EFFECT OF IRRIGATION WITH TREATED WASTEWATER ON SOIL CHARACTERISTICS AND BEAN YIELD: A CASE STUDY OF UNIVERSITY OF ELDORET FARM

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DECLARATION

Declaration by the Candidate

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DEDICATION

This thesis work is dedicated to my family members for their guidance, love, and support when conducting my research.

ABSTRACT

It is proposed that treated wastewater reuse with the correct regulations can be used to supplement the available amount of water for agricultural use. The research determines the effect of using this water on soil and crop yield. An experimental set up was done on 18 (1.5 m x 3 m) plots, where each plot received a different treatment. Experimental field treatments were set up at the University of Eldoret farm that is next to the waste water (WW) treatment plant. The farm is located in Uasin Gishu County, Kenya. The field experiments were carried out between June and October 2018. The research is directed at solving the problem of waste water reuse and disposal into rivers and lakes without strategic measures. Hence, the key objective of the study was to evaluate the effect of treated waste water irrigation on soil physical and chemical characteristics, and bean crop yield. The approach took a randomised complete block design (RCBD) where the treatments were replicated twice. For the treatments, treated waste water at 0 %, 25 %, 50 %, and 75 % NPK and fresh water at 0%, 25%, 50%, 75%, and 100 % NPK was applied to the plots. The fresh water at 100% NPK was considered as the control experiment. For all the plots, supplemental irrigation was carried out for the rainy season based on crop water requirement and growth stages for the crop. Treated waste water samples were collected from the tertiary pond and tested in the chemistry laboratory. Also, soil samples were collected for different plots after the planting period, and tested in the soil science laboratory. The bean yield was measured and recorded after the growth period. Results showed that plots irrigated with treated waste water and under 25% NPK yielded 1.55 Tonnes/ha and 50% NPK yielded 0.71 Tonnes/ha, which is more compared to fresh water irrigated treatments. Based on the statistical analysis, F critical is greater than F observed, that is 10.13 > 0.0164 and 9.28 > 0.0438, to accept the alternative hypothesis. Soils irrigated with waste water had better physical characteristics, more nutrients, and organic matter. Also, by comparing soil characteristics from waste water and fresh water plots, it is evident that soils irrigated with waste water showed prevalent and higher mineral and nutrient content. It is concluded that the simulated irrigation schedule for the two irrigation treatments can be used as a recommendation strategy for the farmers to adopt treated waste water recycling for irrigation. Also, the nutrients in the waste water can be used as an alternative to the inorganic fertilisers that are expensive.

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LIST OF ABBREVIATIONS

AWC	Arabian Water Council
COD	Chemical Oxygen Demand
EABL	East African Breweries Limited
EC	Electrical Conductivity
FAO	Food and Agricultural Organisation
GCC	Gulf Cooperation Council
GDP	Gross Domestic Product
IWA	International Water Association
K	Potassium
KNBS	Kenya National Bureau of Statistics
N	Nitrogen
NEMA	National Environment Management Authority
OM	Organic Matter
P	Potassium
RCBD	Random Complete Block Design
SDGs	Sustainable Development Goals
TDS	Total Dissolved solids.
UN	United Nations
WHO	World Health Organisation
WW	Waste Water

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CHAPTER ONE

INTRODUCTION

1.1 Background Information

There is limited fresh water in the world due to reducing per capita water availability. Fresh water resources have become affected by an increase in population leading to a strain on the available amount (Sato *et al*, 2013). As most of the world's population depends on agriculture for income, alternative water sources have become an area of concern with different studies having been done to determine effective utilisation. According to El Gohary (2015), 70% of the entire universe is composed of water where 85% of the existing land is water as well. However, only a certain amount of this can be utilised for domestic and agricultural use, also, it has been adversely affected through pollution that aggravates the current situation (Alghobar & Suresha, 2016). More water is used for industrial purposes where the treated waste water is either recycled or released into rivers and lakes under predetermined quality guidelines.

