40	0.0000	0.000	0.000	0.000	0.000	0.000	0.098	M³/s
											98.260	l/s

Gauging station; USA RIVER Date: 25 February 2017

Orbuso Furrow- End Head

For Currentmeters

Distance	Sounded Depth	revised depth	Revs. (N)	time (s)	revs per	vel. At point	mean	mean	Area of section	discharge in	Discharge accum.
0.00	0.00	0.000	0	40	0.0000	0.000		0.133	0.060	0.008	0.008
0.20	0.60	0.360	51	40	1.2750	0.199	0.199	0.199	0.125	0.025	0.033
0.40	0.65	0.390	51	40	1.2750	0.199	0.199	0.198	0.133	0.026	0.059
0.60	0.68	0.408	50	40	1.2500	0.196	0.196	0.205	0.136	0.028	0.087
0.80	0.68	0.408	55	40	1.3750	0.213	0.213	0.215	0.138	0.030	0.117
1.00	0.70	0.420	56	40	1.4000	0.217	0.217	0.206	0.130	0.027	0.144
1.20	0.60	0.360	50	40	1.2500	0.196	0.196	0.194	0.110	0.021	0.165

1.40	0.50	0.300	49	40	1.2250	0.193	0.193	0.169	0.098	0.017	0.181	
1.60	0.48	0.288	35	40	0.8750	0.145	0.145	0.143	0.098	0.014	0.195	
1.80	0.50	0.300	34	40	0.8500	0.141	0.141	0.134	0.098	0.013	0.209	
2.00	0.48	0.288	30	40	0.7500	0.128	0.128	0.064	0.012	0.001	0.209	
2.05	0.00	0.000	0	40	0.0000	0.000	0.000	0.000	0.000	0.000	0.209	
	0.00	0.000	0	40	0.0000	0.000	0.000	0.000	0.000	0.000	**0.209**	**m3/s**
											209.3715	**l/s**

Gauging station; USA RIVER									Date: 25 February 2018			
			Orbuso Furrow-End Section 1									
For Currentmeters												
Distance (m)	**Sounded Depth (m)**	**revised depth of obs. (m)**	**Revs. (N)**	**time (s)**	**revs per sec.**	**vel. At point (m/s)**	**mean vel. In vert.**	**mean vel in section**	**Area of section (m2/s)**	**discharg e in section (m3/s)**	**Discharg e accum. (m3/s)**	
0.00	0.00	0.000	0	40	0.0000	0.000		0.133	0.045	0.006	0.006	
0.20	0.45	0.270	51	40	1.2750	0.199	0.199	0.206	0.095	0.020	0.026	
0.40	0.50	0.300	55	40	1.3750	0.213	0.213	0.213	0.104	0.022	0.048	
0.60	0.54	0.324	55	40	1.3750	0.213	0.213	0.242	0.108	0.026	0.074	
0.80	0.54	0.324	72	40	1.8000	0.271	0.271	0.282	0.109	0.031	0.105	
1.00	0.55	0.330	78	40	1.9500	0.292	0.292	0.292	0.110	0.032	0.137	
1.20	0.55	0.330	78	40	1.9500	0.292	0.292	0.295	0.110	0.032	0.169	
1.40	0.55	0.330	80	40	2.0000	0.299	0.299	0.268	0.102	0.027	0.197	
1.60	0.47	0.282	62	40	1.5500	0.237	0.237	0.119	-0.376	-0.045	0.152	
			0	40	0.0000	0.000	0.000	0.000	0.000	0.000	0.152	
		0.000		40	0.0000	0.000	0.000	0.000	0.000	0.000	0.152	
		0.000		40	0.0000	0.000	0.000	0.000	0.000	0.000	0.152	
		0.000		40	0.0000	0.000	0.000	0.000	0.000	0.000	**0.152**	**m3/s**
											151.98	**l/s**

Gauging station; KIKULETWA									Date: 25 February 2018			
			Orbuso Furrow-Head section 2									
For pigm 50.447												
Distance (m)	**Sounded Depth (m)**	**revised depth of obs. (m)**	**Revs. (N)**	**time (s)**	**revs per sec.**	**vel. At point (m/s)**	**mean vel. In vert.**	**mean vel in section**	**Area of section (m2/s)**	**discharg e in section (m3/s)**	**Discharg e accum. (m3/s)**	
0.00	0.00	0.000	0	40	0.0000	0.000		0.215	0.016	0.003	0.003	
20.00	16.00	9.600	205	40	5.1250	0.322	0.322	0.350	0.035	0.012	0.016	
40.00	19.00	11.400	245	40	6.1250	0.379	0.379	0.380	0.038	0.014	0.030	
60.00	19.00	11.400	247	40	6.1750	0.382	0.382	0.382	0.037	0.014	0.044	
80.00	18.00	10.800	247	40	6.1750	0.382	0.382	0.347	0.036	0.012	0.057	

100.00	18.00	10.800	198	40	4.9500	0.312	0.312	0.320	0.035	0.011	0.068	
120.00	17.00	10.200	210	40	5.2500	0.329	0.329	0.320	0.034	0.011	0.079	
140.00	17.00	10.200	197	40	4.9250	0.311	0.311	0.310	0.034	0.011	0.089	
160.00	17.00	10.200	196	40	4.9000	0.309	0.309	0.294	0.034	0.010	0.099	
180.00	17.00	10.200	175	40	4.3750	0.279	0.279	0.140	0.009	0.001	0.101	
190.00	0.00	0.000	0	40	0.0000	0.000	0.000	0.000	0.000	0.000	0.101	
				40	0.0000	0.000	0.000	0.000	0.000	0.000	0.101	
				40	0.0000	0.000	0.000	0.000	0.000	0.000	0.101	
				40	0.0000	0.000	0.000	0.000	0.000	0.000	0.101	
				40	0.0000	0.000	0.000	0.000	0.000	0.000	0.101	
				40	0.0000	0.000	0.000	0.000	0.000	0.000	0.101	
				40	0.0000	0.000	0.000	0.000	0.000	0.000	0.101	M³/s
											100.552	l/s

