# SUITABILITY ASSESSMENT OF EFFLUENTS FROM MWEA IRRIGATION SCHEME FOR REUSE IN IRRIGATION FOR RICE PRODUCTION, KIRINYAGA COUNTY, KENYA

**BY**

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## DECLARATION

I Josephine Nyabonyi Onderi declare that this thesis is my original work and has not been presented for the award of a degree in any other university or any other award.

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## DEDICATION

This document is dedicated to the millions of irrigators whose water shortages it seeks to address. To the policy makers who are involved in irrigation activities. To my beloved family members who endured the pain of my inadequate attention during this study. May our good Lord bless you and keep you long enough to see and enjoy the fruits of this study.

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# TABLE OF CONTENTS

# LIST OF TABLES

## LIST OF FIGURES

## LIST OF PLATES

## ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| **ANOVA** | Analysis of Variance |
| **ARM** | Agricultural Resource Management |
| **DWAF** | Department of Water Affairs and Forestry |
| **EMCR** | Environment Management and Co-Ordination (Water Quality) Regulations, 2006 |
| **ESP** | Exchangeable Sodium Percentage |
| **FAO** | Food and Agricultural Organization |
| **$FeSO_4$** | Ferrous sulphate |
| **GOK** | Government of Kenya |
| **Ha** | Hectares |
| **$H_2SO_4$** | Sulphuric Acid |
| **KALRO** | Kenya Agricultural & Livestock Research Organization |
| **KG** | Kilograms |
| **MAID** | Mwea Irrigation Agricultural Development |
| **Mg/L** | Milligrams per liter |
| **MIS** | Mwea Irrigation Scheme |
| **MOA** | Ministry Of Agriculture |
| **NARL** | National Agricultural Research Laboratories |
| **NWQMS** | National Water Quality Management Strategy (2012-2016) |
| **NIB** | National Irrigation Board, |
| **NRDS** | National Rice Development Strategy |
| **SAR** | Sodium Adsorption Ratio |
| **T** | Tones |
| **TDS** | Total dissolved solids |
| **TSS** | Total suspended solids |
| **WRMA** | Water Resources Management Authority |
| **WUA** | Water Users Association |

## ABSTRACT

Declining quantity and quality of irrigation water are serious challenges facing rice production in Mwea irrigation scheme. As such the aim of this study was to assess the suitability of effluents from the scheme for recycling for the same irrigation purpose within the scheme and areas down stream. Water from River Thiba intake (point 1) and waste water from Kiruara drain (point 2) and Thiba main drain (point 3) were sampled and analyzed for quality parameters thus:- pH, Electrical conductivity (EC), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Calcium, Magnesium, Sodium, Potassium, Bicarbonates and Nitrates. The results were used to compute Sodium Adsorption Ratio (SAR) and further compared to FAO irrigation water quality standards. Also soil samples from three fields adjacent to the water sampling points were analyzed for pH, EC, total organic carbon, total nitrogen, sodium, phosphorus, potassium, magnesium and calcium. In addition, a survey was conducted to obtain the socio-economic aspects of the rice farmers of the scheme. The results indicated that water and wastewater from all the three study sites were suitable for irrigated rice production based on FAO recommended standards of irrigation water. Wastewater recorded a positive progressive gain in all the parameters tested as point 1< point 2< point 3 for Ca, EC, TDS, TSS, Na, K and $HCO_3$ which were statistically significant ($p<0.05$). 88.3% of Mwea Irrigation Scheme farmers experienced water shortage during paddy rice production. It was also observed that already 51.5% of Mwea Irrigation Scheme farmers recycled wastewater/effluents from paddy fields and 50% of those who had not used wastewater said it was not available. The highest production was obtained from Karaba section with a mean of 27.9 bags of paddy rice /acre and farmers attributed this to the use of “enriched irrigation water.” Zinc and potassium were found to be too low in all the three soil samples tested but soil samples from the wastewater reuse site recorded gains in nitrogen and phosphorus indicating a deposition via wastewater. Though Nitrate concentrations in the three study sites were not significantly different ($p>0.05$), they were above 5mg/l which may cause damage to N sensitive plants and eutrophication in the receiving water masses. Also soil phosphorous levels of 30ppm at site 3 implies that farmers using wastewater at and beyond the Prison farm can do one rice season without applying P fertilizers hence a saving for them. Therefore, there is need for alternative disposal of these nutrient rich effluents and the best way is by recycling so as to; save the water masses downstream from eutrophication and growth of aquatic weeds, reduce cost of N fertilizers and obtain more water for expanding rice fields to increase rice outputs and reduce imports.

# CHAPTER ONE: INTRODUCTION

## 1.1 Background Information

Water, comprising over 70% of the earth's surface is undoubtedly the most precious natural resource (Nkwonta and Ochieng, 2009). On the global scene, agriculture accounts for 70% of water consumption (Ngaira, 2009). According to Ndiiri *et al*., (2012), "Rice is the greatest consumer of water among all crops, and it uses about 80% of the total irrigated fresh water resources." Bera (2009); Mishra (2009); Thakur, Rath and Patil, (2011) concur that this crop is the largest consumer of water in the agricultural sector.

Rice is one of the most important staple foods for over half the world's total population ranking third after wheat and maize in terms of production and consumption (Akinbile *et al*., 2011). According to Mati *et al*.,(2011), MOA (2010), and Muhunyu (2012), "Rice is the most important cereal crop after maize and wheat and its annual national consumption is increasing at the rate of 12% as compared to 4% for wheat and 1% for maize."

Studies carried out by Mati *et al.*, (2011); Mishra, (2009) and Ndiiri *et al*., (2012) reveal that as a result of urbanization, the demand for rice has shifted upwards worldwide because people have changed their eating habits. Onyango (2014) reported that due to population growth of about 4% per annum in Sub Saharan Africa, rising incomes and a shift in consumer preference in favor of rice, especially in urban areas, the relative growth in demand for rice is faster in the region than anywhere else in the world. He further says that due to the growing importance of the crop and growing challenges of attainment of food security, it has been estimated that the annual rice production needs to increase from 586 million metric tons in 2001 to meet the projected global demand of about 756 million metric tons by 2030. In Kenya, annual rice consumption stands at 548,000 tons against a production of 83,850tons (NRDS 2008-2018) resulting into increased imports of rice as shown in Table 1.1

**Table 1.1: Rice Production 2007 - 2013**

| Year | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|---|---|
| Area under rice (Ha) | 15,961 | 18,329 | 20,050 | 23,904 | 28,034 | 30,095 | 30,717 |
| Production(Paddy) Tonnes | 62,479 | 52,025 | 54,955 | 85,536 | 111,229 | 126,399 | 129,000 |
| Production(Milled) Tonnes | 40,611 | 33,816 | 35,721 | 55,598 | 72,299 | 82,159 | 83,850 |
| Unit price (per ton) | 53,000 | 59,985 | 68,282 | 57,892 | 62,558 | 73,888 | 85,000 |
| Average yield (t/ha) | 2.8 | 2.9 | 2.7 | 3.6 | 4.3 | 4.4 | 4.3 |
| Consumption(tonnes) | 293,722 | 300,000 | 343,045 | 410,000 | 520,000 | 540,000 | 548,000 |
| Import (tonnes) | - | 266,315 | 307,330 | 354,385 | 447,658 | 462,860 | 464,150 |
| Total Value (Billion KES for prod.) | 2.2 | 2.0 | 2.4 | 3.2 | 4.5 | 6.1 | 7.1 |
| World Production(Million Tons) | 440.3 | 459.5 | 456.4 | 470.1 | 486.4 | 491.2 | 496.9 |
| World Consumption(Million Tons) | 345.4 | 353.6 | 354.6 | 461.7 | 470.6 | 478.3 | 490.2 |

**Source**: National Rice Development Strategy (2008-2018), Revised Edition 2014

Muhunyu (2012) graphically highlighted trends of rice production, consumption and import in Kenya as shown in Figure 1.1 below.

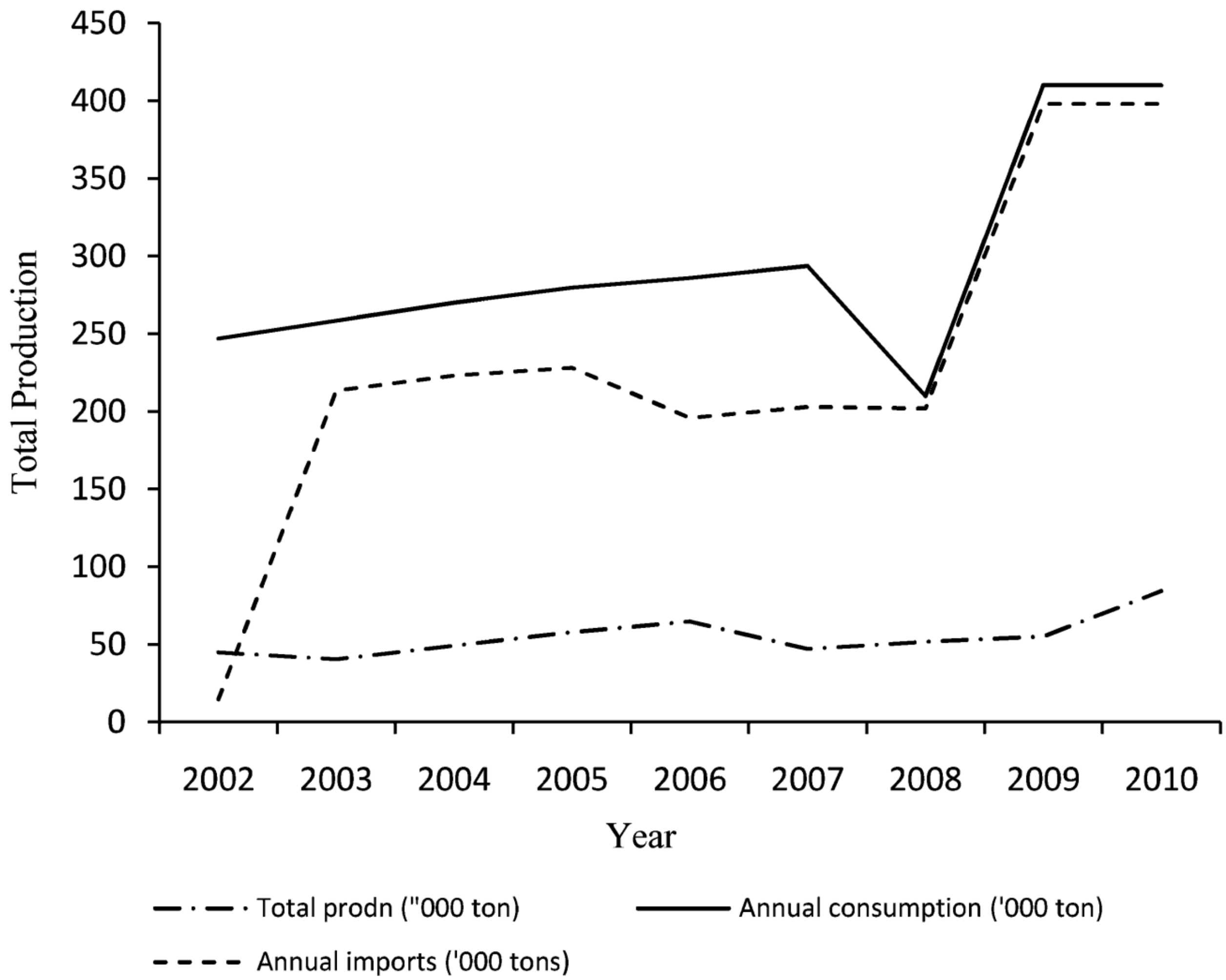


**Figure 1.1: Rice production, consumption and import trends in Kenya (Muhunyu, 2012)**

To reduce on these rice imports, there is need to increase rice production. Muhunyu (2012) stated that "There is a high potential for expansion of irrigable area in Kenya and about 400,000 ha are suitable for rice production." In order to increase acreage under rice, more water is needed and effluent recycling from irrigation fields will increase water availability for irrigation. Muhunyu further says that another 1 million acres can be used for rain-fed rice production.

Studies conducted in various parts of the world reveal that waste water has been used for long, for example:- Waste water of the city of Braunschweig has been re-used since 1896 and in 1996 there were 41 sites in Germany irrigated with domestic waste water and 33 sites with industrial waste water (Kretschmer, Ribbe and Gaese, 2002); Untreated waste water of about $75m^3/s$ and the raw sewage of Mexico City are used to irrigate 85,000 ha of agricultural land in the neighboring state of Hidalgo (Kretschmer *et al.*, 2002); In Sharjah, United Arab Emirates, the recycled waste water is used for landscape and horticultural irrigation (Cooper, 2001) and in Belgium, a food processing industry which freezes locally grown garden market products has recycled all its wastewater by irrigating 550 ha of crops located around the factory. In Kenya, a study conducted in Nairobi in 2006 and 2007, over 720 ha were reported to be under irrigation using sewage effluent (Githuku, 2009).

In Mwea Irrigation Scheme (MIS), irrigation activities are expanding amid declining water availability and fluctuating river discharges. Also, most distribution canals are not lined resulting to seepage and, the paddy fields are not uniform (not level) thus suffer from leakages. Field observations revealed that most of the paddy fields are irrigated through farm to farm system (Plate 4.3) and that some wastewaters draining from one paddy field or block flows back into the main canal for reuse downstream at specific reuse areas (Appendix 6).

**1.2 Statement of the Problem**

Annual rice consumption in Kenya is increasing at the rate of 12% (Muhunyu, 2012 and Onyango, 2014). This has necessitated expansion in acreage under rice production for both rain-fed and irrigated rice so as to produce and supply more rice locally to reduce on the quantities of imported rice.

Though production of rain-fed rice (NERICA) has been recommended in the efforts of bridging the gap between production and imports of rice, irrigated rice is still preferred in Mwea irrigation scheme. All respondents sampled in this study grow Basmati (Pishori) for its high quality. None of the 163 respondents grew the rain-fed (NERICA) rice.

In Mwea irrigation scheme, water shortage has been identified as the biggest challenge to paddy rice production. A study conducted by Muhunyu (2012), revealed that 85 % of the farmers interviewed mentioned water shortages as the biggest challenge hindering expansion of irrigable land hence less rice production. This compares well with the current study where 88.3% of the farmers interviewed reported experiencing water shortage during rice production. Field observations revealed that water shortages have necessitated the use of wastewater/effluent draining from other paddy fields and in drainage canals for rice production.

The use of chemical fertilizers for crop production is very popular in MIS yet studies show that use of nitrogenous fertilizers in rice farming has a potential of causing eutrophication of aquatic systems (Tongkasame, 2007), as was observed in Mwea Irrigation Scheme (Plate 4.5) and, use of Ammonium Sulfate fertilizer acidifies soils and may cause calcium ion losses leading to deflocculated soils (Afullo, 2009). In this study, all farmers interviewed reported using one type of fertilizer or another hence the need to check the quality of effluents from the scheme. Also declining quality of irrigation water due to pollution and use of irrigation effluents can lead to degradation of physical, chemical and biological properties of soil.

Though wastewater is being used in many parts of the world, not much information is available on the suitability of MIS effluent for recycling, hence the aim of this study was to assess whether the effluent could be actually suitable for irrigation to increase on the amount of water available for irrigation and, to solve the twin environmental catastrophes of eutrophication of aquatic systems and deflocculation of irrigated soils Afullo (2009). Afullo further states that “whereas the current irrigation has the potential to cause eutrophication of aquatic systems and deflocculation of irrigated soils, the effluent, from a theoretical perspective, is capable of solving these challenges through recycling.”

## 1.3 Research Objectives

### 1.3.1 Broad Objective:

The broad objective of this study was to assess the suitability of effluents from Mwea Irrigation scheme for re-use in rice irrigation so as to reduce the problems of water shortages and environmental degradation.

### 1.3.2 Specific Objectives

The specific objectives of this study were:-

i. To assess farmers' awareness on the effects of the quality of irrigation water on rice production.
ii. To analyze Mwea irrigation scheme's water at source (River Thiba) and its irrigation effluents (Kiruara Drain and Thiba Main Drain).
iii. To assess suitability of the Mwea irrigation scheme effluents for reuse in irrigation in relation to FAO recommendations.
iv. To determine the effect of effluent irrigation water on the quality of soil and rice yields.

## 1.4 Research Hypotheses

The following research hypotheses were proposed:-

i. Farmers in Mwea irrigation scheme are not aware of the effects of the quality of irrigation water on rice production.
ii. The physico-chemical quality of River Thiba waters and Mwea irrigation scheme effluents do not differ.
iii. The quality of Mwea irrigation scheme effluents is not suitable for reuse in irrigation.
iv. Reuse of Mwea irrigation scheme effluents has no negative effects on the soil and rice yields.