Kenya relies heavily on agricultural activities for income and food. Agriculture constitutes approximately 70% of Kenyan fresh water withdrawals, and in most fast growing economies, it is projected to reach 90% (WWAP, 2012). In Kenya, the figure was estimated to be 80% by the year 2013 (FAO, 2013). Agriculture is not only a source of food but is also the primary source of employment and contributor to Kenya's GDP (Poulton & Kanyinga, 2014). As a result of various factors like climatic change and population pressure, the renewable fresh water capacity is projected to fall to 245 m^3/capita by the year 2025, which is below the UN recommended benchmark of 1000 m^3/capita per year (El Gohary, 2015). The current per capita water demand in Kenya stands at 760 m^3 (Ministry of Water and Irrigation, 2019).

Past research shows that increase in population has also led to forests encroachment, which are catchment areas, reducing the amount of rainfall recorded annually (Sato *et al.*, 2013). Forest encroachment is a threat to water catchment areas in consideration to the fact that some areas receive convectional rainfall that is triggered by dense forests. The population stood at 47.56 million people in 2019 compared to 38.6 million in 2009 national census (KNBS, 2019), thus, the need for sustainable alternatives when it comes to water use to meet the needs for the rapid increase in population. Reduced rainfall amounts, industrialisation, and demand for better living standards have made reliance on water to increase. As a result, management practices have emerged to safeguard the available capacity and achieve effective and efficient use. Some of these water management practices include recycling, treating, and efficient usage, and they apply differently.

Although water harvesting may seem as a cost effective alternative, the reducing rainfall amounts may not reach the required agricultural and food security targets, hence the need to adopt supplemental irrigation (Al-Rashed &Sherif, 2000). As it stands, Kenya is a water scarce country with a per capita renewable amount of fresh water of less than 493 m^3 per year (Services Regulatory Board, 2013). According to Coombes *et al* (2016), treated waste water has been used successfully in various countries such as India, Pakistan, and Egypt. As such, treated waste water can be used as an effective alternative to address the current water shortage. Further, treated waste water re-use can help in achieving groundwater conservation and protection. Most of the treated waste water is released into rivers and lakes under predetermined regulations. Examples of cases that call for alternative sources of water is the extensive part of the Eastern and North Eastern parts, which are deterred from high crop production because of shortage of rains and inadequate ground water to support arable and livestock farming.

Israel is the leading nation in water recycling where nearly 90 percent of wastewater is treated for reuse, most of it in agricultural irrigation (Postel, 2014). As such, it can be used as an effective alternative to the current water shortage considering groundwater conservation and protection. Most of the treated water is released into rivers and lakes under predetermined regulations. In Kenya, however, waste water in the big cities like Nairobi is released into rivers without proper treatment (Ngumba, Gachanja, & Tuhkanen, 2016). This is due to congestion and lack of modern sewage systems. This study, however, does not suggest proper recycling or treatment methods, or which modern treatment methods can improve the water significantly.

1.2 Problem Statement

Shortage of water for agricultural use has led to reduced bean yields in Kenya and Uasin Gishu in particular, which lowers the GDP for the county and country. For example, the current bean yield stands at an average yield of 0.8 t/ha, while the optimum that can be achieved (potential) is 1.8 - 2.0 t/ha (Green Life, 2019). With this, the United Nation has described Kenya to be at a critical condition when it comes to water shortage and food security. In many cases, the government has been compelled to source for grains such as beans from other countries, which puts a strain on its available income (Postel, 2014). This is expected to worsen as the country is having one of the least rate of per capita water availability at 493 m^3 per capita/annum, this is recorded as far below the recommended 1,000 m^3 per capita/annum (Loftus, 2015).

Additionally, due to human activities, there has been a significant reduction in the available water capacity in Uasin Gishu County where farmers are compelled to wait for the long rains to plant their crops. On the other hand, lower rains experienced in the county are not enough to cater for the local demand for dry beans leading to famine and food shortage. In 2010, the total yield of common beans was 417,000 tons, while the demand was 500,000 tons (Katungi *et al*., 2011). This disparity is due to complex biological and physical stresses (such as rainfall variability, insect pests, and diseases and declined soil fertility) which keep the yield at less than 25% of potential yield (Mahuku, Wosula & Kanampiu, 2017).