Appendix 3: R studio program

```
> library(readr)
> Haymale_data <- read_csv("E:/Haymale_data.csv")
> View(Haymale_data)
> head(Haymale_data)
# A tibble: 6 x 12
     SN `Furrow Name` `Permitted Discharge~ `Discharge Extracted~ `Canal Sect
ion`
  <int> <chr>         <chr>                                  <int> <chr>
1     1 Shamima       200                                      189 Section 1
2    NA <NA>          <NA>                                      NA Section 2
3     2 Star          -                                         70 Section 1
4     3 Mbukita       200                                       72 Section
5     4 Orbuso        200                                      209 Section 1
6    NA <NA>          <NA>                                      NA Section 2
# ... with 7 more variables: `Head of Section` <dbl>, `End of Section` <dbl>,
#   `Distance (m)` <dbl>, `Loss Discharge L/s` <int>, `Discharge Loss
#   L/s/m` <dbl>, `Loss %` <dbl>, `Efficiency %(Ec)` <dbl>
> Reg_model<-lm(Haymale_data$`Distance (m)`~Haymale_data$`Loss Discharge L/s`
)
> Reg_model

Call:
lm(formula = Haymale_data$`Distance (m)` ~ Haymale_data$`Loss Discharge L/s`)

Coefficients:
                      (Intercept)  Haymale_data$`Loss Discharge L/s`
                          808.501                              8.489

> Anov<-anova(Reg_model)
> Anov
Analysis of Variance Table

Response: Haymale_data$`Distance (m)`
                                  Df   Sum Sq  Mean Sq F value   Pr(>F)
Haymale_data$`Loss Discharge L/s`  1 14742877 14742877  29.001 4.61e-06 ***
Residuals                         36 18301077   508363
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
> Reg_model2<-lm(Haymale_data$`Loss Discharge L/s`~Haymale_data$`Distance (m)
`)
> Reg_model2

Call:
lm(formula = Haymale_data$`Loss Discharge L/s` ~ Haymale_data$`Distance (m)`)

Coefficients:
                (Intercept)  Haymale_data$`Distance (m)`
                  -15.96525                      0.05256

> Anov2<-anova(Reg_model2)
> Anov2
Analysis of Variance Table

Response: Haymale_data$`Loss Discharge L/s`
                            Df Sum Sq Mean Sq F value   Pr(>F)
Haymale_data$`Distance (m)`  1  91271   91271  29.001 4.61e-06 ***
```

RESEARCH OUTPUT

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Research Article

Estimating Conveyance Efficiency and Maize Productivity of Traditional Irrigation Systems in Usa River Catchment, Tanzania

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Estimating the conveyance efficiency of traditional irrigation schemes systems is very important. It is because of understanding the volume of water lost along with the transportation facility, enhancing water usage and productivity, hence making better decisions about the utilization of water resources. The objective of the study was to determine water abstraction permit compliances and estimate conveyance efficiency and crop and water productivity of traditional irrigation systems in northern Tanzania. The task involved measurement of irrigation water flows to determine the amount of water abstraction, inflow (head) and outflow (tail) between the canals to determine the conveyance efficiency of the main, secondary, and tertiary canals of the traditional irrigation systems. Moreover, water and yield obtained at the farm level were determined. Results indicate that approximately 72% of water transported reaches the destined farm which produced maize (*Zea mays* L) yields of 1054.5 kg/ha, 892.4 kg/ha, and 875.156 kg/ha at downstream, midstream, and upstream which equals 0.41 kg/m^3, 0.15 kg/m^3, and 0.09 kg/m^3, respectively, while about 28% of water is lost along the canals through evaporation, seepage, and deep percolation and overtopping. Consequently, water measured at furrow intakes in total was 3, 500 L/s, equal to 23% more than the permitted amount of 2856.14 L/s at Usa River Catchment. Interventions to minimize water losses starting at the furrow's intakes are urgently required in the current trend of the increasing demand for water resources for food production and schemes performance. Subsequently, more effective conveyance technologies and water management strategies other than canal lining are required.

1. Introduction

Globally rain-fed agriculture's contribution to food production is about 60%; the other 40% is supplemented by irrigated agriculture [1]. However, irrigation consumes about 70% of the available water [2]. Globally, approximately 277 million hectares of agricultural land is under irrigation (about 20% of cultivated land), contributing 40% of the food supplies with 2.3 higher yields compared to rain-fed agriculture as described by Adejumobi et al. [3]. Irrigation efficiency in Sub-Saharan Africa (SSA) was 33% in the year 1998 and is expected to improve by 37% by the year 2030 [1].

The SSA irrigated agriculture is said to use less than 2% of the total renewable water resources to irrigate a land of six million hectares, which is equal to 6% of the total irrigable land. Conversely, Asia region uses 37% and Latin America uses 17% of its total renewable water resources, which seem to be higher than SSA [1]. Utilization of water for irrigation needs a lot of attention in the catchment with scarce water resource. The performance indication of the irrigation schemes is revealed from the irrigation efficiency.

Generally, water from the source is being conveyed through different methods depending on the establishment of the scheme in terms of conveyance distribution and application system. Currently, the conveyance efficiencies for the traditional irrigation schemes in Tanzania range within 70%–80% for the main canal, 50%–80% for the secondary canal, and 23%–63% for a tertiary canal [4]. The different conveyance distribution facilities used include open lined canals, pipes, and earthen canals, which ensure water travel from the source to the farm field. It is believed that most water is being lost during distribution and application in the farm fields. However, conveyance efficiencies mainly relate to the engineering of the infrastructure, while the application efficiencies relate to farmer/agronomic practices [5]. Traditional irrigation schemes in the country rely on the runoff of the river abstraction and gravity flows with the irrigation infrastructures in the state of being temporal and poorly constructed and thus pose difficulty to water abstraction and overall water management, with low irrigation efficiencies. The conveyance efficiency of the irrigation schemes provides insight into the performance of the infrastructure and enhances water resource utilization. In the Usa River Catchment, the irrigation infrastructure is earthen traditional canals and does not have the capacity of holding and maintaining the intended quantity of water directed to the fields. Irrigation canal performance is part of the overall enactment of an irrigation area [6].