## 1.5 Justification and Importance of the Study

Just like in other parts of Kenya, the paddy system of flooded rice production is the predominant method of growing rice in Mwea irrigation scheme (Mati *et al.*, 2011). Cultivation of paddy rice requires a continuous supply of water (GOK. 2008; Ndiiri *et* *al.*, 2012). Since acreage under rice production has been, and, is still increasing (Wendot, 2014; personal communication), there is need to conserve the diminishing fresh water resources by better management and improved utilization. One of the ways of improving utilization of the scarce water is through recycling of waste water from MIS paddy fields (Owilla, 2010- unpublished).

Mwea irrigation scheme is the largest scheme in Kenya with a total gazetted potential area of 30,350 acres of which only 16000 acres are under rice production (Muhunyu, 2012). Since the scheme produces 86% of the total rice produced in Kenya, improving its production will ensure food security in the country thus achieving of the Millennium Development Goals and Vision 2030.

As much as the scheme is striving to expand the acreage under rice production, water is one of the biggest challenges. Therefore, use of its effluents will contribute towards increasing the amount of water available for irrigation. However, the quality of this effluent is not fully documented hence the need to assess its suitability for irrigation in this study.

The information generated from this study is to help inform the stakeholders (farmers, scheme management, researchers, scholars and extension officers) on the quality of MIS effluent and its role in irrigation as the scheme strives to increase its rice production. It is also to assist policy makers to come up with clear guidelines and strategy on its use. The outcome of the study would add knowledge to previous studies on the use of wastewater for agriculture. The expected increase in rice production would help achieve the country's national macroeconomic development objectives of poverty alleviation, food security, employment creation and industrialization.

## 1.6 Conceptual Framework.

Global production of paddy rice is hampered by scarcity of water needed for irrigation. Further, irrigation effluents from rice fields may be polluted producing poor quality water unsuitable for neither recycling nor other uses. Such polluted effluents result into environmental degradation and declined socio-economic status of the farming community. On the other hand if the effluents can be reused, there will be more water for MIS leading to increased rice production, reduced environmental degradation and improved socio-economic conditions of farmers as shown in Figure 1.2 below.

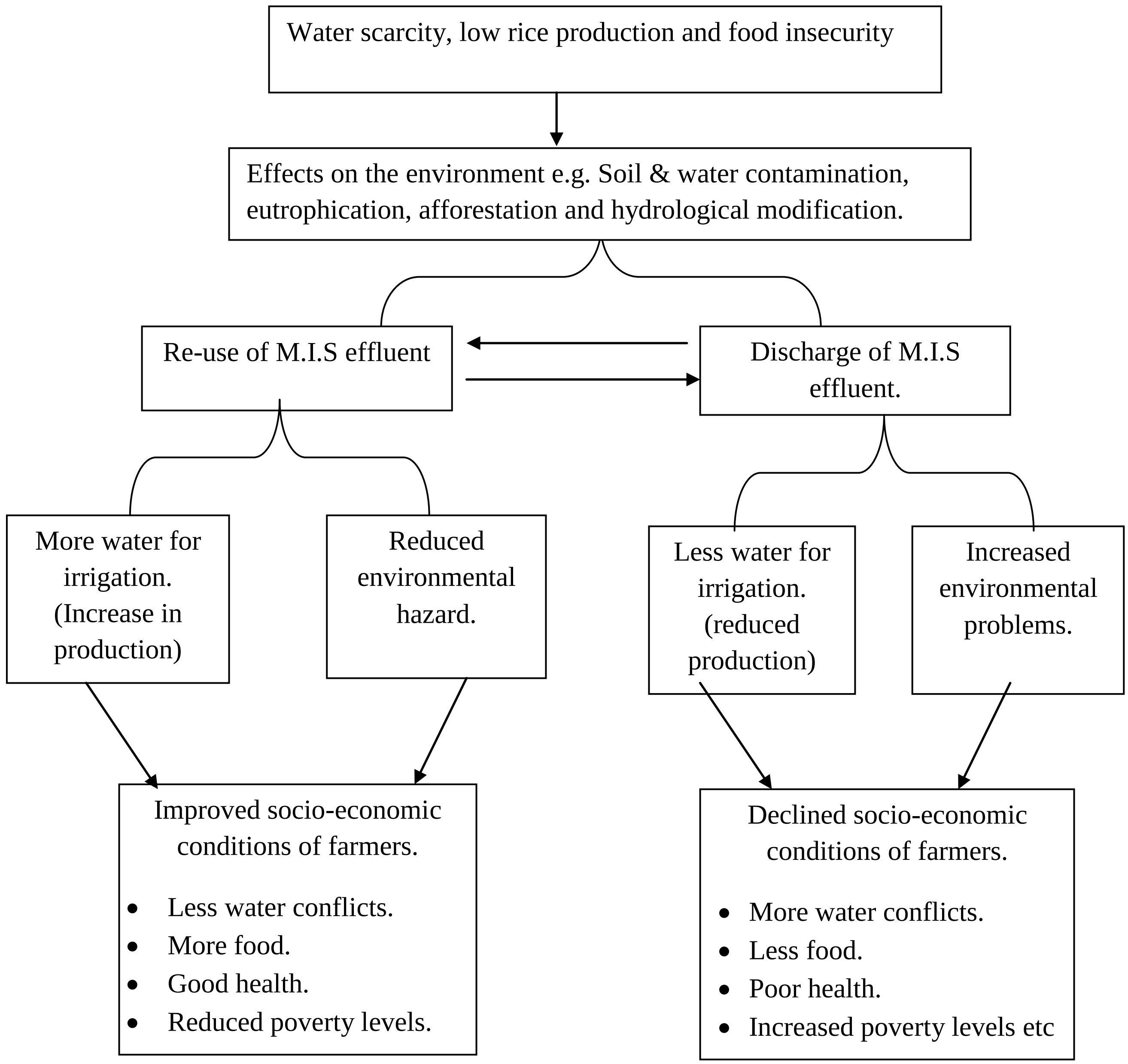


**Figure 1.2: Conceptual Framework**

## 1.7 Scope and Limitations of the Study

### 1.7.1: Scope of the Study

The study was confined to the flood-irrigated rice cultivation in the 5sections of the nucleus region of the scheme namely:- Tebere, Mwea, Thiba, Wamumu and Karaba and, 2 out -grower sections namely Curukia and Kiamanyeki. The nucleus part of the scheme is served with well laid down infrastructures such as feeder roads, irrigation canals, drainage canals and water control gates while most farms in out grower sections lack these infrastructures and receive irrigation water from the neighboring plots (waste water) at irregular intervals.

### 1.7.2: Limitations of the Study

Inadequate funds limited the number of variables and samples taken during this study. The study was also further limited by inadequacy of published literature on irrigation in Kenya. It was also not easy to establish water use efficiency due to various losses through the conveyance and application systems hence difficult to precisely establish the quantity of effluents since there were no measuring tools at the exit. Also Thiba main drain empties its water into river Thiba at a dangerous point where one cannot stand for long trying to take measurements due to the fear of attack by the crocodiles.

## 1.8 Definition of Terms

**Waste water**: This refers to effluent; Water mixed with waste matter; it also refers to water discarded as waste after it has been used for economic or beneficial purpose. Once freshwater has been used for an economic or beneficial purpose, it is generally discarded as waste. In Mwea irrigation scheme wastewater draining from one paddy field or block is discarded into drainage canals as effluent since it has already finished its economic work of irrigating that particular paddy or block. In many countries, these wastewaters are discharged, either as untreated waste or as treated effluent into natural watercourses, from which they are abstracted for further use after undergoing "self-purification" within the stream.

**Recycling**: Recycling means to extract and re use; recovering useful materials from garbage (www.footprint.com/effluent-re-use). It is a process of exchanging a material (waste) to new products to prevent waste of potentially useful material, reduce consumption of fresh raw materials, reduce pollution and reduce the need for conventional waste disposal. In Mwea irrigation scheme, wastewater draining from one paddy field or block is at times reused to irrigate another paddy field or block thus recycling.

**Water pollution**: This refers to contamination of water bodies. Polluted water refers to water that is not safe and not healthy for people and animals to drink or to wash in. It is particularly dangerous to both plants and animals. Effluent rich in nutrients especially nitrates from Mwea irrigation scheme causes growth of aquatic weeds in drainage canals (Plate 4.5) and is likely to cause eutrophication in the receiving water masses.

**Water quality**: This refers to characteristics of a water supply that will influence its suitability for a specific use (Ayers and Westcot, 1985) that is, how well the quality meets the user's need. In this study, water quality refers to how well the effluents from Mwea irrigation scheme are suitable for rice growing.

**Eutrophication**: Is defined as an increase in the nutrient status of natural waters that causes accelerated growth of algae or water plants, depletion of dissolved oxygen, increased turbidity and general degradation of water quality (Pierzynski et al., 1994).

**Total dissolved Solids**: This is a measure of all the total amount of mobile charged ions, including minerals, salts or metals dissolved in a given volume of water, expressed in units of mg per unit volume of water (mg/L).

**Total suspended Solids**: These solids include all the suspended particles in water which do not pass through a filter, a water quality parameter used to assess the quality of wastewater after treatment.

# CHAPTER TWO: LITERATURE REVIEW

## 2.1 Introduction.

The chapter gives an overview of what other researchers have studied in relation to water reclamation and reuse. Section 2.2 gives an overview of global water crisis, 2.3 gives an overview on waste water reuse, 2.4 highlights what has necessitated waste water reuse, 2.5 is about restrictions on waste water reuse and its general acceptability, 2.6 discusses the water quality (standards & monitoring) and section 2.7 highlights the risks associated with waste water reuse.

## 2.2 An Overview on the Global Water Crisis

At the beginning of the 21$^{st}$ century, the earth with a population of over 6 billion humans and other forms of life is facing a serious water crisis (WWAP, 2003). In a study conducted by Srinivasan *et al.,* (2012), freshwater scarcity and security have been cited as the major crisis as well as global environmental problems of the 21$^{st}$ century.

Studies conducted by Bigas (Ed.), (2012) and Rogers, (2004), reported that water scarcity is becoming a major issue in our planet and the main causes of this are:- Global climate change; rapid population and economic growth; increased demands for irrigation water; increased demands for urban water; trans-boundary conflicts; competitions between sectors such as agriculture, industry and energy and, matters relating to environmental protection or some combinations of the above. Heakstra and Mekonnen (2011), also concur that the earth’s freshwater resources are subject to increasing pressure in the form of consumptive water use and pollution.

Previous studies show that one billion people on earth are without reliable water supplies, over two billion people lack basic sanitation and, many places particularly in Sub-Saharan Africa or West Asia and North Africa are already facing critical water shortage (Bigas, Ed., 2012). UNEP (2008) reported that today, 31 countries accounting for less than 8% of the world's population face chronic water shortages and that by 2050, the number of countries facing water stress or scarcity could rise to 54 with a combined population of 4 billion people. UNEP further reports that among the countries likely to run short of water in the next 25 years are Ethiopia, India, Kenya, Nigeria and Peru

On the global scene, agriculture accounts for 70% of the water consumption (Ngaira,2009), and this withdrawal is expected to increase by another 14% in the next 30 years since developing countries will continue exploiting their irrigation potential to feed their growing populations (WWAP, 2003). WWAP further reports that by 2030, 60% of all land with irrigation potential will be in use.

Rice is the greatest consumer of water among all crops utilizing about 80% of the total irrigated freshwater resources (Ndiiri *et al.*,2012). 1kg of rice requires a minimum of 1.2$m^3$ compared to 1$m^3$ required to produce 1kg of wheat. Akinbile *et al.*, (2011), reported that irrigated rice was responsible for about 75% of the world's total rice production meaning that as freshwater becomes increasingly scarce, the demand for available water from urban and industrial sectors is likely to receive priority over irrigation hence less water for irrigating rice fields.

Kenya is a water deficit country since she has water resource availability of only $595m^3$per capita which is well below the recommended global annual water poverty line of $1000m^3$ per capita (Owilla, 2010), meaning that the country has an annual water poverty or deficit of $405m^3$ per capita. Owilla also reported that this is expected to fall further to $250m^3$ by the year 2025 similar to the anticipated trends in the Sub-Saharan Africa .Though Kenya is a water deficit country, physically, it is not water stressed but, is an economic water scarce country whereby human, institutional and financial capital limits access to water even though water in nature is available locally to meet human demands (WWAP, 2016).

## 2.3 Waste Water Reuse

Wastewater reuse is not a recent invention and has evolved over the years (Table 2.1). There are indicators that wastewater was used for irrigation back in ancient Greece and in Minoan Civilization (3000-1000 BC) (Angelakis *et al.,* 1999). Sanchez (1988) reported that irrigation using raw sewage in the Mezquital Valley of the Tuala River basin begun in 1886. Shuval *et al.* (1996) concur that effluent irrigation has been practiced for centuries throughout the world. For Hogg *et al* (1997), "Effluent re-use is a well established practice in the Prairie region with approximately 65 projects irrigating a total of 5700 ha.'' Also Friedler, (1999) noted that waste water reuse was pioneered in the Jeezrael Valley, Israel and irrigation with reclaimed effluent is being performed in Israel for more than 30 years. Today in the European Union, waste water re use is practiced predominantly in arid regions like Greece, Spain and Italy. Israel, Jordan and Tunis are among the leading countries in waste water re use (Kretschmer *et al*., 2002).

In Kenya, a study conducted by Kimani *et al*. (2009) revealed that formal recycling of wastewater for crop production is hardly practiced despite the periodic droughts, its high plant nutrient contents and its utilization in other parts of the world. However, illegal use of raw wastewater for vegetable production despite dangers of fecal pathogens contamination has been observed in major urban centers such as Nairobi and Nakuru where substantial amount of wastewater is produced and, that the practice is especially common during the dry seasons when vegetables produced through rain fed agriculture are least available (Kimani *et al*., 2009).

In Mwea irrigation Scheme, effluent draining from paddy fields is at some points drained into influent canals and reused to irrigate other paddy fields (Appendix 6). In this study, 51.5% of the paddy farmers interviewed reported using wastewater from neighbor’s fields and from drainage canals to grow their rice but, the quality of this effluent is not known hence the need for this study.

**Table 2.1: Historic and milestone events related to the evolution of water reclamation & reuse.**

| PERIOD | LOCATION | EVENTS |
|---|---|---|
| 3000 BC | Crete, Greece | Minoan civilization: use of waste water for agricultural irrigation |
| 97 AD | Rome, Italy | The city of Rome has a water supply commissioner, Sexus Julius Frontinus. |
| 1500- | Germany | Sewage farms are used for waste water disposal. |
| 1700- | United Kingdom | Sewage farms are used for waste water disposal. |
| 1890 | Mexico City | Drainage canals are built to take untreated waste water to irrigate an important agricultural area North of the city, a practice that still continues today. Untreated or minimally treated waste water from Mexico city is delivered to the valley of Mexico where it is used to irrigate 90000 Ha. Of agricultural lands including vegetables. |
| 1926 | United States | In Grand Canyon National Park, treated waste water is first used in a dual water system for toilet flushing, lawn sprinkling, cooling water and boiler feed water. |
| 1929 | United States | The city of Pomona, CA initiated a project utilizing reclaimed water for irrigation of lawns and gardens. |
| 1932-1985 | San Fransisco, CA | Treated waste water is used for watering lawns and supplying ornamental lakes in Golden Gate Park and continued with better quality effluent. |

Modified from: Levine, Leverenz and Asano, (1994)

## 2.4 Drivers of Waste Water Re-Use

Scarcity of conventional sources of water in arid and semi arid regions of the world has been behind the movement to find alternative or additional sources of water, some of the possible ones being deep ground water, treated wastewater and brackish water. ‘‘Shortage of water is the main driving force for conservation of water realized through pricing reforms, waste water treatment technologies and waste water reuse'' (Kretschmer *et al*., 2002).

Waste water is a source of plant nutrients. Obuobie *et al*., (2006) noted that waste water can be an important water and nutrient source that may bring about improvements in health by improving socio-economic conditions of farmers and their families.

"Generally speaking, wastewater (treated and untreated) is extensively used in agriculture because it is a rich source of nutrients and provides all the moisture necessary for crop growth. Most crops give higher than potential yields with wastewater irrigation, reduce the need for chemical fertilizers, resulting in net cost savings to farmers" (Hussein *et al*., 2002). Also From an economic viewpoint, wastewater irrigation of crops under proper agronomic and water management practices may provide the following benefits: (1) higher yields, (2) additional water for irrigation, and (3) value of fertilizer saved (Hussein *et al*., 2002 and Singh, 2012).