Most of the institution's and farms in the county, and Chepkoilel farm, which grow beans, wheat, and maize in large scale depend on rain-fed agriculture leading to seasonal planting (Katungi *et al*., 2011). In Kenya, there are two planting seasons for beans, which are guided by availability of rainfall. This creates a prevailing shortage of beans in some parts of the year. As a result, there is a need for a feasible intervention through finding alternative sources of clean usable water to supplement arable farming. To be precise, the case of Uasin Gishu, calls for new types of techniques as the local farmers harvest very low yields (0 - 0.5 t/ha) due to low rains and poor soils (Mahuku, Wosula & Kanampiu, 2017). Thus, the solution lies in improving the agricultural water use through recycling of treated waste water, which can supplement the inorganic fertilisers, hence reducing production costs, as opposed to water harvesting. This will lead to irrigation practices that improve water use efficiency while still achieving enough bean yields to sustain the increasing population the "more crop per drop" paradigm (Deng *et al*., 2006).

There is no existing knowledge on whether the treated waste water at the University of Eldoret treatment plant can be used safely and effectively for irrigation and lead to improved bean yield. The treatment plant is located next to the Chepkoilel River where the water from the tertiary pond is discharged into the stream (Appendix i). Hence, it is required that specific parameters of the University's waste water are measured and compared with the WHO and NEMA standard guidelines to using treated waste water for irrigation purposes (Appendix iii).

Treated waste water has varying effects on different physical and chemical features of the soil particles such as water holding capacity and availability for plant growth. Chemical impacts on soils are expected to cause variation in crop yield due to a shift in the conditions from healthy growth to quality deterioration and withering risks (Alghobar & Suresha, 2016). However, it is still unclear how this water can affect the soil parameters at the university's farm, and if using it for irrigation at the same farm can lead to higher bean yield. The farm is only used once per year to plant wheat during the long rains. There's need to utilise it fully during the remaining year and improve productivity by recycling the waste water available.

1.3 Objectives

1.3.1 Main Objective

To assess the effect of supplemental irrigation using treated wastewater on soil characteristics and bean crop yield.

1.3.2 Specific Objectives

1. To determine the level of physical and chemical characteristics of treated wastewater effluent from the University of Eldoret's waste water treatment plant.
2. To determine bean crop water requirement and thus develop an irrigation schedule using CROPWAT based on historic climatic data.
3. To assess using field trials the effect of irrigating with treated wastewater on bean yield.
4. To determine effect of irrigating with treated waste water on physical and chemical properties of soil.

1.4 Justification

It is essential to practise a well-planned irrigation at the University of Eldoret farm to alleviate the problem of declining bean yields in the area. Also, it is essential to formulate an effective decision-making technique in place which can act as a reference guide to advise the farmers in the area on the overall effects of irrigation using waste water on the yield and the effect on soil properties. Due to the increasing stress on the available water resources, it is essential to appreciate different types of irrigation water in the areas with declining ground water (Beekman, 1998).

As such, one potential water source is recycling the treated waste water to be used in the agricultural farms located near treatment plants. Also, small scale farming can reuse domestic waste water emerging from homes. In addition, waste water can contribute significant amounts of nutrients into the soils, which is essential for crop growth (Deng *et al*., 2006). The suitability of treated waste water to bean growth depends on the quality of water, which is determined by a comparison with NEMA regulations (Appendix iii). A key advantage of using treated waste water for irrigation is that the results can attest to the need for a water reuse decision support model.

This water reuse approach is well-aligned with the current strategic plan at the Ministry of Water, Irrigation and sanitation, which is purposed to promote water sources to the farmers, which also aligns with Sustainable Development Goal 6 (Clean water and sanitation) (Cook, Kimuyu, & Whittington, 2016). In a session, the Executive director of IWA, professor Kala commented that the wastewater global market reuse and recycling attained about $12.2 billion in 2016 (Carnie, 2019). This is further estimated to reach about $22 billion by the year 2021 (Carnie, 2019). However, in Kenya, only few manufacturing organisations like EABL and Coca-Cola Company have a framework in place for water recycling (EABL Annual Report, 2019). The expansion in the wastewater market is in response to an increasing demand from industries and cities variability, which results to water scarcity when the global demand is on the rise. Therefore, wastewater management can be a potential alternative in helping curb water shortages in Kenya (Drechsel *et al*., 2015).