Tanzania has a total of 1,428 irrigation schemes where 1,328 are smallholders, 85 are private sectors, and 15 are government-owned [7]. The largest irrigation schemes are found in Kilimanjaro, Arusha, Morogoro, Iringa, and Mbeya [7]. Irrigated agriculture in Tanzania reportedly consumes approximately 89% of the total water diverted, compared to 9% domestic use and 2% industrial water use [8]. Simultaneously, on-farm water use efficiency is typically very low, within 10%–20%, contributing to the heavy use of water for irrigation [8].

The conveyance efficiency normally dictates the amount of water to be delivered to the field, which depends on the characteristics of the channel. In the process of transporting water from the source to the farm/land, there is water loss through evaporation, transpiration, percolation, and spills. Consequently, the distance from the water source to the farmland, soil type, channel type and the slope of the channel are the other main causes of water losses.

A similar situation can also be found in the Usa River Catchment which is located in the Arusha region, near Arusha town. The catchment has about twenty (20) identified irrigation schemes that extract water from the rivers in the catchment (Figure 1). The catchment is water-stressed due to excessive withdrawal from surface and groundwater for irrigated farming of diverse crops.

However, no research has been conducted to understand the irrigation conveyance efficiencies and crop and water productivity in the Usa River Catchment. The efficiencies and productivity of the irrigation schemes remain a policy question for the basin water managers and decision-makers. There is a general assumption that some water can be released from the Usa Rivers to irrigation schemes. Similarly, it is not clear where to target such water-saving interventions.

Therefore, this study intended to estimate the conveyance efficiency and crop and water productivity in traditional irrigation schemes and irrigation practices in the Usa River Catchment where there are many farmers-managed irrigation schemes that the basin authority considers to have poor infrastructure, poor water management, and low yields.

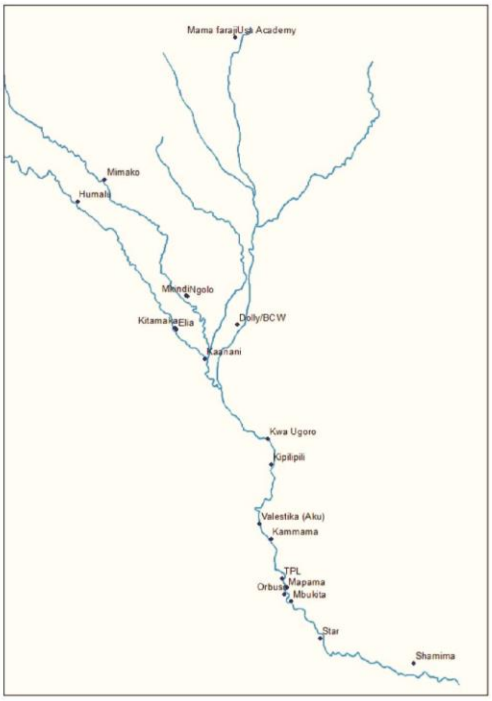

Figure 1: Irrigation water intakes and location.

2. Materials and Methods

2.1. Study Area Description. This study was carried out at the Usa River Catchment, within the Upper Pangani River Basin, North of Tanzania. The catchment is located within the northern region of Tanzania at $3^0 15'00''$ to $3^0 33'00''$ S and longitude $36^0 45'00''$ to $36^0 58'00''$ E (Figure 2). The catchment has an area of 320 km^2 and forms part of the larger Kikuletwa Catchment. The catchment is located at the foot of Meru Mountain lying between Kikavu River Catchment running from Kilimanjaro Mountain and Nduruma River Catchment running from Meru Mountain. The rivers found within the catchment running from Meru Mountains include Malala, Tengeru, Usa River, Maji ya Chai, Mogadirisho, and Ngaresero, which discharge water in Kikuletwa River (Figure 2). The Usa River Catchment consists of administrative wards of Songoro, Nkoaranga, Maji ya Chai, Usa River, Kikwe, Seela, Singisi, and Poli. The largest plain area is found downstream of the catchment where the largest farms are located. The downstream of the catchment is at 914 m–1194 m, above-average mean sea level.

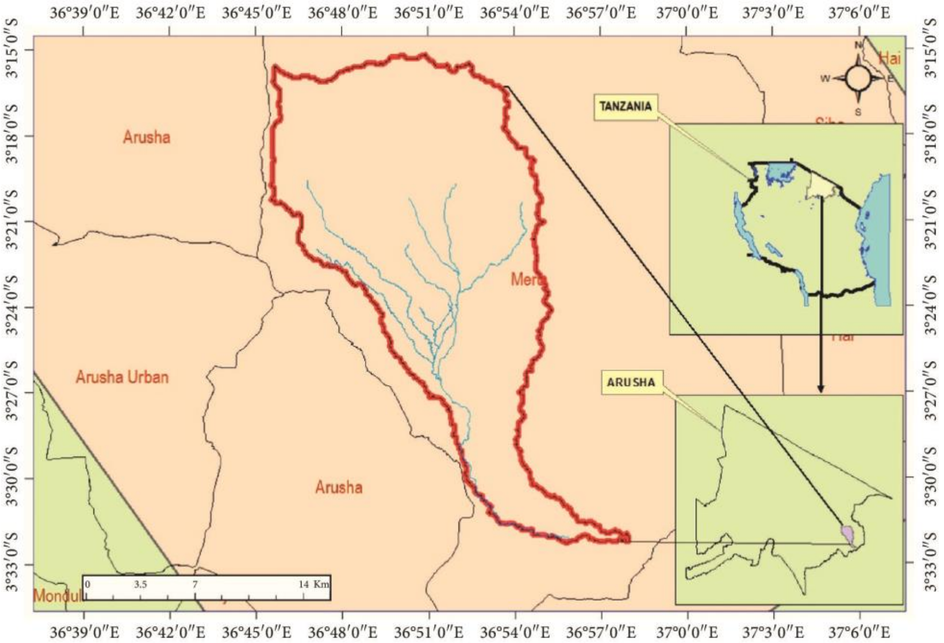

FIGURE 2: Usa river catchment location.