In their study, Ramirez *et al*., (2002) reported that organic carbon, total nitrogen, microbial biomass C and N and, microbial activities increased with increase in the time duration of waste water irrigation.

Waste water has also been used for irrigation so as to safeguard the environment against pollution. For example, Asano (1998) reported that during 1950-1960, interests in applying wastewater on land in the Western hemisphere as wastewater treatment technologies advanced and application became a cost-effective alternative of discharging effluent into surface water bodies. Kretschmer *et al*., (2002) noted that Belgium has no water scarcity problem but is recycling waste water from a food processing industry by irrigating 550ha of crops located around the factory as a way of solving water quality issues. Therefore with appropriate design, the expanded effluent re-use could reduce or eliminate undesirable discharges to natural water ways.

Effluent irrigation can make a significant contribution to reducing water demand, improving soil condition and reducing the amount of pollutant discharged into our waterways provided it is managed to protect the environment and public health.

(www.environment.nsw.gon.an/water/effluent.htm).

## 2.5 Acceptability and Restrictions of Waste Water Reuse

Waste water re use has not been fully accepted for example in Kenya, the use of waste water is illegal (Githuku, 2009). Opaa and Omondi (2012) concur that in Kenya wastewater reuse is illegal, restricted and limited due to lack of policy and recognition by the existing legislation such as Water Quality Regulations 2006.

According to Lazarova et al., (2000), the integration of wastewater re use in the existing management master plans has been essentially geared towards agricultural irrigation however some countries lay conditions on its use. For instance in the United States, the use of reclaimed water for irrigation of food crops is prohibited in some states while others allow it only if the crop is to be processed and not eaten raw.

Also Hogg et al., (1997), reported that "Mexico does not allow wastewater to be used to irrigate lettuce, cabbage, beets, coriander, radishes, carrots, spinach and parsley. Acceptable crops include maize, alfalfa, cereals, beans, chili and green tomatoes."

Ayers and Westcot (1994) reported that the use of domestic wastewater in irrigation can be an attractive way to raise crop yields, but it has been known to result in a dramatic increase in the breeding of mosquitoes a situation which led to a ban on wastewater re-use for rice irrigation in California.

Though agriculture use is being advocated, there is need for secondary treatment of effluent prior to distribution. Seqer (1996) reported that highest priority should be to guarantee and safeguard hygienic standards and, that it has no adverse effects on the environment. ‘‘A monitoring program is necessary at the reclaimed water irrigation site to satisfy regulatory discharge requirements, and to provide timely information regarding the potential accumulation of constituents that may reach toxic concentrations or may threaten the pollution of adjacent natural resource’’(Thorton and Smith, 1987).

Kretschmer *et al*., (2002) concurs that an integrated planning approach is necessary incase re-use of waste water shall be one management alternative in a water stressed basin. Technological, economic and health aspects as well as legal framework have to be considered hence waste water re use is an interdisciplinary challenge for the present and the future however, Hogg *et al*., (1997) reported that provided proper management practices are followed, use of effluent should be sustainable.

### 2.6 Water Quality – Standards and Monitoring

Water quality refers to the chemical, physical and biological characteristics of water (Diersing, 2009). Frequently more than one use is made of water. It may be needed for domestic supply; for livestock; for irrigation; for hydroelectricity generation; for dilution and disposal of waste (industrial or sewage); for cooling thermal power stations; for fishing; for recreation and for navigation (Barrow, 1987), hence water quality refers to the characteristics of a water supply that will influence its suitability for a specific use (Ayers and Westcot, 1985).

Water quality is most frequently used by reference to a set of standards against which compliance can be assessed. Nkwonta and Ochieng (2009) noted that although scientific measurements are used to define the quality of water, it is not a simple thing to say that " This water is good" or "This water is bad" therefore when we speak of water quality, we usually want to know if the water is good enough for its intended use (DWAF, 1996).

In setting of standards, agencies make political, technological, scientific decisions about how the water will be used. For irrigation water evaluation, emphasis is placed on the chemical and physical characteristics of the water and only rarely any other factors considered important (Ayers and Westcot, 1985).

Water used for irrigation can vary greatly in quality depending on the type and quantity of dissolved salts thus there have been a number of different water quality guidelines related to irrigated agriculture and each has been used but none has been entirely satisfactory because of the wide variability in field conditions (Ayers and Westcot, 1985).

Recommendations on the quality of irrigation water differ depending on the source making the recommendations for example, table 2.2 shows standards for the quality of irrigation water as given by Environmental Management and Co-ordination (Water quality) Regulations (2006), and FAO 1985.

**Table 2.2: Irrigation water quality standards**

| Parameter | Permissible Level | |
|---|---|---|
| | EMCR | FAO |
| pH | 6.5-8.5 | 6.0-8.5 |
| Aluminium | 5(Mg/L) | |
| Arsenic | 0.1(Mg/L) | |
| Boron | 0.1(Mg/L) | 0-2mg/L |
| Cadmium | 0.5(Mg/L) | |
| Chloride | 0.01(Mg/L) | 0-30me/L |
| Chromium | 1.5(Mg/L) | |
| Cobalt | 0.1(Mg/L) | |
| Copper | 0.05(Mg/L) | |
| E. Coli | NIL/100ml | |
| Flouride | 1.0(Mg/L) | |
| Iron | 1(Mg/L) | |
| Lead | 5(Mg/L) | |
| Selenium | 0.19(Mg/L) | |
| Sodium Absorption Ratio | 6(Mg/L) | 0-15 me/L |
| Total Dissolved Solids | 1200(Mg/L) | 0-2000mg/L |
| Electrical Conductivity | | 0-3dS/m |
| Calcium | | 0-20me/L |
| Magnesium | | 0-5me/L |
| Sodium | | 0-40me/L |
| Carbonate | | 0-.1me/L |
| Bicarbonate | | 0-10me/L |
| Sulphate | | 0-20me/L |
| Nitrate-Nitrogen | | 0-10mg/L |
| Ammonium-Nitrogen | | 0-5mg/L |
| Phosphate-Phosphorous | | 0-2mg/L |
| Potassium | | 0-2mg/L |

Source: Ayers and Westcott (1985), FAO and EMCR (2006), Ninth Schedule (r.20)

Fin Frock *et al*.,(1960) described good quality rice irrigation water as water with specific electoral conductivity ($Kx10^6$) of less than 750; Boron concentration of < 1 ppm and SAR Index (Tendency to form alkali soil) of 10.0.

For Grist (1986); Johnstone and Muller (1966), characteristics of good irrigation water that determine quality include- total concentration of soluble salts, relative proportion of sodium to other cations , concentration of boron and other toxic elements, and under certain conditions, the bicarbonate concentration as related to concentration of calcium and magnesium.

Water quality concerns have often been neglected because good quality water supplies have been plentiful and readily available. However, this situation is now changing in many areas and intensive use of nearly all good quality supplies means that new irrigation projects and old projects seeking new or supplemental supplies must rely on lower quality and less desirable sources (Ayers and Westcot, 1985). To avoid problems when using these poor quality water supplies, there must be sound planning to ensure that the quality of water available is put to the best use.

Potential water quality related problems expected to develop are:-

(a). Salinity – Salinity refers to the total quantity of salts in the water. The dominant salt is sodium chloride but there are others which include carbonate and bicarbonate salts, magnesium and calcium sulfates and potassium. In irrigated areas, salts originate from a saline, high water table or from salts in the applied water however salinity is of concern only in arid and semi-arid environments where accumulated salts are not flushed regularly from the soil profile by rainfall (WHO, 2006). Salinity problem exists if salt accumulates in the crop root zone to a concentration that causes a loss in yields and this may occur through: - Salinity changes the osmotic pressure of the root zone, provokes specific ion (Sodium, Boron and Chloride) toxicity, interferes with plant uptake of essential nutrients (e.g. potassium and nitrates) due to antagonism with sodium, chlorides and sulfates and, it may destroy the soil structure (WHO, 2006) as a result of high sodium concentration.

(b). Water infiltration- An infiltration problem related to water quality occurs when the normal infiltration rate for the applied water or rainfall is appreciably reduced and water remains on the soil surface too long or infiltrates too slowly to supply the crop with sufficient water to maintain acceptable yields. High sodium concentration in irrigation water degrades the soil structure by causing soil dispersion and clogging of pore spaces (WHO, 2006) making water infiltration difficult. Low salinity water and high sodium concentration in the water accelerate the effects.

(c). Toxicity - Toxicity problem occurs if certain constituents (ions) in the soil or water are taken up by the plants and accumulate to concentrations high enough to cause crop damage or reduced yields. The ions of primary concern are Chloride, Sodium and Boron, (Ayers and Westcot, 1985). Toxicity often accompanies and complicates salinity or water infiltration problems.

(d). Miscellaneous - These are several other problems related to irrigation water quality that occur with sufficient frequency for them to be specifically noted. For example:- High nitrogen concentration in the water stimulates growth of plants especially algae which cause eutropication Also if the total nitrogen delivered to the crop via wastewater irrigation exceeds the recommended nitrogen dose for optimal yields, it may stimulate vegetative growth, but delay ripening and maturity, and in extreme circumstances, cause yield losses (Hussain *et al.*, 2002). Havens and Frazer (2012), concur that a high concentration of N may stimulate excessive growth and cause lodging, delayed crop maturity and poor crop quality; A high bicarbonate water (>2me/L) in the water used for flooding and growing paddy rice is reported to cause severe zinc deficiency (Mikkelson, 1983); Deterioration of equipment due to water induced corrosion or encrustation; Diseases e.g. Malaria due to low infiltration or Poor drainage providing conducive environment for vector multiplication; Suspended organic as well as inorganic sediments cause clogging of gates, sprinkler heads, drippers and Pumps if screens are not used; High maintenance costs as sediments tend to fill canals and ditches often; and sediments tend to slow down water infiltration rate of an already slowly permeable soil.

Monitoring of water quality in Kenya is done by the Water Resources Management Authority (WRMA) a body which the National Water Quality Management Strategy (NWQMS) (2012-2016) notes is facing the following challenges:- Inadequate human resource capacity, inadequate allocation of funds and, lack of clear management and ownership structure for the laboratories. NWQMS (2012-2016) also admits that water quality has tended to take a back seat compared to water quantity in the provision of water in our water resources.

## 2.7 Risks Associated With the Use of Waste Water

Though waste water use for agriculture has been recommended, several risks are associated to it such as;-

1). Environmental risks. These risks include salinization, eutrophication, pollution of soils and toxicity from toxic substances or heavy metals (Saqer, 1996).

Although trace elements are not a major problem in irrigation water (they occur in very low concentrations), it is now recognized that most of them are readily fixed and accumulate in soils causing an irreversible problem (Ayers and Westcot, 1985). Recent surveys of waste water use have shown that more than 85% of the applied trace elements accumulate in the soil and mostly in the surface a few centimeters affecting plants. Other risks include water logging and water contamination by heavy metals, nitrate and organic matter.

High levels of toxins in water affect plants by reducing yields, lowering product quality, foliar injury, contamination by pathogens and uptake of toxins in produce which are often consumed by animals and humans.

2) Health risks: Use of waste water for irrigation has been found to pose health risks such as; - spread of infectious diseases by bacteria (typhoid, fever, dysentery, tetanus), viral infections (meningitis, hepatitis, respiratory diseases), worm infections (round, whip and tape worms) and other diseases for instance a study conducted in Dakar, Senegal showed that 60% of the farmers utilizing wastewater from irrigation were affected with intestinal parasites (Faruquin *et al*., 2004; Mc Cartney *et al*., 2007). Also studies carried out in Pakistan showed that farmers using wastewater for irrigation had a higher preference of infections with hookworm and other helminthes than those who used convectional canal water (Feenstra *et al*., 2000; Van der Hoek *et al*., 2002b; Mc Cartney *et al*., 2007)

# CHAPTER THREE: MATERIALS AND METHODS

## 3.1 Introduction

This is a methodological chapter where 3.2 gives an overview of the study area, 3.3 provides the research design, 3.4 outlines data collection and data analysis is covered in sub-heading 3.5

## 3.2 Study Area Characteristics

This study was carried out in Mwea Irrigation Scheme, Kirinyaga County, about 100 km North East of Nairobi, Kenya (Figure 3.1). The experimental site is situated between latitudes $37^0$ 13'E and $37^0$ 30'E and longitudes $0^0$32'S and $0^0$46'S. The region is classified as tropical with a semi-arid climate having an annual mean air temperature of 20-25$^0$C with about 10$^o$C difference between the minimum temperature in June/July and maximum temperatures in October/ March. Annual mean precipitation is 950 mm with annual sunshine of 2485h (Ndiiri *et al*.,2012). The soils have been classified previously as Vertisols (Sombroek *et al*., 1982).

The scheme was started in 1956 and has a total potential area of 30,350 acres, of which 16,000 acres have been developed for paddy rice production producing 86% of the total rice produced in Kenya (Muhunyu, 2012). Besides the nucleus region of the scheme, another 5,000 acres of rice are under cultivation in the out grower region of the scheme bringing the total acreage under rice to 21000 acres. Maize and horticultural crops are also grown under furrow irrigation in the scheme.

The scheme is served by two main rivers viz:- River Thiba and River Nyamindi which irrigate 80% and 20% of the scheme, respectively (Wendot,2014, Personal communication). Irrigation water is drawn from the rivers with the help of fixed-intake weirs by gravity and then conveyed and distributed via open unlined channels irrigating various blocks in turns depending on the irrigation schedules and quantities of water available.

The nuclear scheme is divided into 5 sections, namely;- Tebere (T), Mwea (M), Thiba (H), Wamumu (W) & Karaba (K) while the out grower region include areas of Kianugu, Ndekia, Curukia and Kiamanyeki. The sections are further divided into 70 blocks also know as water management units (WMU) to ease management. The nuclear scheme has a well developed infrastructure which includes feeder roads, feeder & drain canals, water control gates/ valves etc which lack in out grower sections.

Mwea irrigation scheme was chosen because it is the oldest and largest public irrigation scheme in Kenya. It is the most active irrigation scheme and produces 86% of the total irrigable rice produced in Kenya. Irrigation is still expanding in the scheme e.g. about 5000 acres have been opened up in out grower regions and more acreage is available for paddy rice cultivation for instance, in Marurumo area, 4000 acres are available for rice growing if water could be availed (Mwaura,2014, personal communication).

Most rice production activities are manually undertaken apart from land preparation (rotavation). Currently, mechanization in rice production is being introduced mainly for weeding where push weeders have been introduced and combine harvesters for harvesting rice.

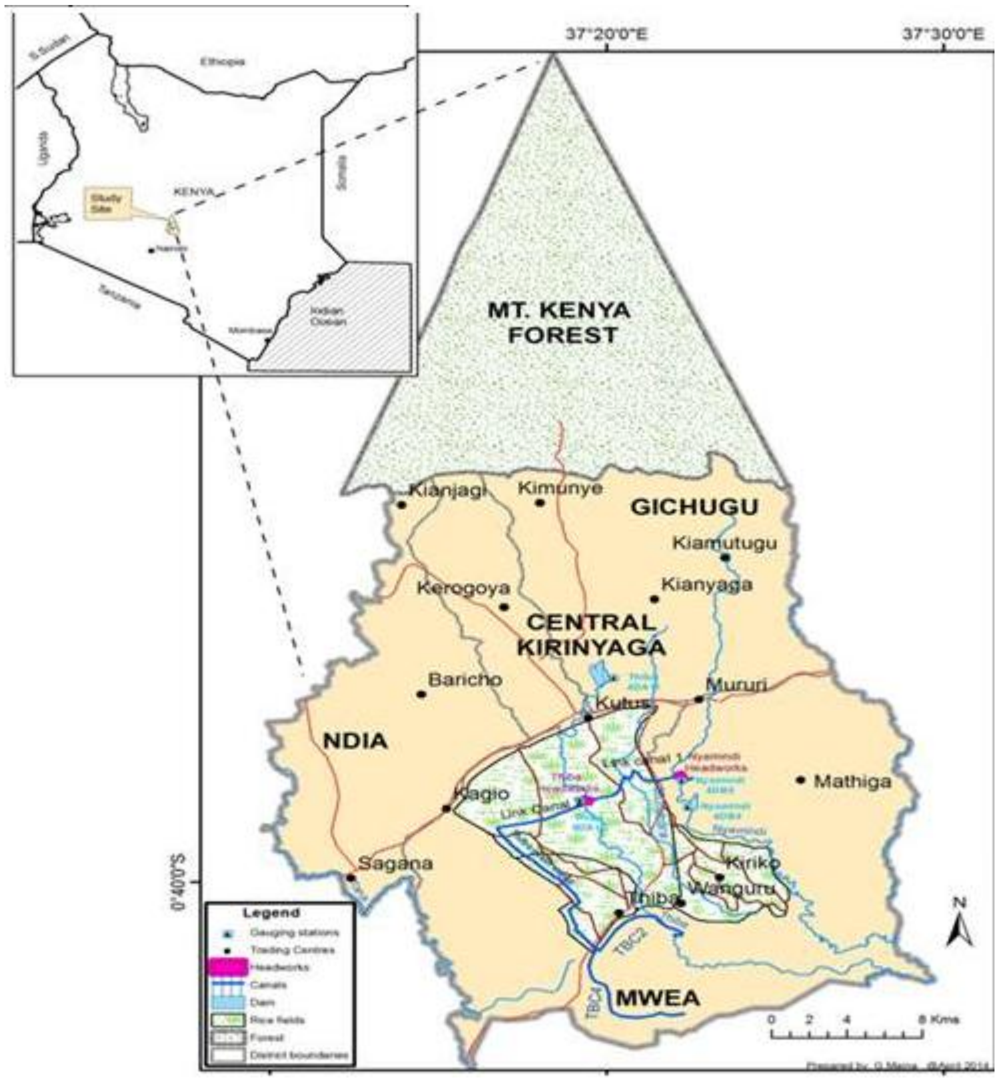


**Figure 3.1: Figure 3.1 Map of Mwea Irrigation Scheme**

## 3.3 Research Design

This study employed a mixed approach. Experimental approach dominated this study and this involved water, wastewater and soil sampling from three different sites in the scheme followed by laboratory analysis. The experimental layout was as illustrated in Table 3.1 below.