1.5 Hypothesis

Null Hypothesis:

H_0: $\mu_{1\ \text{treatment 1}} = \mu_{2\ \text{treatment 2}} = 0$, all the irrigation treatments result in the same crop yields.

Alternative Hypothesis:

H_a: $\mu_{1\ \text{treatment 1}} \neq \mu_{2\ \text{treatment 2}} \neq 0$, all the population means (crop yield) for the given irrigation treatments are different.

1.6 Scope

The research concentrated on irrigation with treated waste water where one bean variety was planted as the test crop at the University of Eldoret main campus farm. Waste water used was pumped from the last pond of the treatment plant. Further, it analyses irrigation with treated wastewater by using a randomised complete block design with two replications. The planting schedule was set for June to October, 2018 where beans were irrigated through a predetermined irrigation schedule. Data was collected throughout the planting season and analysed after harvesting the bean crop, 95 – 110 days.

1.7 Limitations and Assumptions

Some of the limitations to this study are the possible metal content in the wastewater which could lead to bean crop damage. However, tests were conducted to determine the metal content that was found to fall within the NEMA standards for irrigation water quality. Also, it was assumed that since the farm used was relatively small in size, two replicates would be effective in validating the results observed. Using two replicates can influence occurrence and minimisation of errors during data collection. In this case, Kawulich (2004) suggests increasing the sample size of the data to be collected to reduce such errors. Use of two replicates only was also limited by availability of finances for the drip kit.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This section is a highlight of the existing research works, waste water reuse globally, in Africa, and locally in Kenya. Also, it highlights the water treatment methods that are available locally and the components of this water. A comparison of different irrigation techniques used to apply treated wastewater to the plants, and consequences of supplemental irrigation were marked. Further, it discusses the methods used in data collection and analyses such as the CROPWAT Model. From a comprehensive study of past research, it is depicted that one will identify the gap in literature to form the basis for investigation.

2.2 Wastewater

The definition of waste water has been presented by different studies as water that is significantly affected by anthropogenic activities like pollution, washing, cleaning, farming, and industrial activities (Mema, 2010; Zhang & Shen, 2019). Anthropogenic activities lead to deterioration of resources on a global scale (Zhang & Shen, 2019). In regard to water, it can come from a mix of industrial, commercial, domestic or agricultural activities, storm or surface run-off water. It can also originate from infiltration or inflow from sewer system. According to Mema (2010), the sewage water or municipal wastewater is normally conveyed in a mix sanitary sewer or sewer line, and treated in a plant for wastewater management. The treated water is let through effluent pipes to the disposal medium such as rivers, farms, and lakes.

2.2.1 Physical and Chemical Characteristics of Wastewater

Different studies have shown that anthropogenic activities highly affect water quality standards (Zhang *et al.*, 2010; Chauhan, 2014). Waste water parameters have been analysed before where research has concentrated on the variations of total suspended solids, nitrogen, lead, total phosphorous, chemical oxygen demand (COD), copper, nickel, and iron (Carstea *et al.*, 2016).

According to Patil *et al*. (2012), the overall quality and contamination of irrigation water has been a key issue of concern especially in places with limited water supply. The domestic wastewater discharged from homes and urban settlements has been studied by different researchers (Chauhan, 2014). Based on colour, most of the researchers record an absence of colour, and some traces of colour depending on the water source. Percentage hydrogen (pH) ranges from 6.3 to 7.3, which further influences the existence of nutrients. The constituents in waste water can be grouped into basic categories according to Table 2.1 and 2.2 as quoted by (Carstea *et al*., 2016).

Table 2.1: Constituents in household/domestic wastewater

Constituent	Description
Microorganisms	Pathogenic bacteria
Biodegradable organic materials	Lakes and rivers depletion of oxygen, also ponds.
Additional organic materials	Detergents for washing, farming pesticides, fats, oily oils, colouring, organic solvents, phenols, cyanide.
Nutrients	Nitrogen, phosphorous, ammonium.
Additional inorganic materials	Acids, like bases, sulphides
Thermal effects	Hot water
Odour	Hydrogen sulphide

Source: based on Carstea et al, 2016; Chauhan, 2014; Zhang et al., 2010.