2.1.1. Topography of the Catchment. The topography of the Usa River Catchment is generally characterized by a slightly rolling plain from Mbuguni ward which steepens towards the foot of Meru Mountain where the rivers start. The average elevation is 1100 m above the mean sea level and the slope is dissected by the permanent, perennial, and seasonal rivers. Small springs are found in the middle part of the catchment which also recharges the rivers. The large area of the catchment is exhausted by anthropogenic activities like agriculture, pastoralists, and habitation. The land formation of the catchment is partly rocky, which is covered by the small layer of soil that supports the life of the living things and agricultural activities and partly is fertile soil. Moreover, the northern part of the catchment is where the Arusha National Park is located, which helps to recharge rivers due to the presence of forests. The hydrogeology of the catchment allows underground water movement as a result of recharging the available water resource and the soil reserving moisture for irrigation agriculture. Therefore, the area has great potential for irrigated agriculture due to the market demand for agricultural products to be supplied to the nearby populated City of Arusha.

2.2. Catchment Delineation and Intake Furrow Measurement. The catchment was delineated using ArcSwat Software from the Digital Elevation Model DEM of the area with a resolution of 30 m × 30 m. The Digital Elevation Model was derived from the United States Geological Survey USGS data from 1995 to 2015 (Figure 2). Subsequently, irrigation water intakes (furrows) were located using coordinates taken by Garmin 60s GPS device (Figure 1) from upstream to the downstream followed by water intakes measurement using a current flow meter (SEBA Universal Meter F1 device with propeller 125 mm and pitch 300 mm). Additional data on the amount of water permitted per irrigation scheme was collected from the Pangani Basin Water Board Office (Table 1).

2.3. Conveyance Efficiency Determination. The flow measurement using current meter (SEBA Universal Meter F1 with propeller 125 mm and pitch 300 mm) device as shown in Figure 3 was carried out at every division point of the channel from the intake of the irrigation canal to the fields (Figure 4). The raw data were converted to flow rate (volume) using calibration formulae of the respective current meter impeller used. The difference between the inflow (head) and the outflow (end) of every segment was computed to determine the quantity of water lost in each of the segments as conveyance efficiency (Table 2). Furthermore, distances of one section of the channel were estimated using the GPS set to the distance calculation mode and walk along or near the section. The locations where the water flow measurements were taken at the intake (head), channel junctions (end/head), and the other point along the channel (end) are shown in Figure 4:

$$Q_{\text{Dischargeloss}} = Q_{\text{head}} - Q_{\text{tail}}, \quad (1)$$

Table 1: List of irrigation furrows with measured water abstraction at the intakes and water permits in Sept 2017.

S/N	Furrow name	Permit no.	Quantity permitted (L/s)	Quantity measured (L/s)	% of abstraction	River source	Status intake
1	Shamima	140236	200	189	95	Kikuletwa	With gate
2	Star	140616	68	70	103	Kikuletwa	Without gate
3	Mbukita	140237	200	151	76	Kikuletwa	Without gate
4	Orbuso	2285	200	215	108	Kikuletwa	With gate
5	TPL	3156	280.3	130	46	Kikuletwa	With gate
6	Mapama	140550	300	242	81	Kikuletwa	With gate
7	Kammama	140040	200	204	102	Kikuletwa	With gate
8	Valestika	3727	142.2	130	91	Kikuletwa	Without gate
9	Kipilipili	3151	14.16	147	1038	Kikuletwa	O/gate/repair
10	Kwa Ugoro	4761	113.28	150	132	Kikuletwa	Without gate
11	Dolly/BCW	1765	84.96	224	264	USA	With gate
12	Kaanani	1110055	200	135	68	Malala	Without gate
13	Kitamaka	140014	200	138	69	Malala	With gate
14	Elia	140046	20	69	345	Malala	Without gate
15	Mkindi	140047	100	83	83	Tengeru	with gate
16	Ngolo	14007	100	115	115	Tengeru	Without gate
17	Humalu	11101807	50	55	110	Malala	Without gate
18	Mimako	140191	85	227	267	Tengeru	With gate
19	Furrow No.1	11101545	100	453	453	USA	Without gate
20	Makiba	3143	198.24	373	188	Kikuletwa	Without gate
			2856.14	3500			

Figure 3: Water flow measurement at traditional canal using current meter.

where $Q_{Dischargeloss}$ means quantity of water lost in a channel in L/s, Q_{head} means quantity of water at the head (inflow) in L/s, and Q_{tail} means quantity of water at the end of channel (outflow) L/s.

Discharge loss in percentage ($Q\%$) is as follows:

$$Q_{Loss\%} = \frac{Q_{inflow} - Q_{outflow}}{Q_{inlow}}, \quad (2)$$

where Q_{inflow} is water quantity at the channel head (L/s) and $Q_{outflow}$ is water quantity at the channel tail (L/s).

Conveyance efficiency (E_c) is as follows:

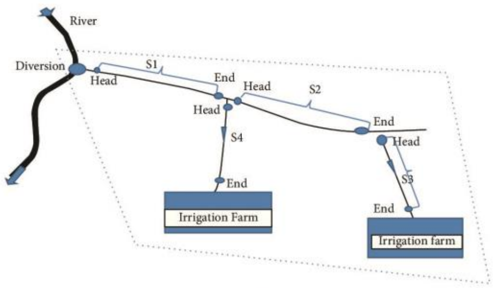

Figure 4: Typical layout of traditional irrigation scheme infrastructure (s = section).

$$E_c = \frac{Q_{outflow}}{Q_{inlow}} \times 100\%. \quad (3)$$

2.4. Crop Water Productivity Determination. In order for the crop plant to grow, water, soil, nutrient, and sunlight in terms of energy are needed. During their growth, plants tend to develop organic matter where in turn dry matter is obtained. During the data collection for crop water productivity, the pieces of lands of 110 m × 95 m, 98 m × 102 m, and 89 m × 90 m size for downstream, midstream, and upstream, respectively, were identified. In our study, maize (*Zea mays* L) crop was selected because it is the staple food. Similarly, the irrigation schedule at every plot was monitored while the amount of water irrigated was measured using current meter and calculated. Subsequently, the produce from each plot was harvested, dried, and then weighed.