**Table 3.1: Experimental Layout**

| Site / Water Sample | Thiba Headworks (Intake Area) | Kiruara (Drainage area where 2 blocks of the scheme drain) | Karaba (Drainage area where 4 blocks of the scheme drain) |
|---|---|---|---|
| Water Sample | 3 | 3 | 3 |
| Soil Sample | 1 | 1 | 1 |

Non experimental (Survey) design was also used to determine the existing conditions at Mwea irrigation scheme and structured research administered questionnaires were used to collect important information about the population which included- population demography and level of education of the farmers, acreage under paddy rice production, farmers experience in growing rice, management practices in rice production, water and wastewater reuse in rice production. Transverse walk and field visits were also undertaken to make any necessary observations such as whether farmers were actually re using wastewater from paddy fields to accomplish the study.

## 3.4 Data Collection

### 3.4.1 Water and Wastewater Sampling

Water and wastewater samples were collected from 3 sites, that is, at the main inlet point of river Thiba, and at two re-use points namely; Kiruara Drain and at Thiba Main Drain- points 1, 2 and 3, respectively. River Thiba main inlet served as the control point since irrigation water from the river source was assumed to be clean and free from contamination while Kiruara Drain and Thiba Main Drain were the first and second re-use points bearing effluents/wastewater from the rice fields.

Nine water and waste water samples were collected, three samples from each of the three points 1, 2 and 3 and, sampling was carried out according to APHA *et al*., (2005)'s recommendations, that is, filtering and use of sterilized bottles which were obtained from the lab. Before sampling, the bottles and containers were rinsed thrice with water from the sampling site. Then three samples of equal volumes were taken from the two edges and at the middle of the canal and mixed to produce a composite sample from which a 500mls representative sample was drawn into labeled containers for subsequent analysis.

Immediately after sampling, field parameters such as pH and Electrolytic conductivity (EC) were determined using a portable pH and EC meter respectively and recorded in my field notebook. The samples were then carried in a cooler box which kept them as cool as possible without freezing to minimize the potential for volatilization or biodegradation (Jayalakshmi *et al.,* 2011), and immediately taken to the Government chemist laboratory in Nairobi within 3 hours. In the lab, the samples were acidified with nitric acid to a pH below 2.0 to minimize precipitation and adsorption of certain cations. Whenever immediate analysis was not possible, the samples were stored at $4^{o}C$ according to Jayalakshmi *et al.,* (2011). Each sample was analyzed in triplicate giving each parameter 27 sets of results whose mean and standard errors were determined at 95% confidence limit.

### 3.4.2 Soil Sampling and Pretreatment

Soil samples from the 3 fields adjacent to the water sampling points were taken at the end of the growing season for analysis. The soil sampling sites were: - site 1 being Mwea irrigation agricultural development (MIAD) farm which receives water directly from river Thiba intake (the first field to be irrigated); site 2 was at Curukia block - the first farm which receives its irrigation water from Kiruara Drain, and site 3 was at Mwea GK Prison farm which basically utilizes water which has passed through several fields before exiting back to river Thiba.

From each of the 3 sites, 8 samples were obtained from 0-30 cm depth (as recommended by Carter and Gregorich, (2006) for annual vegetation) by the zigzag method using a soil auger to ensure homogeneity. These were then thoroughly mixed and a composite sample of 1kg obtained, labeled, recorded in my field note book and immediately delivered to the MIAD lab in Mwea within 1 hour. In the lab, soil samples were air-dried to minimize changes in soil physical and chemical properties, ground and sieved under a 2.0 (< 2.0) mm sieve and stored in sample bags for subsequent analysis as outlined by Okalebo et al., (2002).

### 3.4.3 Household Survey

For interviews, a survey research design was used; a structured questionnaire was developed and pre-tested by officers from KALRO Mwea and MOA Mwea East Sub-county. The interviews were conducted with the help of eight officers from MIS water users association.

The scheme manager provided a list of all farmers in the scheme which comprises of seven (7) sections and seventy (70) blocks then, systematic random sampling method was used whereby the sections were randomly numbered from one to seven. The first member listed in each block in each odd numbered section was interviewed and thereafter the $31^{st}$, $61^{st}$, $91^{st}$, etc members. Then the second member listed in each block in each even numbered section was interviewed as was the $32^{nd}$, $62^{nd}$, $92^{nd}$ etc members. The farmers' responses were categorized and tabulated.

#### 3.4.3.1 Sample Size Estimation

The sample size was estimated using the equation used by Valedes and Bamberger (1994) as $d=n^{-1/2}(c^2pq)^{1/2}$ where-

**d** is the precision of an estimate for a particular confidence intervals with high values indicating low precision and low values indicating high precision.

**c** is the Z-score for the selected level of confidence (in this case 95%)

**n** is the sample size.

**p** is the probability at which the event being measured is likely to occur and

**q** is the probability that the event will not occur ($q=1-p$)

**Note:** Though the desired precision of the estimate is half the width of the desired confidence interval (Webster, 1995) a higher value in this case was adopted because the scheme irrigators have a strong homogeneity in terms of farm and canal design characteristics; water distribution schedules; crop type; production programme and agronomic practices a case which exhibits strong internal similarity (Owilla 2010 and Webster 1995)

The scheme has 4189 registered farmers. Using a confidence level of 95% (x=0.05), which corresponds to Z score of 1.96 and setting the d value at 0.786 and p at 0.5 (results in the highest precision) the sample size was found by substituting the values of d, c, p and q into the equation:-

$$0.786=n^{-1/2}(1.96)^{2}(0.5)(0.5)^{1/2} \quad = 163$$

A sample of 163 farmers was studied. This was limited by funds, time and the large spatial area of the farm land to be covered. This overall sample size of 163 was then apportioned to the sections of the scheme and results represented in Table 3.2 using the $n^{th}$ value=30 criteria.

**Table 3.2: Number of farmers sampled per section**

| Section | Frequency | Percent | Cumulative Percent |
|---|---|---|---|
| Tebere | 26 | 16.0 | 16.0 |
| Mwea | 30 | 18.4 | 34.4 |
| Thiba | 25 | 15.3 | 49.7 |
| Wamumu | 26 | 16.0 | 65.6 |
| Karaba | 26 | 16.0 | 81.6 |
| Curukia | 20 | 12.3 | 93.9 |
| Kiamanyeki | 10 | 6.1 | 100.0 |
| Total | 163 | 100.0 | |

#### 3.4.3.2 Survey Data Collection

Data on rice production and irrigation water used for 2013/2014 season were collected from both original scheme tenants and farmers in the out-grower sections of the scheme. A structured questionnaire (Appendix 1) was the tool used for this purpose to prevent observation bias. Data collection was carried out in November and December 2014 through direct interviews. Data collection was preceded by training of enumerators (plate 3.1), farmer sensitization meetings and pretesting of the questionnaire.

**Plate 3.1: Training of enumerators at Mwea Irrigation scheme board room on 15/10/2014**

Secondary data were collected from relevant institutions mainly MIAD, MIS, MOA Mwea East and Mwea West sub-county offices, KALRO Mwea, MIS Water Users Association and from several publications.

## 3.5 Data Analysis

### 3.5.1 Water and Waste Water Analysis

The water and wastewater parameters measured during the study included:- pH, Electrolytic conductivity (EC), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Calcium, Magnesium, Sodium, Potassium, Bicarbonates & Nitrates. The results were used to compute SAR and further compared with FAO irrigation water quality standards

Water analysis was done using DR 5000 Spectrometer ($2^{nd}$ edition2005). The DR 5000 spectrometer does the readings directly at different nanometers (nm) by placing the blank holding a sample cell into the cell holder for example: Sulphates were tested using SulfaVer 4 method 1 (method 8051) where one SulfaVer 4 reagent powder was added to 10ml of the sample and swirled. The sulphate ions in the sample reacted with the barium in the SulfaVer 4 to form a precipitate of barium sulphate. The results were measured at 450nm.

Nitrates were determined by cadmium reduction method (8039) where one NitraVer 5 nitrate reagent powder pillow was added to 10ml sample in a sample cell and mixed. A number of colours developed due to the presence of nitrates. The cadmium metal reduced nitrates in the sample to nitrite which reacted in an acidic medium with sulfanilic acid to form an intermediate diazonium salt. The salt coupled with genistic acid to form an amber coloured solution read at 500nm.

Total Suspended Solids (TSS) were measured photometrically using method 8006 where the sample was shaken then the readings taken directly at 810nm by placing the blank holding sample cell into the cell holder. For TDS, the water sample was evaporated and dried in a weighed dish at $180^0$C to a constant weight. The increase in weight over the empty dish represented the Total Dissolved Solids.

pH was measured electrometrically using a pH meter while EC was measured using a conductivity meter, “Lovibond Datronix” by dipping the respective calibrated meter into the sample and taking readings directly.

Sodium and potassium were measured by corning flame photometer where the sample was sprayed to a gas flame of sufficient thermal energy to cause the elements present emit their characteristic radiation. The required spectoral emission was isolated by means of a filter and its intensity measured by a photosensitive detector coupled to an amplifier at wavelengths of 589nm and 768nm respectively.

To measure calcium, EDTA was added to the sample containing calcium and magnesium ions. By making the water sample pH sufficiently high (12-13) most of the magnesium present was precipitated and using an indicator which combines with calcium ions only it was read directly with EDTA.

SAR was calculated using the formula below-

$$S.A.R = \frac{Na^{+}}{\sqrt{\frac{1}{2}(Ca^{2+} + Mg^{2+})}}$$ Source: Ayers and Westcott, (1985)

These laboratory results were analyzed using SAS programme whereby the means were determined by analysis of variance and further separated using Tukey test. The means from point 2 and point 3 were then compared with FAO irrigation water quality standards as outlined in table 4.4.

**3.5.2 Soil Analysis**

For soil analysis, parameters measured included: - pH, Electrical conductivity, organic matter content, total soil carbon, Total Nitrogen, Phosphorous, Calcium, Sodium and Magnesium. The soil pH was measured potentiometrically in the supernatant suspension of 1:2.5, soil:water mixture using a pH meter (Carter and Gregorich, 2006). 25g of soil was weighed into a plastic container; 62.5ml of distilled water added, stirred and allowed to stand for 10 minutes. The readings of the solution were taken using a pH meter and recorded.

Electrical conductivity (EC) of the soil was determined by adding 100mls of distilled water to 20g of soil in a plastic container, stirred and left to stand for 10 minutes. Readings of the solution were taken using an electro-conductivity meter.

Organic carbon percentage from which percentage organic matter is derived was estimated by Walkley - Black method (Schumacher, 2002) where 1g of 0.2mm soil sample was weighed into a 500ml conical flask including 2 tablets to standardize $FeSO_4$. 10mls dichromate solution was added, the flask gently swirled and kept on asbestos sheet. Rapidly 20ml concentrated $H_2SO_4$ was added by directing the steam into the suspension. The flask was swirled again 2-3 times and allowed to stand for 30 minutes then 200mls of distilled water was added followed by 0.5g of sodium fluoride and 1ml of diphenylamine indicator. The contents were then titrated with ferrous sulphate solution till the colour flashed from blue-violet to green. Whenever the burette reading was 0.4ml, it was repeated with less soil while for burette readings of ≥17ml, it was repeated with more soil and calculations were done as shown below,

Organic carbon (%)$= 10\,\frac{(B-T)}{B} \times \frac{0.003\times 100}{wt\ of\ soil(g)}$

Where B=volume (ml) of ferrous sulphate used for the blank titration

T=volume of ferrous sulphate used for the titration of soil sample.

Actual organic carbon (%) = organic carbon estimated × 1.3

(There is incomplete oxidation of OM in this procedure so the organic carbon is multiplied by 1.3 on assumption that there is 77% recovery)

Organic matter (%) =Actual carbon % ×1.724. (1.724 is called the Van Bemmeler factor which is used because organic matter contains 58% carbon)

For total nitrogen, Kjeldahl method (Carter and Gregorich, 2006) was used whereby 0.5g of air-dried soil was weighed in 100ml digestion tube (Kjeldahl flask). 10mls of concentrated $H_2SO_4$ was added and mixed well. About 1ml of 30% $H_2O_2$ was added drop by drop and the tube put in a digestion rack ensuring that aspirator works normally, 30% $H_2O_2$ was added every 1-$1\frac{1}{2}$ hour in a well aerated place. The heating continued (digestion) until the solution turned light yellow. When the power was turned off and the heater allowed to cool, 20mls distilled water was added and allowed to cool. The digest solution was transferred into a 100ml volumetric flask and filled up to the mark with distilled water. This digest solution was used for potassium, sodium, calcium, magnesium and phosphorous determination using AAS machine.

### 3.5.3 Analysis of Survey Data

The first stage of data analysis was data cleaning where the questionnaires were examined to ensure that they were complete and consistently filled in. The data was then coded and entries done in Microsoft Excel Spreadsheets. Analysis using descriptive techniques, cross tabulation and means with Statistical Package for Social Sciences (SPSS) version 17 was then done. Also MS-Excel was used to generate tables and graphs.

# CHAPTER FOUR: RESULTS AND DISCUSION

## 4.1 Introduction

The findings of this study have been presented as follows: Section 4.2 presents results of the socio-economic survey; Section 4.3 presents the physico-chemical parameters of irrigation water and wastewater from the three study sites; Section 4.4 presents the comparison of water parameters between points 2 and 3 wastewater sources in relation to FAO recommendations, and section 4.5 presents the results of soil analysis.

## 4.2 The Socio-economic Survey

### 4.2.1 Population Demography and Education

The population in the area under study was studied to give an insight of the social norms. Muhunyu, (2012) reported that the evolution of farming systems is affected by the social norms and practices that determine the way in which production and consumption are organized at a household or village level.

From the survey, 59.5% of the respondents were males and 40.5% females meaning that more males than females either own or are registered tenants of rice fields. This means that men and women are engaged in rice farming. Men participate more in decision making though women are the implementers because they are the majority in providing labor. Age distribution of the respondents were 20.2% (18-<35 yrs), 46.6% (35-<50 yrs) and 33.1% (>50 yrs) as tabulated in Table 4.1 and this shows that majority of the rice farmers are old (79.7%), have a wealth of experience in growing rice but resistant to implementing some new technologies and research recommendations.

**Table 4.1: Age of the respondents**

| Age of respondents | Frequency | Percent | Cumulative Percent |
|---|---|---|---|
| 18 -< 35 yrs | 33 | 20.2 | 20.2 |
| 35 < 50 yrs | 76 | 46.6 | 66.9 |
| 50 and above | 54 | 33.1 | 100.0 |
| Total | 163 | 100.0 | |

Also from the survey, 52.1% of the respondents attained primary education, 41.7% studied up to secondary level and only 6.1% joined tertiary institutions as shown in Appendix 5 meaning that majority of the farmers are literate and can be able to understand information and recommendations from various institutions on rice production.

### 4.2.2. Paddy Rice Acreage

On acreage under paddy rice cultivation, 45.4% cultivate up to 3 acres, 39.3% do 4 acres and 15.3% grow more than 4 acres of paddy rice implying that most of the farmers are small scale rice growers. Land ownership is mainly under leasehold (78.5%) where rice farmers are tenants and NIB is the trustee of the scheme land. About 21.5% of the respondents own land permanently and are mainly from out grower region of the scheme. When land ownership is not permanent, there are high chances of it being misused or exploited in many ways such as indiscriminate and overuse of agro-inputs to maximize on production at the expense of natural resource conservation.