Table 2.2: Other parameter ranges

Constituent	Range
Nitrate	5 to 18.5 ppm
COD	506.9 mg/l to 602.9 mg/l
TDS	409 to 1505 ppm
BOD	246.3 mg/l to 569. 5 mg/l
pH	6.3 to 7.3
Sulphate	1 to 90 ppm
Potassium	10 to 60 ppm
Sodium	50 to 250 ppm

Source: based on Carstea *et al.*, 2016; Chauhan, 2014; Zhang *et al*., 2010.

2.2.2 Waste Water Recycling

Recycling of waste water is an essential practice for water conservation, flood prevention, and ecological balance. According to Dhakal and Nakarmi (2016), it will reduce already experienced stress on the available water supplies. Due to urbanisation, economic growth, and climate change, the available clean water supplies are dwindling leading to a near future crisis (Zhang & Shen, 2019). In most developing countries like Kenya, the growing demand for industrial and usable water due to rapid urbanisation has become costly. Most needs of the citizens are not met and most people end up with no water for domestic use (Fontaine & Lemar, 2017). Although these studies highlight the problems emerging from water shortage, they do not go ahead to give strategic recommendations on how to achieve water sustainability.

In countries like Kenya, few strategic measures have been put in place to solve water wastage when it rains. This has led to large amount of water going to waste due to lack of collecting mechanisms. Hence, there is need for further research on the feasible strategies that can be used in effective recycling of waste water. Shortage of fresh water contributes to severe problems within the Mediterranean region (Shemer & Semiat, 2017).

Waste water treatment processes have been identified to be expensive and require resources and heavy financing (Cheremisinoff, 2019). It is almost close to impossible for developing countries to recycle water to domestic use standards like drinking. As such, reuse for agriculture and industrial use has become the most viable alternative for most of these countries (Gude, 2017). One of Kenya's key development agendas is to increase agricultural production by reducing overreliance on rain-fed agriculture (Kimenyi, 2002). One of the ways in which this can be achieved is through water reuse and recycling for irrigation. However, such initiatives have not been adopted well in Kenya since most cases involve growing vegetables with raw sewage, which can be detrimental to people's health (Ndunda, 2013). This advocates for better methods of waste water recycling to achieve safe harvesting, hence the need for further studies.

2.2.3 Wastewater Irrigation

The process of wastewater treatment where solids in the sewer water are partly eliminated and partly changed through decomposition from sophisticated and highly putrescible organic substances to stable treatment processes have been done (Walsh, 2016). However, it is still important and a requirement that the solids and liquids are disposed after removing them (Katungi *et al.*, 2011). According to Sperling and Chernicharo, (2017), once this water has been treated into safer standards, it can be reused for irrigation during the dry periods to supplement rain water. In most countries, this technique has been adopted, but with minimum guidelines and studies to understand its full potential (Kilelu, 2004). Most of its use is domestic, where people use water generated from kitchens and washrooms for irrigation (Coombes, Smit, Byrne, & Walsh, 2016). However, this does not shed light on how such practices have led to food security or improved soils. Hence, the need to measure the available quantities for commercial and large scale use and for it to be more cost effective as compared to rain water harvesting. Further, due to its components, it is essential to simulate crop yield using a model to determine its effects (Ray *et al*, 2015), which limited research is available.

2.2.4 Wastewater Treatment Processes

The processes of wastewater treatment are designed to improve the wastewater quality (Zeng & Liu, 2015). The treatment processes may help minimise the pathogens such as bacteria, biodegradable organics, suspended solids, and several other disease causing organisms. These methods are more common and relevant for use in places where the water is used for domestic or drinking purposes. The nutrients include phosphates and nitrates (Zeng & Liu, 2015). Such nutrients contribute towards high concentration levels of algae that is unwanted. Algae and other nutrients growth can themselves become a heavy biodegradable organic load. Hence, further research would shed more light on whether waste water treatment methods improve water quality, and to what extent this treated water can be reused.