Table 2: Conveyances efficiencies.

Furrow name	Canal section	Discharge extracted (L/s) H/section	E/section	Distance (m)	Discharge loss (L/s)	Discharge loss L/s/m	Loss %	Efficiency % (E_c)
Shamima	Section 1	189	105	1902	84	0.044	44.4	55.6
	Section 2	83	53	891	29	0.033	35.5	64.5
Star	Section 1	70	41	1183	29	0.025	41.4	58.6
Mbukita	Section 1	72	53	716	19	0.027	26.4	73.6
Orbuso	Section 1	209	152	3648	57	0.016	27.3	72.7
	Section 2	100.5	98	273	3	0.011	2.5	97.5
TPL	Section 1	153.3	136.1	2251	17	0.008	11.2	88.8
Mapama	Section 1	429	162	3924	267	0.068	62.3	37.7
Kammama	Section 1	223	209	864	13	0.015	6	94
	Section 2	196	161	202	34	0.168	17.5	82.5
	Section 3	81	74	454	7	0.015	8.5	91.5
	Section 4	71	58	1148	13	0.011	18.8	81.2
Valestika	Section 1	152	87	2270	65	0.029	42.8	57.2
	Section 2	48	30	873	18	0.021	37.5	62.5
Kipilipili	Section 1	447	297	2228	150	0.067	33.5	66.5
	Section 2	132	125	262	7	0.027	5	95
	Section 3	54	43.3	1109	11	0.010	20.4	79.6
Kwa Ugoro	Section 1	448	82.5	3128	365	0.117	81.6	18.4
	Section 2	46	26	1781	20	0.011	43.1	56.9
Dolly/BCW	Section 1	257	221.7	1357	35	0.026	13.6	86.4
	Section 2	132	123	898	9	0.010	7.1	92.9
	Section 3	81	27	2546	54	0.021	66.8	33.2
Kaanani	Section 1	198	120.9	1457	77	0.053	38.8	61.2
	Section 2	99	19.7	830	79	0.095	80.1	19.9
Kitamaka	Section 1	41	39	20	2	0.100	4.9	95.1
Elia	Section 1	22	8	672	15	0.022	65.4	34.6
Mkindi	Section 1	37	33.9	345	3	0.009	9.1	90.9
Ngolo	Section 1	143	100	1215	43	0.035	30.1	69.9
Humalu	Section 1	48	40	504.5	8	0.016	16.7	83.3
	Section 2	32	24	69	8	0.116	25	75
Mimako	Section 1	94	90	634	4	0.006	4.4	95.6
	Section 2	58	48	931	10	0.011	17.5	82.5
	Section 3	42	35	463	7	0.015	16.7	83.3
Furrow no. 1	Section 1	440	415	1452	25	0.017	5.7	94.3
	Section 2	335	330	975	5	0.005	1.4	98.6
	Section 3	310	271	1321	39	0.030	12.5	87.5
	Section 4	82	45	531	37	0.070	45.1	54.9
Makiba	Section 1	373	221	846	152	0.180	40.8	59.2
Total					Averages	0.041	28.1	71.9

3. Results

3.1. Field Survey Result. During the field visit observation, twenty (20) furrow intakes were identified in the catchment (Figure 1). A number of furrow intakes were located at midstream and downstream of the catchment. Upstream of the catchment is steep and has small streams that accommodate the irrigation during the dry season.

3.2. Water Flow Measurements

3.2.1. Intakes. Many of the furrow intakes weirs were constructed using stones, sandbags, and tree logs (Figure 5), which do not catch water intended for irrigation and frequent maintenance. However, the weirs are provided for the purpose of directing water to the irrigation scheme and

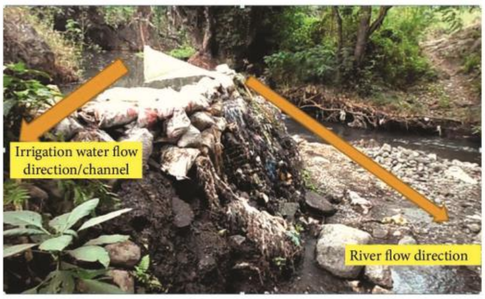

Figure 5: Furrow intake constructed with sand bag/stone/trees logs.

allowing fixing water gates for regulating irrigation water flow to meet the demand of a particular farm or scheme (Figure 6). Moreover, some of the furrow intakes were constructed using reinforced concrete but still do not work to the required form (Figure 6) while others were constructed locally using stones, tree logs, and sand buckets (Figure 5).

Furthermore, water diverted at the intakes was measured to see how much is withdrawn and how much is permitted to abstract (Table 1). Information on water use permit provided and amount of water permitted to abstract was collected from the Pangani Water Office. During the measurement of water flows at the intakes, it was discovered that some of the furrow intakes abstract more water relative to the allocated amount (Table 1).In that fact, water flows at the intakes exceeded the permitted amount because the irrigation water demand of respective scheme is high or because of the issue of regulating structure that controls the amount of water to flow. The issue of monitoring the diverted water to ensure that it complies with water use permit granted to the Water User Association (WUA) is a problem within the catchment. The water irrigation furrow intakes were scattered from upstream to the downstream; however, after the river confluence going downwards there are many accumulated furrow intakes due to favoring landforms and availability of land for farming (Figure 1).