About 68.7% of farmers interviewed indicated that they had grown rice for over 10 years while 25.2% have done it for between 5-10 years leaving only 6.1% for less than

5 years (Table 4.2) meaning that majority of the farmers are experienced in rice growing thus can provide accurate and reliable information on rice cultivation.

**Table 4.2: The period which respondents have grown rice in MIS**

| Years grown rice | Frequency | Percent | Cumulative Percent |
|---|---|---|---|
| less than 5 yrs | 10 | 6.1 | 6.1 |
| 5 to 10 yrs | 41 | 25.2 | 31.3 |
| over 10 yrs | 112 | 68.7 | 100.0 |
| Total | 163 | 100.0 | |

The main variety of rice grown in Mwea irrigation scheme is Basmati (Pishori) which accounts for 94.5% mainly because of its high quality which makes it more preferred by customers compared to shindano varieties. The shindano (BW, IR etc) are only grown for household consumption. None of the respondents grew NERICA rice despite its recommendations from the ministry of agriculture and research institutions.

### 4.2.3 Application and Usage of Irrigation Water

This survey indicated that 76.1% of MIS farmers receive irrigation water from feeder/line canals, 19.5% from main/branch canals, 3.7% from neighbors' fields and 0.6% get irrigation water from other sources as shown on plates 4.1, 4.2 and 4.3. The most recommended way of water abstraction is through the established feeder canals but because of irrigation water shortages or positioning of the rice fields along the irrigation canals especially in out-grower sections, some farmers have resorted to other methods of abstraction to survive. RiceMAPP, (2016) recommend farmers to try to secure a substitute source such as drainage canal, small river, pond etc. River Murubara which is used as a drain for Nyamindi system is one of the small rivers used to irrigate several farms. Farmers have also established several small water retention ponds especially in out-grower sections to cater for periods of water shortages.

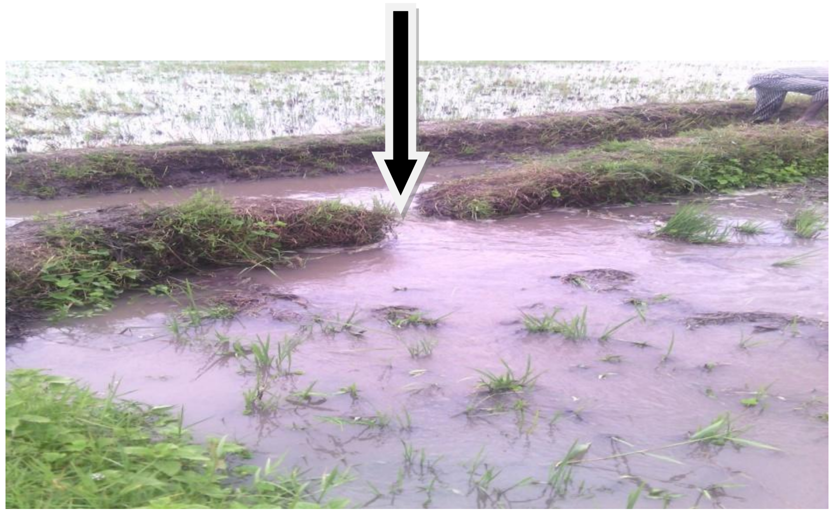

**Plate 4. 1: Irrigation water obtained from the feeder/line canal**

**Plate 4.2: Farmers siphoning water for irrigation (notice the rice nursery and fields beyond the canal) from the main canal.**

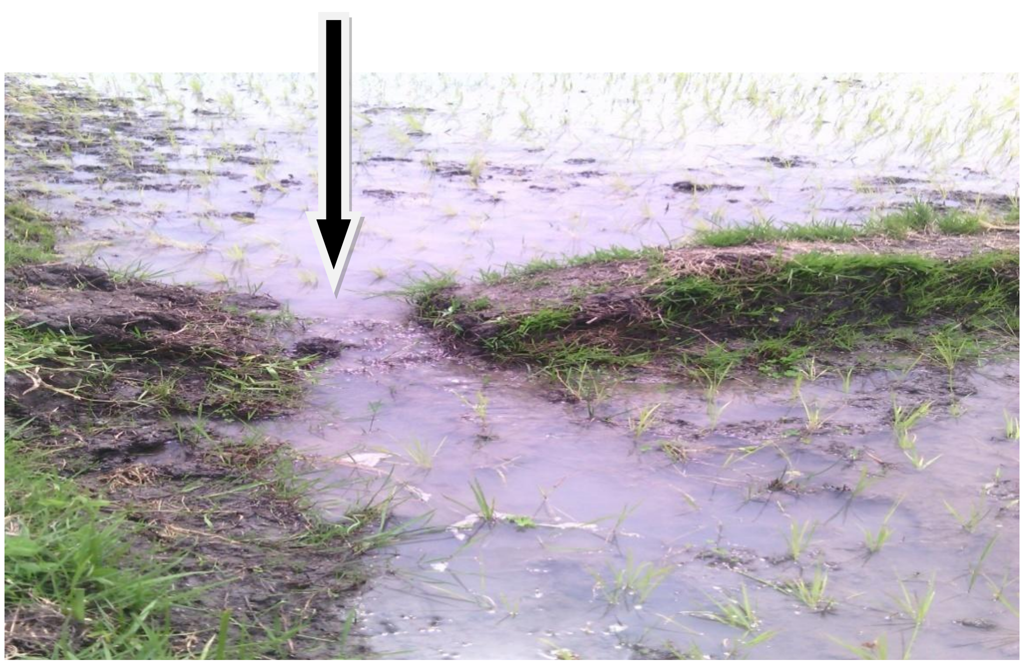

**Plate 4.3: Irrigation water obtained from the neighbor's field ((field observation at Thiba section, July 2015)**

In response to the planting period, 87.7% of the respondents indicated that they plant their rice in the month of August, when more water is available. In general however, most farmers interviewed (88.3%) reported experiencing water shortages during paddy rice production. The peak period of water shortages was reported to be during rice vegetative growth stage (65.6%) followed by 17.2% during rice flowering and grain-filling stage. These results concur with the ones given by RiceMAPP, (2016) on water balance as shown in figure 4.1

59.5% of the farmers interviewed reported receiving irrigation water once a week, 20.9% receive twice a week, 4.9% thrice a week, 8.0% irrigate their fields after one week and only 6.1% of the farmers sampled irrigate their paddy fields daily (Figure 4.2). Though recommendations have been made on alternate wetting and drying technology to save on irrigation water, (Ndiiri et al., 2012 and RiceMAPP, 2016), they have not been fully adopted and most farmers would wish to irrigate their fields daily so, this irrigation interval is only necessitated by water shortages.

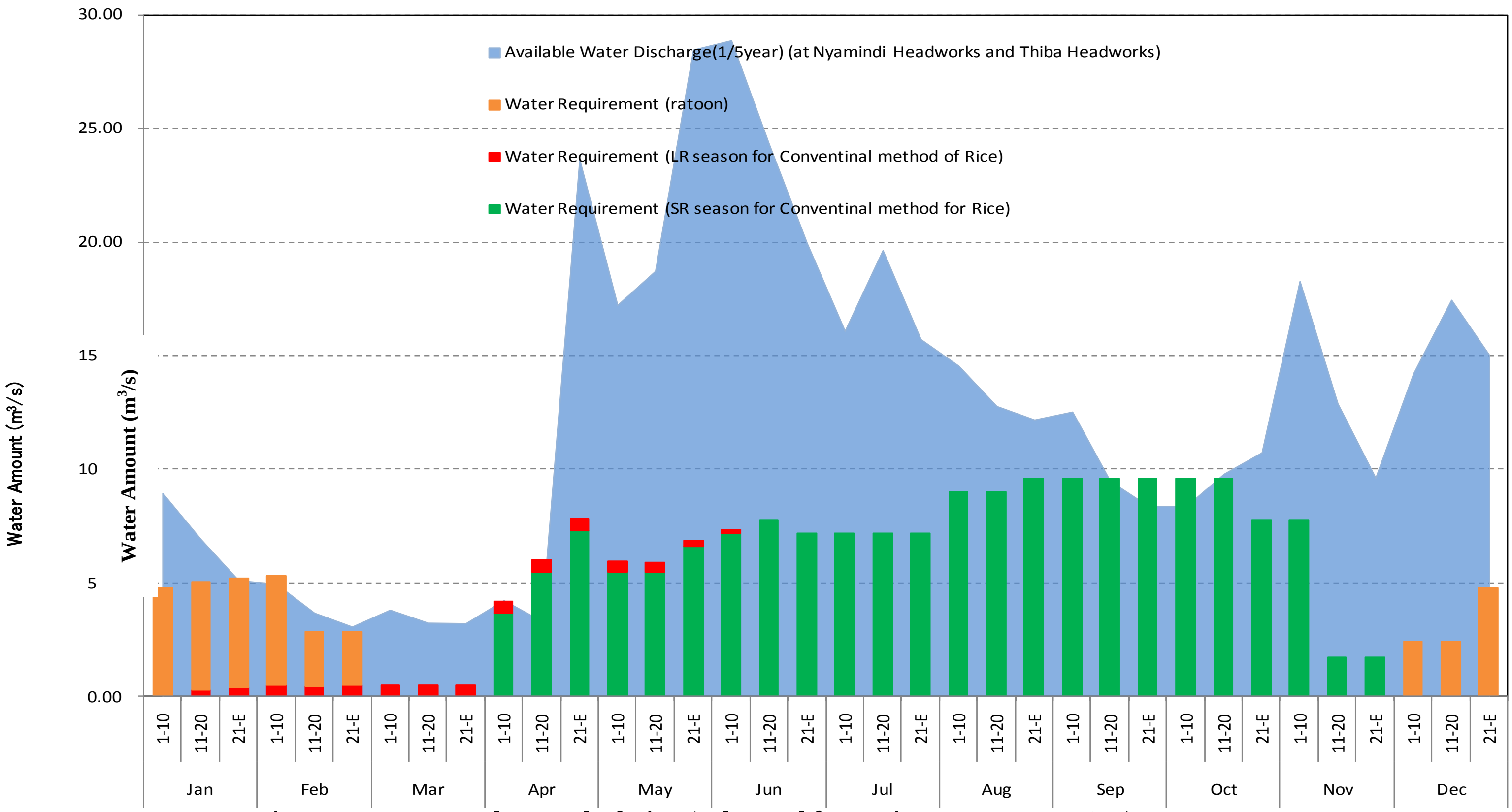


**Figure 4.1: Water Balance calculation (Adapated from RiceMAPP, June 2016)**

This study also noted that though all rice irrigators pay operation and maintenance fees as required by NIB/MIS, during periods of water shortage, the scheme develops an irrigation rationing program which is strictly followed.

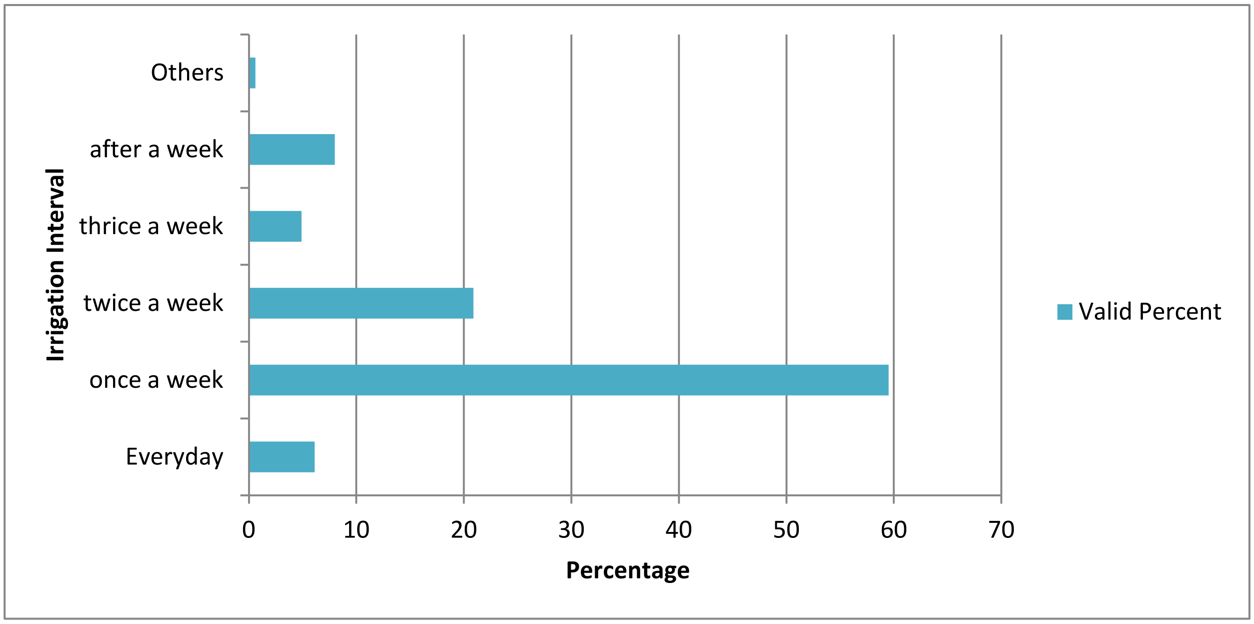


**Figure 4.2: Irrigation interval at MIS**

### 4.2.4 Irrigation Water Rating by the MIS Farmers

Of the total number of farmers interviewed, 47.2% reported that the quality of irrigation water was fair while 19%, 16%, 13.5% and 4.3% viewed irrigation water to be poor, good, very good and very poor, respectively (Table 4.3). However, 46.6% of the farmers expressed their feelings that the quality of irrigation water had improved with time while 27% of them felt that it was deteriorating and 26.4% said that there were no changes experienced on irrigation water quality. Water quality in this context refers to its colour, presence of oduor and foreign materials in the water. This shows that most farmers are comfortable with the current status of irrigation water.

**Table 4. 3: MIS Farmers rating of irrigation water**

| PARAMETER | RATING (%) | | | | |
|---|---|---|---|---|---|
| | Very Poor | Poor | Fair | Good | Very Good |
| Water Quality | 4.3 | 19.0 | 47.2 | 16.0 | 13.5 |
| Water Availability | 4.3 | 10.4 | 47.9 | 35.0 | 2.5 |
| Water Accessibility | 4.9 | 9.2 | 50.3 | 31.9 | 3.7 |
| Water Reliability | 4.9 | 12.3 | 56.4 | 22.7 | 3.7 |

### 4.2.5. Use of Agro-chemicals and Inorganic Fertilizers

On the use of agrochemicals, 87.1% of the respondents used herbicides during rice growing period and 98.8% used insecticides and fungicides. This shows an increase from 1% herbicides used in a study by Muhunyu (2012) implying a likelihood of a change in the composition of water and this may lead to increased contamination on the environment mainly water, water masses and soils. Muhunyu further commented that the use of herbicides is not encouraged by the Public Health officers because the contaminated water drains back to the canals and rivers and is used downstream, thus representing an environmental and human health hazard. There is need to use available alternatives to chemical pest control such as varietal resistance and integrated pest management (IPM) technologies.

All farmers interviewed reported to be using inorganic fertilizers of one kind or another in rice growing. For planting 52.1% used diammonium phosphate (DAP), 2.5% used muriate of potash (MOP) and 31.9% used triple superphosphate (TSP) while for top dressing, 85.3% applied Sulphate of Ammonia (SA). Several other combinations were also used as shown in Figure 4.3. This is likely to contribute salts to both irrigation effluents and irrigated soils.

Although muriate of potash is the recommended basal fertilizer, slightly more than half of the farmers apply DAP because it can be obtained cheaply through the government subsidy program in pretence that it will be used for its recommended crops such as maize.