3.2.2. Irrigation Conveyance Infrastructure. The Usa River Catchment irrigation scheme's main canals, secondary, and tertiary were earthen which transport water from the intake to the scheme. The irrigation infrastructure system found in the catchment can be represented in a tree form. The main stem taps water from the soil and transports it to the branches. The branches supply the twigs with water and finally it enters into the leaves, where it will either be used by the plants for growth or be lost into the air through evaporation.

The same can be seen in Usa River Catchment traditional irrigation schemes infrastructure where main/primary canal (stem) taps water from the river and then it is distributed by the smaller secondary canal (branches) to the tertiary canal (twigs), which are smaller, and enters into the fields (Figure 4). According to the study conducted in the catchment, water losses at the canals were on average 0.041 $Ls^{-1}m^{-1}$ (Table 2). Further, traditional irrigation does abstract water from the source after being given water permit and conveys the same using earth canal to the farm. Moreover, the distributing structure like junction, turnout boxes, and the gate valve farmer uses traditional materials like stone, soils/earth, and tree logs.

The same can be seen in Usa River Catchment traditional irrigation schemes infrastructure where main/primary canal (stem) taps water from the river and then it is distributed by the smaller secondary canal (branches) to the tertiary canal (twigs), which are smaller, and enters into the farm (Figure 4). According to the study conducted in the catchment, it is shown that water losses at the canals were on average of 0.041 $Ls^{-1}m^{-1}$ (Table 2). Further, traditional irrigation does

Figure 6: Furrow intake with no river training.

abstract water from the source locally and conveys the same using earth canal to the farm. Moreover, the distributing structure like junction, turnout boxes, and the gate valve farmer uses traditional material like stone, soils/earth, and tree logs

3.3. Water Abstraction Compliances and Distributions. About twenty (20) irrigation furrow intakes are owned by the farmer groups called Water User Associations (WUA). The main objectives of forming Water User Association are to manage sustainably water resource in their area, to educate and advise water uses and productivity, to resolve water conflict, for participatory management of water resource and environment, and to identify new members [9]. Each furrow intake has a management team which is called the furrow committee that is responsible for the distribution and allocation of water to its members during the dry periods. The leaders normally got problems where they were being blamed by irrigators that they do not allocate water equally and fairly. This was revealed after water flow measurement at the intakes where twelve (12) out of twenty (20) furrow intakes, which is equal to 60%, abstract more water relative to the granted permits (Table 1). The data explains that reasons are due to unavailable control and regulating structures or being subject to operational management on water allocation for irrigation in a particular furrow. This is true at the catchment because Water User Association (WUA) called "UWAMAKIJU" committee meets once every week discussing issues of water allocation and distribution, resolving conflict, and coming up with a resolution as per articles of association of "UWAMAKIJU" during the dry season. In this research, an irrigation infrastructure has shown inefficiency of water supply controls at the intake, because the diverted water from the source/intake is higher than the discharged amount to the farm (Table 1).

3.4. Results of Crop Water Productivity. The catchment was divided into three agroecological zones: upstream, midstream, and downstream. In each zone, the crop and water productivity were calculated and showed variation in values. Under normal circumstances, every zone has got its constraints of crop production. Table 3 describes that total volumes of water of 2694.6 m^3, 6190.2 m^3, and 8046.0 m^3 for 1.045 ha, 0.9996 ha, and 0.801 ha at downstream, midstream, and upstream, respectively, were used. Similarly, yields of 1102 kg, 892 kg, and 701 kg, equal to crop productivity of 1054.5 kg/ha (0.41 kg/m^3) , 892.4 kg/ha (0.15 kg/m^3), and 875.2 kg/ha (0.09 kg/m^3), were harvested per season.

4. Discussion

4.1. Water Conveyances, Losses, and Efficiency. The obtained results were analyzed using R-program and found that the correlation between distance and the loss of water in the canal is more significant since the p value is less than 0.05 ($p > 4.61e{-}06$) (Figure 7). As the length of the irrigation channel increases, it escalates the water loss on channel, hence low conveyance efficiency (Figure 8). Subsequently, the relationship of the water losses and efficiency is mutual because when water is lost along the channels, this affects the efficiency of conveyance and vice versa (Figure 9). The phenomena of water losses are caused by temporal channels, earthen traditional canals, and insufficient size to hold a quantity of water, inefficient monitoring, and poor irrigation water management. In practice, farmers need water for irrigation while engineers and economists need the amount of water for irrigation to be realized in terms of technical efficiency and productivity.

4.2. Management of Traditional Irrigation Systems. The poverty alleviation is associated with development of irrigation infrastructure and agricultural water management and promotes welfare of rural community and economic growth by increasing agricultural production and productivity [10, 11]. The farmers cultivate crops based on food and market need, but water is allocated as per schedule agreed. Administrator and policy-makers should insist on good practices and water use efficiency to enhance sustainability of water resource and irrigation agriculture. However, the government policies and international partners in irrigation emphasize water uses efficiencies, good agricultural practice (GAP), and sustainable water practices in irrigation systems by improving infrastructure and introducing new technology in line with irrigation scheduling to "gain efficiency" [12, 13]. Substantial decrease of water from the sources creates pressure on stakeholders and hence raises awareness for irrigation water use. Conveniently, to satisfy the future water demand for irrigation agriculture, infrastructure improvement and water management from source and at the farm field are of vital importance. The fragmented management system and weak involvement of stakeholders exacerbated irrigation water management hence amplifying inefficiency of water resources utilization [14].

4.2.1. Compliances to Permitted Water Quantities. According to the field survey, irrigation agriculture withdraws 3,500 L/s out of a permitted amount of 2856.14 L/s (Table 1); however, catchment consists of several rivers that collect water from the catchment covering an area of 320km^2 having rivers Tengeru, Malala, Maji ya Chai, Usa River, and Kikuletwa. The furrow intakes are distributed throughout the catchment from downstream to the upstream (Figure 1). However, the water abstraction is managed from Basin Water Offices (BWOs) through the water management act of 2009, Section 23 (a)(b), Section 31(2), and National Water Policy 2002 [15, 16]. But the water allocation is a difficult activity because it involves two sides that are water users and policy-makers. However, planning and decision-making are supposed to be participatory, involving all stakeholders stated in the National Water Policy of 2002, Section 3.1 (iv). Different amount of water from the river's source is withdrawn in each furrow during the season of irrigation (Figure 10) and distributed among the members at furrow level. However, the management of water flows at the intakes was inefficient because more water is withdrawn relative to the permitted amount (Table 1). In this research, an irrigation infrastructure has shown inefficient water supply at the intake, because the diverted water from the source/intake is higher than the permitted amount for irrigation due to headworks malfunctioning (Table 1).

Further, abstracting much water from the river source reduces the share of the downstream water user and environmental flow and creates pressure on the catchment. Despite its importance to our lives and irrigation development, water is unevenly distributed in time, space, and quantity and is with great variations in quality. Some areas get more water than they need while others are suffering from water shortage. When there is water scarcity, food security is threatened and production of energy becomes difficult, affecting economic activity, posing a threat to environmental integrity, and creating water conflicts between the water users [17]. The fragmented planning between the water stakeholders aggravates the issue of water resource utilization making it more difficult. Additionally, the balance of water available in the river sources is not well known due to flow variation, recharge capacity which is subject to weather, and unavailable gauging stations. According to the analysis, the linear relationship of the discharge permitted from the water office and the discharge measured at the intake is not significant ($p > 0.05$) (Figure 11). Furthermore, the trend has also shown that as the water office grants more water permits, the enforcement in the water management and water control should be improved.

4.2.2. Management of the Irrigation Infrastructure System. The water supply for irrigation aims to be used for crop production which involves conveying water from the source. Water losses in conveyances reduce water diverted while echoing to increase crop productivity to meet the increasing world population remains a challenge [18]. Using more precise water delivery practices gives water managers more flexibility to deliver water where it is needed and when it is needed [19]. Simultaneously, the scattered schemes and positioning away from the irrigation scheme from the water source are one of the barriers to conveyance efficiency as illustrated in Table 2. Consequently, irrigation water demand

Table 3: Irrigation schedule, hours, water quantity, farm size, and crop water productivity.

Zones	Irrigation schedule	Water (L/s)	Time (hrs)	Volume (m^3)	Size of farm (ha)	Yield (kg)	Water productivity (kg/m^3)	Crop productivity (kg/ha)
Downstream	1	53	3	572.4	1.045			
	2	52	3	561.6	1.045			
	3	45	2.5	405	1.045			
	4	42	4	604.8	1.045			
	5	51	3	550.8	1.045			
	Average	48.6	3.1	2694.6	1.045	1102	0.41	1054.545
Midstream	1	68	5.5	1346.4	0.9996			
	2	57	6	1231.2	0.9996			
	3	58	5	1044	0.9996			
	4	51	4	734.4	0.9996			
	5	53	3	572.4	0.9996			
	6	52	4	748.8	0.9996			
	7	57	2.5	513	0.9996			
	Average	56.6	4.3	6190.2	0.9996	892	0.15	892.357
Upstream	1	47	6	1015.2	0.801			
	2	50	5.5	990	0.801			
	3	47	6	1015.2	0.801			
	4	48	4.5	777.6	0.801			
	5	45	7	1134	0.801			
	6	50	6	1080	0.801			
	7	45	6	972	0.801			
	8	59	5	1062	0.801			
	Average	48.9	5.8	8046.0	0.801	701	0.09	875.156

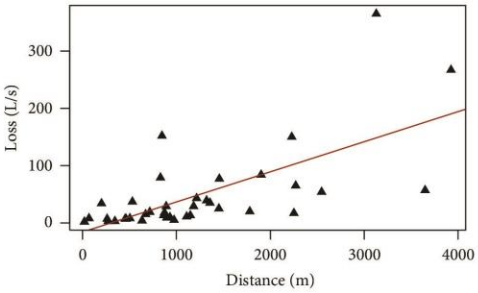

Figure 7: Loss versus distance.

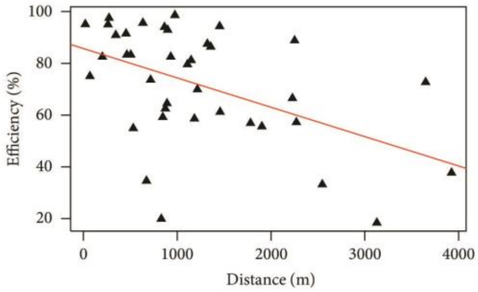

Figure 8: Efficiency versus distance.

is increasing globally over time with population increase, for rising income and changes in dietary preference [20]. Conveniently, to satisfy the future water demand for irrigation agriculture, infrastructure improvement and water management from source to farm field are of vital importance. Eventually, more than 850 million out of more than 1 billion are the rural poor people living on less than 1$ a day depending on irrigation agriculture [11]. In the context of agroecological zones, the water competition is increasing across due to demand changes caused by population increase and climate change effect [21]. Much of the investment is needed to improve and adapt existing irrigation infrastructure systems in areas already very reliant on intensively irrigated agriculture [22] that run from upstream to the downstream across an agroecological zone of the catchment. Investing in irrigation agriculture and water management is very important because of the debate on climate change, population growth, and food security [23]. The sustainability of irrigation agriculture in terms of irrigation water supply for food production and environment uses in a catchment in question needs reliable irrigation headwork, proper and modern conveyances, application efficiency in the field, and water management enforcement. Further, access to irrigation infrastructure reduces the incidence of poverty, and upgrading watercourse saves water which results in higher cropping intensity, higher crop productivity, greater food security, and improved farm incomes [23].