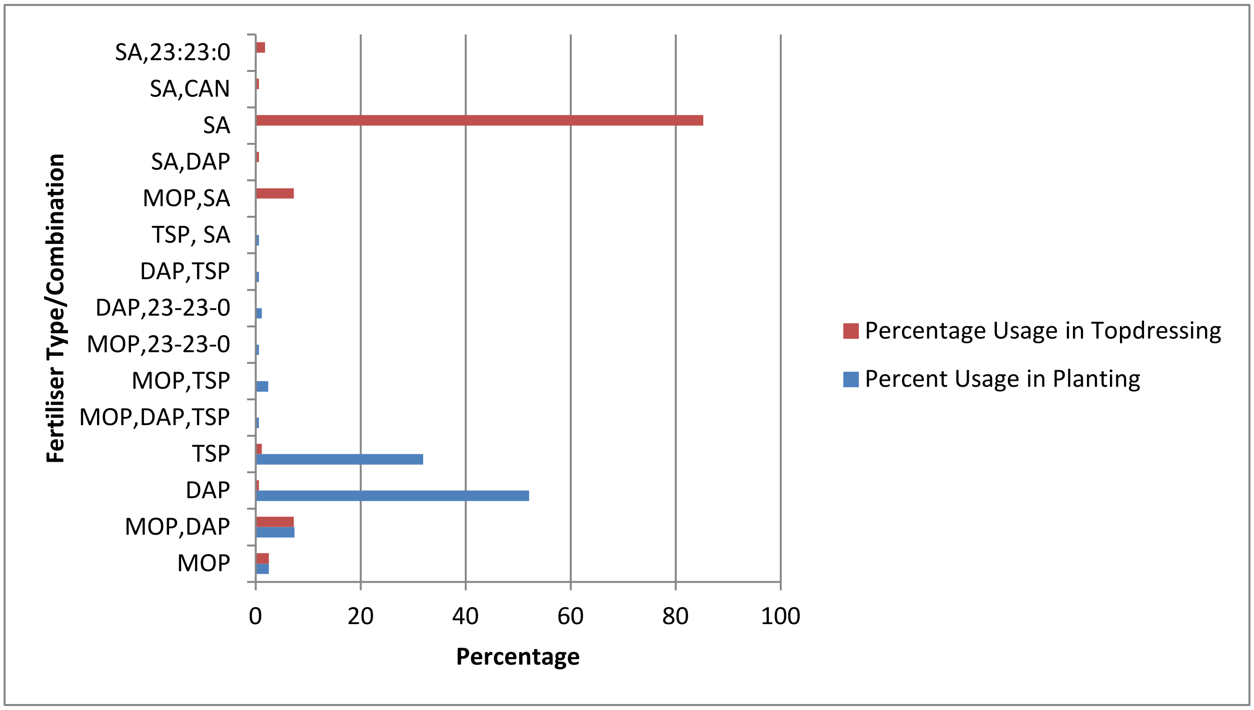


**Figure 4.3: Inorganic Fertilizers Applied on Rice at MIS**

The quantity of fertilizer applied during planting varied from 1 to 4 bags per acre, of which 95.7% used 1 bag per acre. On average, farmers used 1 to 5 bags of SA per acre for top dressing of which 27.6%, 23.9% and 22.7% of the respondents applied 3, 2 and 1 bag per acre, respectively.

### 4.2.6 Use of Waste Water /Drain Water/Effluents for Rice Production

On the use of drain water, 51.5% reported to have used drain water (Fig.4.4) whenever they experienced irrigation water shortages. Out of 84 respondents who used drain water, 81(96.4%) did so because it is readily available either from drainage canals or from other farmers' fields, 2.4% because it is cheap and only 1.2% of the respondent used it because of its high nutritive value. This fully agrees with RiceMAPP,(2016) that "When irrigation water is in short supply, farmers use any method available to irrigate their rice crop. Some divert water late in the night but pumping from drainage canal is one of the easiest methods." For the 79 farmers who had not used wastewater, 50.6% of them said it was not available due to their position or distance from the drainage canal while 22.8% said it was contaminated and 25.3% don't like it making it clear that 48% of farmers who never used effluents for irrigation had negative perspective about it which is in line with a statement by Githuku (2009) and USEPA (2012), that "Waste water re use has not been fully accepted".

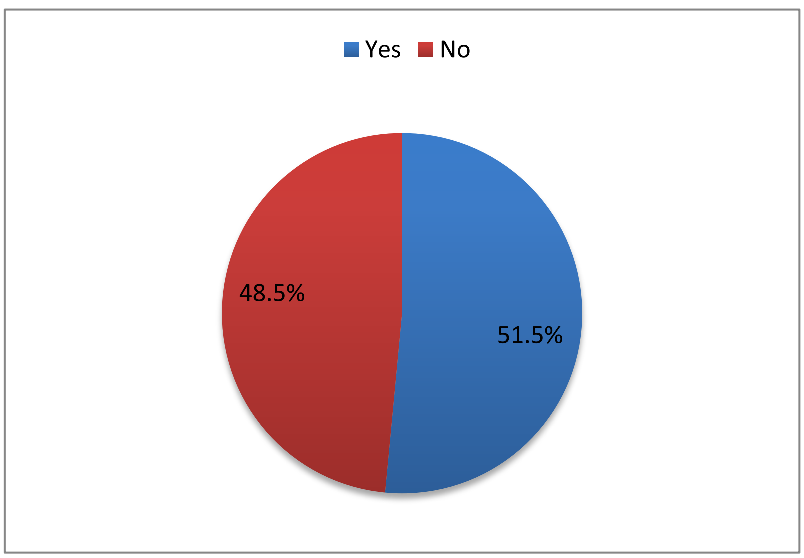


**Figure 4.4: Response of MIS Farmers on Waste Water Re-use**

### 4.2.7. Production of Paddy Rice in MIS

On production of paddy rice, survey results gave a range of 12-38 standard bags of paddy rice per acre (A standard bag weighs 80kg) giving a mean production of 25.4

bags per acre. The average production results per section are provided in Figure 4.5 where Karaba (K) section had the highest mean production of 27.9bags/acre followed by Wamumu (W) section with 27.1bags/acre. Thiba (H) section came third with a mean of 26.2 bags/acre, Curokia section fourth with 25.7 bags/acre, Mwea (M) section fifth with 25.1 bags/acre, Tebere (T) section sixth, with 24.3 bags/acre and last but not least, Kiamanyeki section with 15.8 bags/acre.

Karaba section is located at the tail end of the scheme utilizing irrigation water mixed with wastewater/effluent rich in nutrients washed off from other paddy fields. Mwea section receives irrigation water direct from river Thiba inlet. Curokia section is irrigated using water mixed with effluents/ wastewater also rich in nutrients from Mwea and part of Thiba sections but being an out-grower section, its water supply is neither adequate nor reliable while Kiamanyeki section utilizes wastewater which is never adequate due to its position in relation to the main water infrastructures.

Muhunyu (2012) reported that the optimum yield of aromatic rice varieties is 5.5ton/ha (27.8 bags of 80kgs/acre) a situation which compares well with Karaba (27.9 bags/acre) section of the scheme though the average production of the whole scheme is 25.4 bags/acre.

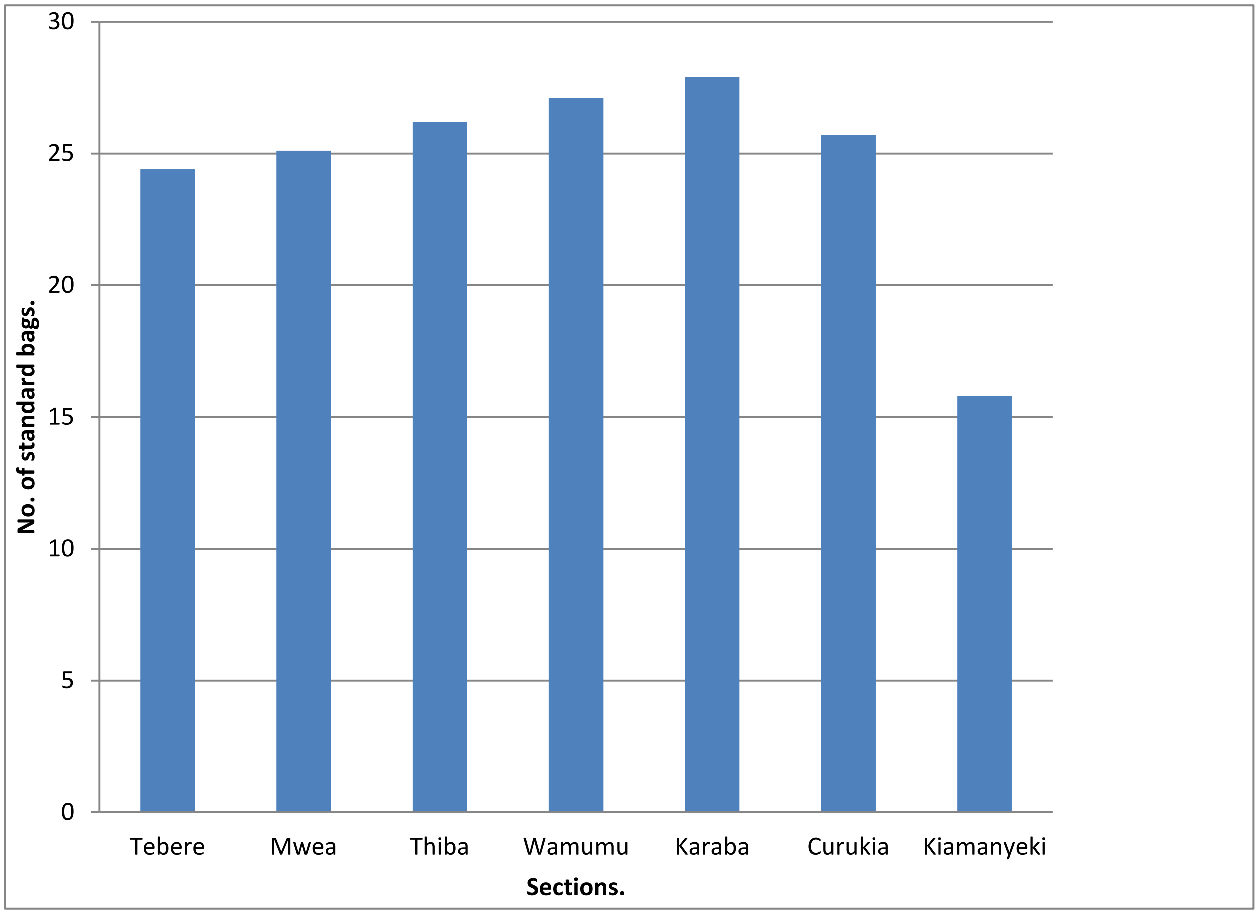


**Figure 4. 5: Average production of paddy rice in standard bags per acre per section**

From the survey results it was noted that paddy rice production is done by both men and women majority of whom are in their active age (66.9% between 18-50 yrs, Table 4.1).The farmers are literate because they acquired formal education and are likely to have enough experience in growing rice because 93.9% have grown it for over 5 years (Table 4.2). From their response, they are aware of irrigation water quality and constraints which they go through during paddy rice production. They have also learned survival techniques such as siphoning water from the main canals (Plate 4.2), using overflow/wastewater from neighboring fields (Plate 4.3) and planting in line with the scheme's irrigation water distribution schedules.

The percentage of respondents using drain water for rice production was only 51.5% though half (50.6%) of those who never used drain water for irrigation said it was because the wastewater was not available meaning they are willing to use the drain water if available. This confirms that MIS farmers value the contribution of MIS wastewater/effluent reuse in paddy rice production despite the fact that only 1.2% used it because of its high nutritive value. Though wastewater reuse is illegal in Kenya (Githuku, 2009; Opaa and Omondi 2012), it is evident that MIS famers use it and since acreage of paddy rice in the scheme has increased from 14400 acres in 2012 to over 20000 acres in 2014 (Mwaura, 2014. Personal communication), wastewater reuse can be attributed to this paddy acreage increase especially in the out grower region of the scheme.

Currently, the System of Rice Intensification (SRI) which employs alternate wetting and drying of paddy fields is an innovation or value addition in rice production that is being advocated for in the scheme so as to reduce on the quantity of irrigation water needed. Though SRI is expected to increase irrigation water use efficiency (Mati *et al.,* 2011 and Ndiiri *et al.*, 2012), most farmers in the scheme are still using the conventional way of flooding paddy fields using a lot of water for rice growing, a situation which agrees with the previous findings that rice is the largest consumer of water in the agricultural sector (Bera, 2009; Mishra, 2009; Ndiiri *et al.,* 2012 and Thakur *et al.*, 2011).

Mwea irrigation scheme farmers use a variety of agro-inputs during rice production and these are believed to be enriching irrigation effluents with nutrients such as nitrates as they flow down the canals leading to losses of these valuable plant nutrients and eutrophication of water bodies receiving the effluents a situation which fully concurs with previous studies by Afullo, (2009).

## 4.3 The Physico-chemical Parameters of River Thiba Waters, Kiruara Drain and Thiba Main Drain Waste-Waters of the Mwea Irrigation Scheme

This section gives laboratory results for various physical and chemical properties of irrigation water supplied into the scheme and effluents/wastewaters from the scheme. The quality indicators are then discussed in relation to FAO irrigation water quality standards outlined in table 4.4 below.

**Table 4.4: Laboratory Determinations Needed to Evaluate Common Irrigation Water Quality Problems**

| **Water parameter** | **Symbol** | **Unit**[1] | **Usual range in irrigation water** | |
|---|---|---|---|---|
| **SALINITY** | | | Value | Units |
| Salt Content | | | | |
| Electrical Conductivity | $EC_w$ | dS/m | 0 – 3 | dS/m |
| Total Dissolved Solids | TDS | mg/l | 0 – 2000 | mg/l |
| Cations and Anions | | | | |
| Calcium | $Ca^{++}$ | me/l | 0 – 20 | me/l |
| Magnesium | $Mg^{++}$ | me/l | 0 – 5 | me/l |
| Sodium | $Na^{+}$ | me/l | 0 – 40 | me/l |
| Carbonate | $CO_3^{--}$ | me/l | 0 – .1 | me/l |
| Bicarbonate | $HCO_3^{-}$ | me/l | 0 – 10 | me/l |
| Chloride | $Cl^{-}$ | me/l | 0 – 30 | me/l |
| Sulphate | $SO_4^{--}$ | me/l | 0 – 20 | me/l |
| **NUTRIENTS**[2] | | | | |
| Nitrate-Nitrogen | $NO_3$-N | mg/l | 0 – 10 | mg/l |
| Ammonium-Nitrogen | $NH_4$-N | mg/l | 0 – 5 | mg/l |
| Phosphate-Phosphorus | $PO_4$-P | mg/l | 0 – 2 | mg/l |
| Potassium | $K^{+}$ | mg/l | 0 – 2 | mg/l |
| **MISCELLANEOUS** | | | | |
| Boron | B | mg/l | 0 – 2 | mg/l |
| Acid/Basicity | pH | 1–14 | 6.0 – 8.5 | |
| Sodium Adsorption Ratio[3] | SAR | (me/l)[1, 2] | 0 – 15 | |

**Source**: Ayers & Westcott 1985, FAO

The levels of different chemical properties of irrigation water and effluents determined in the samples from collection sites 1, 2 and 3 are shown in Table 4.5 while comparison of some of the parameters are shown in Figures 4.6 and 4.7

**Table 4.5: The physico-chemical analysis of river Thiba water and irrigation effluents from Mwea irrigation scheme at point 1, 2 and 3 respectively.**

| **Parameter** | **pH** | **EC** dS/m | **TDS** mg/l | **TSS** mg/l | **$Ca^{2+}$** me/l | **$Mg^{2+}$** me/l | **$Na^{+}$** me/l | **$K^{+}$** mg/l | **$HCO_3^-$** me/l | **$NO_3^-$** mg/l | **SAR** me/l | **$NO_2^-$** mg/l | **$Cl^-$** me/l | **$SO_4^-$** me/l |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Point 1 River Thiba | 7.26a | 0.05b | 36.8b | 41.3b | 0.16c | 0.82a | 0.20b | 1.23b | 0.90b | 5.83a | 0.31a | 0.02a | 0.79a | 0.67b |
| Point 2 Kiruara Drain | 7.29a | 0.12ab | 74.1ab | 71.5ab | 0.39b | 0.99a | 0.47a | 1.77b | 1.47b | 7.10a | 0.48a | 0.06a | 0.87a | 2.36a |
| Point 3 Thiba Main Drain | 7.68a | 0.20a | 130.7a | 139.0a | 0.69a | 1.74a | 0.54a | 2.80a | 2.41a | 8.05a | 0.37a | 0.07a | 0.88a | 6.87a |

Values in column followed by the same lower case letters are not significantly different (p=0.05)

The pH mean values of water from the three points were generally basic but with slight differences. The mean pH for Thiba Main Drain (point 3) was slightly high at 7.68 followed by Kiruara Drain (point 2) at 7.29 and River Thiba intake (point 1) with a water pH of 7.26. The pH values were not significantly different, meaning that the nitrogen fertilizers in residual water drained from point 2 and 3 did not alter the water pH. Further, according to FAO, (1985) these values are within acceptable range for good irrigation water quality (Table 4.4). Field visits revealed that farmers use manure (Plate 4.4) in their rice fields increasing soil organic matter which is the key modifier and buffer of soil quality.