4.2.3. Water Use and Crop Water Productivity. Table 3 indicates that amount of water applied for irrigation was 2694.6 m^3, 6190.2 m^3, and 8046.0 m^3 with yield of 1054.5 kg/ha (0.41 kg/m^3), 892.4 kg/ha(0.15 kg/m^3), and 875.2 kg/ha (0.09 kg/m^3) at downstream, midstream, and

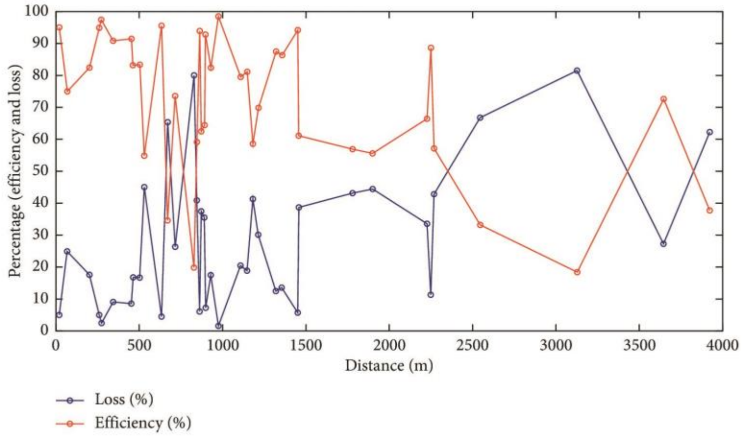

FIGURE 9: Efficiency-loss against distance.

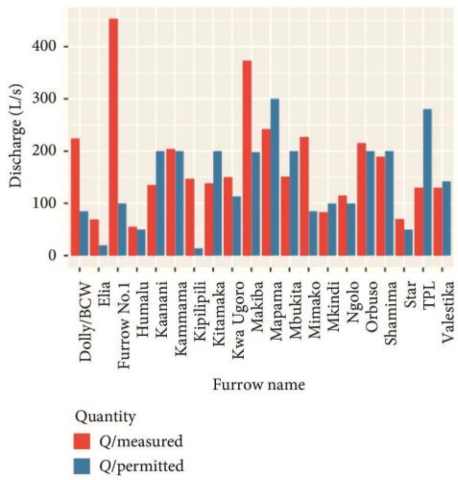

FIGURE 10: Quantity permitted and measured.

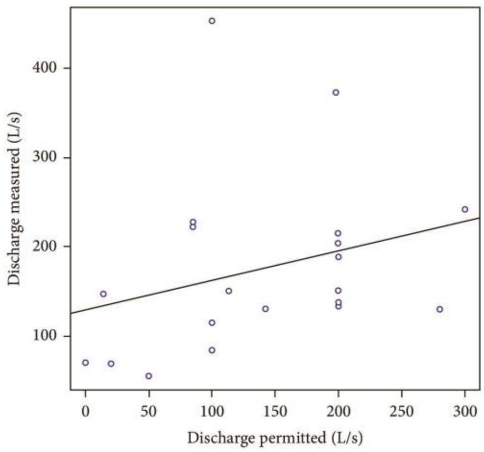

FIGURE 11: Analysis of discharge measured versus permitted.

upstream, respectively, in one season; however an average conveyance efficiency is 72%. At the crop level, water productivity (WP) can be defined as the ratio of biomass with economic value (for example, grain yield of cereals) over amount of water transpired (WPt) [24]. Moreover, Kijne et al. [25] defined water productivity (WP) as a measure of the ability of agricultural systems to convert water into food. Similarly, Cook et al. [26] also defined as measure of output from a given agricultural system in relation to water it consumes, which can be measured in portion or entire system. Based on the review done by Zwart and Bastiaanssen [27] and Yazar et al. [28], globally crop water productivity for maize (*Zea mays* L) ranges from 1.1 kg/m^3 to 2.7 kg/m^3 while in this research, it ranges from 0.09 kg/m^3 to 0.41 kg/m^3. Furthermore, in the field experimental research on traditional irrigation scheme by Igbadun et al. [29], the crop water productivity of maize (*Zea mays* L) at Mkonji Subcatchment of Great Ruaha River Basin obtained ranges from 0.40kg/m^3 to 0.55 kg/m^3 for the applied water. Following the results of our research and the other researchers regarding the CWP, traditional irrigation schemes have low crop water productivity, which therefore needs improvement in irrigation water management, traditional infrastructure, and water application in the field.

5. Conclusion and Recommendations

The traditional irrigation system in the catchment needs improvements of water utilization for easy and sustainable management of water for irrigation and enhanced agricultural crop productivity. The proper and designed infrastructure of the irrigation schemes contributes to reliable water allocation and efficient water supply to the destined command area. However, Usa River Catchment (URC) traditional irrigation schemes infrastructure system contains various constraints at the institutional and local level of utilization of this scarce water resource. These include water allocation, distribution, irrigation scheduling and maintenance of water channel, weak stakeholders involvement, and indifference in local and central administration. The provision of these administrative infrastructures and agronomy in the system will improve the provision of irrigation water supply services in the catchment which will be reliable and efficient. This measure will bring a positive effect to the irrigation water supply and allocation in the basins' irrigation schemes. Subsequently, water flow measurement structures are also needed to ascertain the quantity of water committed to the scheme by water office. Furthermore, land for irrigation should be monitored by keeping the farm size at a selected fertile area so that water could not be lost unnecessarily in irrigation conveyances and at farm field applications. This is important for the catchment to utilize the water resource in irrigated agriculture, water for environmental flows, and ecosystem uses by providing basin water resource management plan based on water balance, water demand, and requirement of the reserve [16]. Similarly, controlling water abstraction from the sources and illegal water abstraction as stipulated in the water policy of 2002 and the water resource management act of 2009 [16] should be enforced. Besides, the new technology of irrigation system should be introduced in the catchment for sustainability of agricultural irrigation and water resource utilization. Similarly, irrigators' involvement in water management and advising them on high value crop cultivation, water serving irrigation practices, and perpetual water flow measurement for records and decision-making on water allocation at scheme level up to the water office and decision-makers is of great importance.

Data Availability

The data can be made available upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding this paper.

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Poster presentation