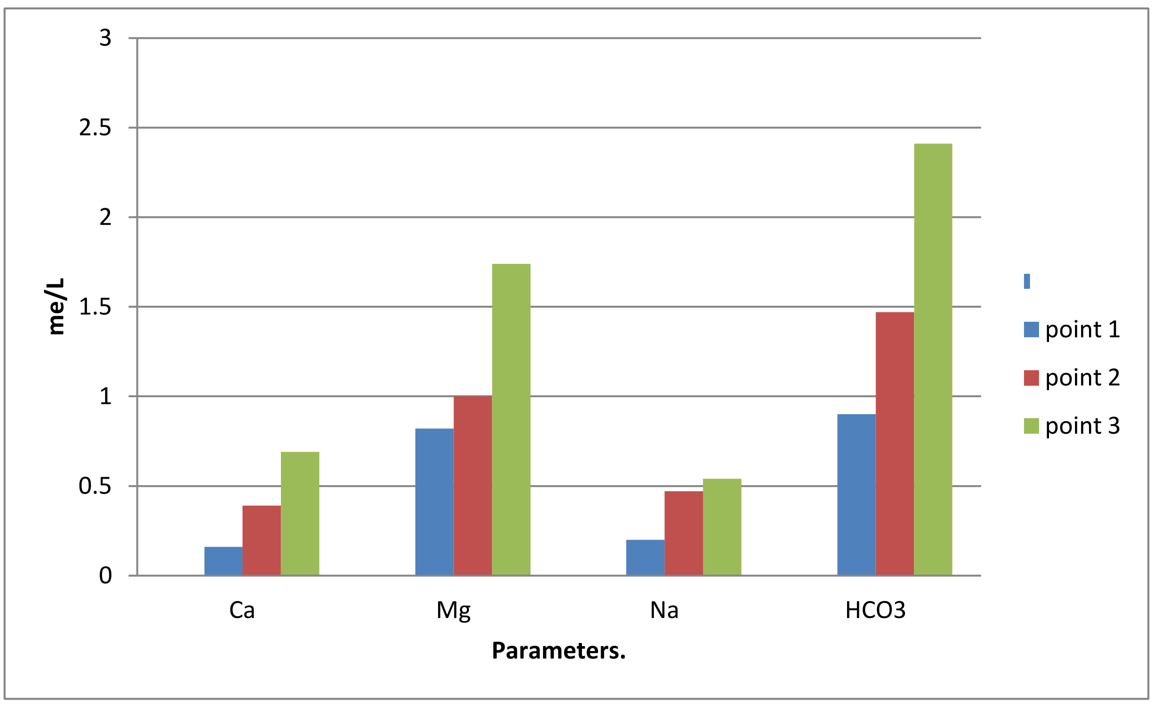


**Figure 4.6**: Effect of intensity of cultivation (as denoted by points of water intake) on the quality of irrigation water (Point 1, control = no irrigation has been done; point 2 = only one section irrigation and point 3 = drain water from 4 sections irrigated)

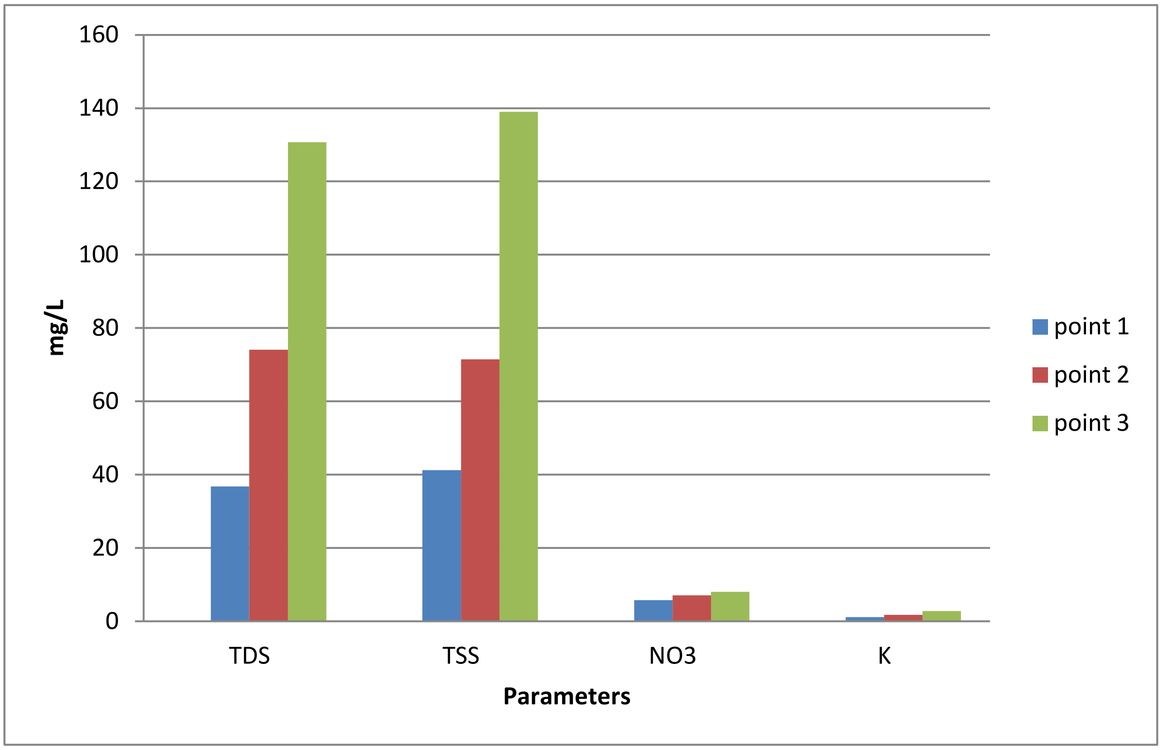


**Figure 4.6: Quality of irrigation water analyzed at points 1, 2 and 3 in mg/l**

Calcium levels in water increased as irrigation water moved down the irrigation scheme and recorded in the three treatment points as follows:- 0.69 me/l (point 3) > 0.39me/l (point 2) > 0.16 me/l (point 1). The Ca levels were significantly different among the three treatment points as $p = 0.0243$ between point 1 and point 2, $p = 0.0002$ between point 1 and point 3 and, $p = 0.0086$ between point 2 and point 3.This shows that the presence of bicarbonates in water did not affect the availability of Ca at points 2 and 3 as calcium bicarbonate precipitates. Though the use of SA fertilizer is linked to possibly Ca losses in form of Calcium nitrate and Calcium sulphate (Afullo, 2009), the use of organic manure (Plate 4.4) observed during field visits might have buffered Ca from being lost. This finding is supported by Fenton and Conyers (2002) findings that very low organic matter causes calcium deficiency especially in sandy soils that are low in organic matter and with a pH of less than 4. Also the high pH values in the water and waste water may have favoured calcium availability.

**Plate 4.4: Organic manure for use in rice fields**

Nevertheless, according to the FAO (1985) standards the Ca results obtained were within the recommended values for irrigation water.

The mean water magnesium level was higher at Thiba main drain (point 3) followed by Kiruara drain (point 2) and River Thiba intake at point 1 as 1.74me/l.>0.99me/l>0.82me/l for points 3, 2 and 1, respectively. Though there is a gradual increment from point 1 through point 3, the values were not statistically different as p=0.9467 between points 1 and 2, p=0.2778 between points 1 and 3 and, p=0.4015 between points 2 and 3 indicating that the agro inputs used by Mwea Irrigation Scheme farmers did not contribute to any substantial changes in magnesium levels. The mean Magnesium values obtained from all the three treatment points are within FAO standards for irrigation water (Table 4.4).

On sodium, the mean values in the 3 points were 0.54me/l at point 3> 0.47me/l at point 2> 0.20me/l at point 1.This shows a progressive increase from the river intake through Kiruara drain and Thiba main drain. Statistical analysis revealed significant differences ($p=0.0096$) in Na levels between River Thiba intake (point 1)and Kiruara drain (point 2), and $p=0.0059$ between River Thiba intake (point 1) and Thiba main drain (point 3) while there was no difference between Kiruara drain (point 2) and Thiba main drain (point 3) both of which are drain irrigation water sources. These values fall within FAO recommendations (Table 4.4) of 0-40me/l though for surface irrigation, concentrations of above 9me/l can be severe causing toxicity to sodium sensitive crops and concentrations of below 3me/l indicates none (Ayers and Westcot, 1994) hence none of the three sources studied pose Sodium toxicity to plants. High Sodium concentrations cause soils to disperse or lose soil structure. As soil structure deteriorates soil compaction or tightness will increase thus water infiltration, water percolation and root growth are all decreased negatively affecting plant growth and productivity.

The mean values for K show an increase with Thiba main drain (point 3) having 2.80mg/l> 1.77mg/l for Kiruara drain (point 2)> 1.23mg/l at River Thiba intake. Potassium ranks $7^{th}$ among the elements in order of abundance and is an essential element in both plants and human nutrition (APHA 2005). It occurs in ground water as a result of mineral dissolution and some irrigation waters contain enough dissolved K to obviate the need for K fertilization. The results obtained indicate no significant difference between River Thiba intake (point 1) and Kiruara drain (point 2) (p=0.1981) but there were significant differences between River Thiba intake at point 1 and Thiba Main Drain at point 3 (p=0.007) and between Kiruara Drain at point 2 and Thiba Main Drain at point 3 (p=0.0373).

Whereas point 1 and point 2 fall within FAO recommended standards for irrigation water, point 3 has slightly above the recommended values (Table 4.4) meaning the irrigation water is being enriched as it mixes with wastewater down the irrigation drains. This concur with previous work reported by James, Hanks and Jurinak (1982) that water direct from mountain sources may be too low in K but irrigation water that comes by way of return flow add considerable K to offset removal.

On salinity, Total Dissolved Solids were 36.76mg/l, 74.13mg/l and 130.65mg/l for points 1, 2 and 3 respectively; and EC levels were 0.05dS/m, 0.12dS/m and 0.20dS/m for points 1, 2 and 3 respectively. Salinity is a measure of dissolved salts in irrigation water and a high salt content implies that salinity is high. From the results, it was observed that salinity increased down the irrigation canals. Though these values fall within FAO recommended standards (Table 4.4), irrigation water should contain a minimum EC of at least 0.2dS/m or its TDS exceeding 200mg/l to prevent surface dispersion. This means that River Thiba (point 1) and Kiruara drain (point 2) waters are corrosive and tend to deplete the surface soils of their soluble salts and exchangeable cations (Ayers and Westcot, 1985) and Ca is amenable to this washing (Affulo, 2009) making the effluent at Thiba Main Drain (point 3) better for use compared to River Thiba waters. Statistical analysis revealed that TDS correlates positively with EC as found out by Jayalakshmi *et al.*, (2011). There was no significant difference between point 1 and point 2, and between point 2 and point 3 but there was a significant difference between point 1, River Thiba intake and point 3, Thiba Main Drain where p=0.0199 for TDS and p=0.0143 for EC.

TSS values increased progressively down from point 1 to point 3, ranging from 139.0mg/l at point 3 > 71.5mg/l at point 2 > 41.3mg/l at point 1. Point 1 was statistically different from point 3 (p=0.0132), while point 1 and 2, and point 2 and 3 were not different. This may be attributed to the number of paddy fields irrigation water sweeps through before it is discharged back to the river although this needs further studies for proper confirmation and documentation. The TSS takes into account colloidal matter such as clay, silt, finely divided organic and inorganic matter, plankton and other microscopic organisms.

The values of $NO_3$ in irrigation water showed an increase from the intake at point 1 through point 3 as 8.05mg/l>, 7.10mg/l>, 5.83mg/l for point 3, point 2 and point 1 respectively. $NO_3$ is the most highly oxidized form of nitrogen compounds commonly found in natural waters. Unpolluted water contains minute amounts of nitrates which in surface water is a nutrient taken up by crops and converted into cell protein. Excess concentration in drinking water (>10mg/l) is hazardous to children because it is reduced to nitrites in their intestinal tracts causing methemoglobinaemia/‘‘blue baby syndrome”. Some of the MIS farmers use canal water for drinking and other domestic functions (own observations) hence there is need to constantly monitor the water. The values from all the 3 points are within FAO recommendations and statistical analysis did not show any significant difference between the three points (as $p>0.05$) but the $NO_3$ levels exiting from the scheme through Kiruara Drain, point 2 and Thiba Main Drain, point 3 need to be disposed off well for purposes of conserving the environment and avoidance of undesirable miscellaneous problems such as excessive vegetation at the expense of produce and, one of the best ways is through recycling.

Like all other parameters, bicarbonates also increased as irrigation water moved from point 1 through point 3 and the values obtained were 0.90me/l for point 1< 1.46me/l for point 2 < 2.41me/l for point 3. Statistical analysis revealed a significant difference between point 1 and point 3($p=0.0045$) and, between point 2 and point 3($p=0.0487$) but there was no significant difference between point 1 and point 2 ($p=0.2128$) possibly because between point 1 and point 2, irrigation water has just swept through very few paddy fields compared to the number of fields between point 1 and point 3 and, between point 2 and point 3. These values are within FAO recommended standards (Table 4.4) but from previous studies, a high bicarbonate water (>2me/L) as in point 3 (2.41me/l) in the water used for flooding and growing paddy rice is reported to cause severe zinc deficiency (Mikkelson, 1983). Also high presence of bicarbonates will precipitate Ca when the soil is dry leading to an increase in Na relative to Ca hence development of thin surface crusts which impedes water infiltration.

Sulphate values obtained were 0.67me/l< 2.36me/l< 6.87me/l for point 1, point 2 and point 3 respectively. The results are within the FAO recommendations of 0-20me/l (Table 4.4). Increased values at point three concurs with James *et al.,* (1982), that return flow irrigation water contains nearly always added sulfate. Results for other parameters are shown in Appendix 2 and 3

### 4. 4 Comparison of Kiruara Drain and Thiba Main Drain Waters to FAO Standards

The means of the water quality parameters obtained from points 2 and 3 were compared with FAO recommendations as shown in Table 4.6.

**Table 4. 6: Comparison of Kiruara drain (point 2) and Thiba main drain waters (point 3) to FAO recommendations**

| **Parameter** | **pH** | **EC** dS/m | **TDS** mg/l | **TSS** mg/l | **Ca2+** me/l | **Mg2+** me/l | **Na+** me/l | **K+** mg/l | **$HCO_3^-$** me/l | **$NO_3^-$** mg/l | **SAR** me/l |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Point 2 | 7.29 | 0.12 | 74.1 | 71.5 | 0.39 | 0.99 | 0.47 | 1.77 | 1.47 | 7.10 | 0.48 |
| Point 3 | 7.68 | 0.20 | 130.7 | 139.0 | 0.69 | 1.74 | 0.54 | 2.80 | 2.41 | 8.05 | 0.37 |
| FAO standards (Ayers & Westcot 1985) | 6.0-8.5 | 0-3 | 0-2000 | - | 0-20 | 0-5 | 0-40 | 0-2 | 0-10 | 0-10 | 0-15 |

It was observed that all parameters tested at both wastewater sources were within the FAO recommended range for irrigation water (Table 4.4) hence the waste waters are suitable for production of paddy rice.

Though Nitrates fall within the FAO recommendations of 0-10mg/l, studies have shown that $NO_3$ less 5 mg/l has little effect even on nitrogen sensitive crops but may stimulate nuisance growth of algae and aquatic plants in streams, lakes, canals and drainage ditches as in Plate 4.5 below (Ayers and Westcot, 1994). Pierzynski et al., (1994), concur that the threshold for eutrophication in fresh water environments is 0.5-1.0 mg N L-1. Therefore waste waters from Mwea Irrigation Scheme have a potential of contaminating receiving masses down stream and recycling of these waster waters will solve the problem.

**Plate 4.5: Growth of aquatic weeds in the canals (A section of Kiruara drain, 2015)**

### 4.5 Soil Quality Analysis.

The quality of soils obtained from sites 1, 2 and 3 being MIAD block, Kiruara Area and Mwea GK prison land respectively, are presented in the Table 4.7.

**Table 4.7: Soil Analysis Results from 3 Different Sites at MIS**

| **SOIL PARAMETER** | **SITE 1, MIAD BLOCK** | | **SITE 2, KIRUARA AREA** | | **SITE 3, PRISON FARM** | |
|---|---|---|---|---|---|---|
| | Value | Class | Value | Class | Value | Class |
| pH | 7.48 | Alkaline | 7.71 | Alkaline | 7.59 | Alkaline |
| Total Nitrogen % | 0.182 | Low | 0.175 | Low | 0.21 | Ideal |
| Total organic Carbon % | 1.54 | Adequate | 1.49 | Adequate | 1.86 | Adequate |
| Phosphorous (Olsen) ppm | 6 | Very low | 11 | Very low | 30 | Ideal |
| Potassium me% | 0.2 | Low | 0.18 | Low | 0.14 | Low |
| Calcium me% | 12.7 | Adequate | 6.7 | Adequate | 14.7 | Adequate |
| Magnesium me% | 2.17 | Adequate | 4.03 | High | 3.69 | High |
| Manganese me% | 0.99 | Adequate | 0.27 | Adequate | 0.11 | Adequate |
| Copper ppm | 3.09 | Adequate | 3.43 | Adequate | 1.28 | Adequate |
| Iron ppm | 338 | Adequate | 95.8 | Adequate | 18.3 | Adequate |
| Zinc ppm | 4.32 | Low | 4.62 | Low | 2.4 | Low |
| Sodium me% | 1.42 | Adequate | 0.7 | Adequate | 1.49 | Adequate |
| EC mS/cm | * | | * | | 0.78 | Ideal |

* Threshold value too low to warrant Ec to be determined

Most parameters are adequate at site 3 except for potassium and zinc which are low not only at site 3 but in all the three sampling sites. The lowest zinc values at site 3 may be as a result of high bicarbonate content in waste waters at the tail end of the scheme. This agrees with Mikkelson (1983), that high bicarbonate water (> 2 me/l) in water used for flooding and growing paddy rice is reported to cause severe Zinc deficiency.

Total Nitrogen and Phosphorous are ideal at site 3 which basically utilizes wastewater from many paddy fields/blocks implying that deposition has occured compared to site 2 which utilizes waste water from fewer blocks and site 1 which uses clean water for irrigation. With P values of 30ppm, rice farmers can do a season without application of P fertilizers hence a saving on production costs. On average, farmers apply 80kgs of basal fertilizer @ kshs 64 per kg retail price for DAP/ TSP/23:23:0 meaning a saving of about 5000/= per acre can be achieved per acre in that one season.

Total N values were 0.182, 0.175 and 0.21 at site 1, 2 and 3 respectively. Total organic carbon % were 1.54 (site 1), 1.49 (site 2) and 1.86 (site 3) while phosphorous levels were 6 ppm, 11 ppm and 30 ppm at site 1, 2 and 3 respectively. EC value for site 3 was 0.78mS/cm but the threshold values were too low at site 1 and 2 to warrant EC determination. This corresponds with results obtained by Singh (2012), who found out that organic carbon, total nitrogen, available phosphorous, electrical conductivity, nitrate nitrogen and ammonium nitrogen were higher in wastewater irrigated soils compared to soils irrigated using clean water.

K levels were low at all sites necessitating the use of MOP as the basal fertilizer. From the survey results, Figure 4.3 shows that only 2.5% of the respondents use Muriate of Potash (MOP) for planting rice while another 10.4% use it in combination with other fertilizer types. This is in line with Muhunyu (2012) who reported that though MOP is recommended for planting rice, only 2% of MIS farmers used it. Also from water analysis (Table 4.5), K values are high at drainage points indicating that it is not deposited in soils but eroded in drain water.

# CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

This study established that farmers are aware of the effects of the quality of irrigation water on rice production. The quality in this context refers to their physical assessment on the colour, presence of odour and foreign material in both irrigation water and waste water. It is because of this awareness that irrigation effluents are being used by 51.5% of the farmers and, 50.6% of those who did not use it said that it was not available meaning they value its use but since they are located far from the drainage canals, the waste/drain water is recycled until it gets finished before reaching them, so they only have to depend on irrigation water which is often rationed or difficult to reach them through irrigation canals resulting to water conflicts during times of shortages and low production of paddy rice. Also in their response, farmers attributed high paddy rice production in Karaba section to the use of irrigation water mixed with effluents draining from other sections of the scheme mainly Mwea, Thiba and Wamumu sections.

The physico-chemical quality of Mwea irrigation scheme effluents were higher than river Thiba waters in EC,TDS, TSS, $Ca^{2+}$, $Na^{+}$, $K^{+}$ and $HCO_3$. Generally, there was a progressive increase of all parameters from Thiba intake (point 1) < Kiruara drain (point 2) < Thiba main drain (Point 3) including pH, nitrates, nitrites, chlorides and SAR but these were not statistically different thus indicating that the quality of water and the effluents were not different with respect to the latter parameters.

This study also found out that waste waters (effluents) from the two drainage sites of Kiruara drain and Thiba main drain are suitable for reuse in paddy rice production. The physico-chemical properties of MIS effluents obtained from the two effluent drain sites fell within FAO irrigation water quality recommendations therefore reusing the effluents would increase the quantity of water available for growing rice.

It was also found that soils of site 3 which utilizes water mixed with waste water/effluents draining from other paddy fields recorded ideal soil nitrogen and phosphorous contents and higher electrical conductivity compared to other sites hence the waste water has a positive effect on the soil. Accumulation of N and P in soils at site 3 implies that wastewater from point 3 can be used without or with reduced fertilization thus lowering the cost of producing rice though field trials are needed to validate this.

**5.2 Recommendations**

- Waste water should be reused on paddy rice production to increase available water for irrigation in Mwea, and to reduce inorganic fertilizer use.
- The scheme management and WUA should put up measures to harness any little waste water draining from Thiba main drain for use at the lower part of the scheme.
- Continuous soil testing on soils irrigated using waste water should be carried out to ascertain that there is no risk of heavy metals accumulation.
- MIS farmers should be encouraged to intensively use well decomposed organic manures for their many advantages including soil amendment properties to avoid/reduce the problem of salinity and sodium rich water.
- Besides wastewater recycling to improve on the volume of irrigation water at Mwea Irrigation Scheme, farmers should be encouraged to adopt the system of

rice intensification (SRI) technology which employ alternate wetting and drying of paddy fields to reduce the amount of water used for rice production.

- Farmers should be encouraged to continuously analyze their soils so as to come up with proper fertilization regimes.
- Since all parameters tested progressively increased as point 1< point 2< point 3, further studies should be carried out to establish the relationship between the area (Number of paddy fields) irrigated and the gain in concentration of various physico-chemical parameters in effluent water so as to establish when maximum thresholds for irrigation are reached for appropriate action to be taken.
- The presence of Azolla, a nitrogen fixing weed found present in some paddy fields need to be studied to ascertain its contribution on available N in irrigation water and irrigated soils.
- Kirinyaga Water and Sewerage Company should provide MIS residents with clean/piped water for domestic use to avoid use of canal water for the same as observed during the study.

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# APPENDICES

## Appendix 1: Household questionnaire

CONSENT PAGE

Hello. My name is Josephine Nyabonyi Onderi a Post Graduate student at Kenyatta University. I am conducting a survey in the area in order to assess the suitability for irrigation of waste water from Mwea Irrigation Scheme.

Your household has been selected by chance from all households in the area. I would like to ask you some questions related to the farming activities in the scheme.

The information you provide will be useful to find out whether waste water from the scheme can be of good quality for farming so as to increase on the quantity of water available for irrigation to produce more rice and also conserve the environment. This will also help to plan future development programs in this area and also in the country.

This research is part of the requirements needed to complete the course.

Participation in the survey is voluntary and all the information you give will be confidential. The information will be used to prepare general reports, but will not include any specific names so there will be no way to identify that you are the one who gave this information.

If you have any questions about the survey, you can ask me. At this time do you have any questions about the survey?

Signature of Interviewer: ____________________

Date: ____________________

Respondent Agreed to be Interviewed

1. YES
2. NO

Yours Sincerely,

J. N. Onderi.

1. Date__________________
2. Number of the farmer___________ Section ___________ Block ____________
3. Gender of respondent 1) Male 2) Female
4. How old are you? 1) Below 18 years 2) 18-35years 3) 35-50years 4) Above years.
5. Level of education completed 1) Primary, 2) Secondary 3) Tertiary.
6. House Hold size 1) 1-5 persons, 2) 6-9 persons, 3) >10 persons.
7. How long have you grown rice? 1) less than 5 years, 2) 5-10 years 3) over 10 years
8. What is your acreage under rice production: - 1) 1-3 acres, 2) 4 acres, 3) over 4 acres
9. Do you grow any other crops apart from rice? 1) Yes, 2) No
10. If yes, state the acreage for any other crops under irrigation ________________
11. What is the nature of your land ownership:- 1) Leasehold, 2) Inheritance, 3) Permanent ownership
12. What variety of rice do you grow?1) Pishori 2) BW 3) IR 4) ITA 5) NERICA 6) Any other
13. Why do you prefer the variety mentioned above? 1) Hardy 2) High yielder 3) High quality 4) It is grown by everybody.
14. What is your source of irrigation water? 1) Main canal, 2) Branch canal, 3) Line/ feeder canal, 4) Neighbor's field, 5) Any other.
15. Which month do you start planting your rice? Main season ___________ Short season________
16. Why do you plant during the period mentioned above? 1) Due to water availability, 2) When others start, 3) Tradition, 4) I don't know.
17. How often do you get water for irrigating your rice? 1) every day, 2)once a week, 3) twice a week, 4) thrice a week, 5) after a week.
18. What can you say about irrigation water:-

| Parameter | 1. Very poor | 2.Poor | 3. Fair | 4.Good | 5.Very good |
|---|---|---|---|---|---|
| Quality | | | | | |
| Availability | | | | | |
| Accessibility | | | | | |
| Reliability | | | | | |

19. Do you pay for irrigation water? 1). Yes, 2). No, 3). don't know
20. Do you use herbicides when growing your rice? 1) Yes, 2) No
21. What of Pesticides? 1) Yes, 2) No
22. What type and quantity of fertilizers do you use in growing your rice?

| Source | Type | No. of bags Per acre |
|---|---|---|
| Planting (MOP, SA, DAP, TSP, UREA, CAN, 23:23:0, NONE) _______ | _________ | ________ |
| Top dressing (MOP, SA, DAP, TSP, UREA, CAN, 23:23:0, NONE) _______ | ________ | _______ |

Key 1) MOP, 2) SA, 3) DAP, 4) TSP, 5) UREA, 6) CAN, 7) 23:23:0, 8) NONE

23. What is your production in standard bags per acre? (A standard bag weighs 80kg)_________
24. Do you experience irrigation water shortages? 1) YES, 2) NO.
25. If yes, when? During 1) land preparation, 2) planting, 3) vegetative stage, 4) flowering and grain filling stage
26. Do you irrigate your field using drain water? 1) Yes 2) No
27. If yes, give reasons for your answer 1)Readily available 2) Has more nutrients 3) Cheap
28. If no, what are the reasons 1) Not available 2) contaminated 3) Don't like it
29. Are you aware of water scheduling/rationing programme? 1) Yes 2) No
30. What are your feelings on water quality as days pass by? 1) Improving, 2) Deteriorating, 3) No changes
31. Have you noted any changes in rice yields over the years? 1) Yes, 2) No.
32. If yes, are the yields 1) increasing 2) decreasing
33. What do you attribute the changes to? 1) Poor seed, 2) poor quality of irrigation water, 3) Lack of water, 4) Pests and diseases, 5) Declining soil fertility, 6) Overuse of Agro inputs, 7) Any other
34. What is your source of labour? 1) Family 2) Hired 3) Any other
35. Do you practice crop rotation on rice paddies? 1)Yes 2)No
36. If yes, with what other crops? ______________________________________
37. Where do you sell your rice? 1) Mwea Rice Mills, 2) Brokers at the farm, 3) Local millers, 4) Any other ______________________________
38. State 3 main challenges you face during rice production?
    a.)_____________________________________________________
    b.)_____________________________________________________
    c.)_____________________________________________________
39. In your own view, what can the scheme management do to increase water supply for irrigation?__________________________
    ____________________________________
    ______________________________________________________

## Appendix 2: Mean Separation

| **Parameter** | **Point 1 And Point 2** | **Point 1 And Point 3** | **Point 2 And Point 3** |
|---|---|---|---|
| PH | 0.9915 | 0.1973 | 0.2313 |
| EC | 0.2050 | 0.0143* | 0.1790 |
| TDS | 0.2455 | 0.0199* | 0.1148 |
| TSS | 0.3309 | 0.0132* | 0.0604 |
| Ca | 0.0243* | 0.0002* | 0.0086* |
| Mg | 0.9467 | 0.2778 | 0.4015 |
| Na | 0.0096* | 0.0059* | 0.6247 |
| K | 0.1981 | 0.0070* | 0.0373* |
| $NO_3$ | 0.8287 | 0.6460 | 0.9173 |
| $HCO_3$ | 0.2128 | 0.0045* | 0.0487* |
| SAR | 0.5173 | 0.8021 | 0.9103 |
| Chlorides | 0.5271 | 0.9956 | 0.5239 |
| $SO_4$ | 0.6552 | 0.1250 | 0.0369* |
| $NO_2$ | 0.2800 | 0.8162 | 0.1689 |
| $Fe^{3+}$ | 0.9908 | 0.8298 | 0.7692 |
| Fluorides | 0.2006 | 0.6152 | 0.1361 |
| Silica | 0.5223 | 0.3780 | 0.9038 |

Where * indicates a statistical difference between the two points

**Appendix 3: Descriptive Statistics for MIS Irrigation Water and Effluent Quality**

| Parameter | Point 1<br>River Thiba | Point 2<br>Kiruara Drain | Point 3<br>Thiba Main Drain |
|---|---|---|---|
| PH | 7.2625(0.1419) | 7.2875(0.1419) | 7.6767 (0.1638) |
| EC | 0.0525(0.0253) | 0.1200(0.0253) | 0.1967 (0.0293) |
| TDS | 36.7667(14.2527) | 74.1333(14.2527) | 130.650 (17.4559) |
| TSS | 41.3333(11.6303) | 71.5000(14.2441) | 139.0000(14.2441) |
| Ca | 0.1575(0.0430) | 0.3867(0.0497) | 0.6900(0.0497) |
| Mg | 0.8225(0.3634) | 0.9850(0.3634) | 1.7433(0.4196) |
| Na | 0.1950(0.0398) | 0.4700(0.0460) | 0.5400 (0.0563) |
| K | 1.2333(0.1850) | 1.7667(0.1850) | 2.8000 (0.2266) |
| $NO_3$ | 5.8333(1.5049) | 7.1000(1.5049) | 8.0500 (1.8431) |
| $HCO_3$ | 0.9000(0.2152) | 1.4650(0.2152) | 2.4100 (0.2485) |
| SAR | 0.3175(0.1037) | 0.4750(0.1037) | 0.3733(0.1198) |
| Chlorides | 0.7850(0.0550) | 0.8725(0.0550) | 0.8800(0.0636) |
| $SO_4$ | 0.6725(1.3234) | 2.3575(1.3234) | 6.8700(1.5282) |
| $NO_2$ | 0.0160(0.0160) | 0.0553(0.0160) | 0.0710(0.0196) |
| $Fe^{3+}$ | 3.5533(1.4929) | 3.2800(1.4929) | 1.8800(1.8284) |
| Fluorides | 0.2300(0.0333) | 0.3333(0.0333) | 0.4000(0.0577) |
| Silica | 15.6667(6.0873) | 25.6667(6.0873) | 11.5000(7.4554) |

**Key**: The figures in brackets are the respective standard error of the mean.

**Appendix 4: Conversion factors for irrigation water quality laboratory reports**

| Component | To Convert | Multiply By | To Obtain |
|---|---|---|---|
| Water nutrient or TDS | mg/L | 1.0 | ppm |
| Water salinity hazard | 1 dS/m | 1.0 | 1 mmho/cm |
| Water salinity hazard | 1 mmho/cm | 1,000 | 1 µmho/cm |
| Water salinity hazard | $EC_w$ (dS/m) for EC <5 dS/m | 640 | TDS (mg/L) |
| Water salinity hazard | $EC_w$ (dS/m) for EC >5 dS/m | 800 | TDS (mg/L) |
| Water $NO_3N$, $SO_4$-S,B applied | Ppm | 0.23 | lb per acre inch of water |
| Irrigation water | acre inch | 27,150 | gallons of water |

| Abbrev. | Meaning |
|---|---|
| mg/L | milligrams per liter |
| meq/L | milliequivalents per liter |
| Ppm | parts per million |
| dS/m | deciSiemens per meter |
| µS/cm | microSiemens per centimeter |
| mmho/cm | millimhos per centimeter |
| TDS | total dissolved solids |

Source: Bauder *et al.*, (2014)

**Appendix 5: Education level of the respondents**

Education level of the respondents

| Level | Frequency | Percent | Cumulative Percent |
|---|---|---|---|
| Primary | 85 | 52.1 | 52.1 |
| Secondary | 68 | 41.7 | 93.9 |
| Tertiary | 10 | 6.1 | 100.0 |
| Total | 163 | 100.0 | |

**Appendix 6: Irrigation network and discharge check points**