The common wastewater treatment processes are biological water treatment, physical water treatment, sludge treatment, and chemical treatment (Droste and Gehr, 2018). These processes aim to address specific aspects of wastewater. Also, Miklos and colleagues (2018) asserts that treatment methods are often intended to put the quality of the water in check, especially for the purposes of the targeted outcomes for reuse initiatives. The processes of water treatment also seek to neutralise industrial wastes or totally remove them (Weckenbrock & Alabaster, 2015). Among the effluents in wastewater are toxic chemicals that are got rid of through chemical treatment techniques, and using Chlorine (Cl_2) and Ozone (O_3) as oxidising agents to kill bacteria and purify wastewater to acceptable threshold levels, respectively (Glaze *et al*., 1987). With removal of the toxic chemicals, treated waste water can then be used for irrigation purposes (Weckenbrock & Alabaster, 2015). However, there is limited research on how treatment processes in Kenya affect the nutrient content in wastewater.

2.2.5 Levels of Wastewater Treatment Process

Primary chemical treatment has been designed to eliminate suspended, gross and floating solids from the raw sewages. According to Sato *et al*., (2013), primary chemical treatment includes screening process to trap the sedimentation and solid through gravity to do away with the suspended solids. Additionally, the secondary biological treatment eliminates the dissolved organic substances like food substrates and converting it to CO_2, water and energy for their growth (Jefferson *et al*., 2000). Lastly, the use of tertiary water treatment can help eliminate over 99 percent of the entire impurities from sewage, yielding an effluent of domestic use quality and drinking water as demonstrated by the World Bank group resource guide (World Bank, 2009). However, there is limited research on how treated processes in Kenya affect nutrient content of the waste water.

2.2.6 Methods of Wastewater Treatment

The physical treatment techniques involve approaches where zero gross biological or chemical changes are conducted and strictly physical situations are adopted to treat or improve the wastewater. Perfect examples are the coarse screening used to eliminate the larger unstrained sedimentation and objects (Crini et al., 2019). In the procedure for sedimentation, the physical situations/phenomena associated to settling of solids through gravity are permitted to function. Normally, this procedure involves holding the waste water for a short time period in some tank in quiescent-conditions, allowing the metal solids to first settle down, and getting rid of the effluent which is 'clarified' (Jefferson et al., 2000). However, this method is not effective as it does not remove dissolved components, hence, the need to understand other treatment methods suitable for achieving irrigation water standards.

Chemical treatment constitutes the adoption of certain chemical reactions to enhance the domestic water quality. Generally, the dominantly used chemical process in such cases is clarification. Chlorine is a highly concentrated oxidizing chemical, which is applied in killing bacteria and to help reduce the pace of the decomposition rate of wastewater (Crini *et al.,* 2019). The killing of the bacteria is achieved when important biological processes are impacted on by chlorine chemical. Neutralisation is a common chemical process used in numerous industrial processes for treatment operations (Gunatilake, 2015). Irrespective of this, these studies fail to point out whether the methods used help in achieving reusable water.

Neutralisation process involves the addition of base or acid to help adjust the levels of pH to its neutrality. Given that lime is a base, it is sometimes applied in acid wastes neutralization (Jefferson, 2000). The biological treatment on the other hand make use of microorganisms in its treatment processes, and in most cases bacteria is used in the decomposition process of waste where carbon dioxide is generated (Gunatilake, 2015), water and additional produce. Normally the biological treatment processes can be grouped into anaerobic approach and aerobic methods of treatments based on the dissolved oxygen availability (Jefferson, 2000).

2.3 Waste Water Reuse

2.3.1 Global Wastewater Reuse

The Organization of the Petroleum Exporting Countries (OPEC) Fund for International Development, which is commonly abbreviated as The OPEC Fund for International Development (OFID), together with International Water Association (IWA) fronts the argument that urgent, decisive, and big actions need to be taken to significantly increase wastewater treatment, recycling, and reuse (Beekman, 1998). The report emphasizes that cities are the primary drivers of the global economies, and thus, must be in front in using their resources to allow for transition to a circular economy. The report recognizes that wastewater is a global challenge. Today, about eighty percent of all the wastewater around the globe is discharged into the rivers, oceans and lakes when untreated (Raschid-Sally & Jayakody, 2009).

Untreated wastewater discharge creates hazards that relate to people’s health and environmental challenges in different parts of the world cities. It also contributes towards Greenhouse effect through the emission of Carbon Dioxide, methane, and nitrous oxide gases into the atmosphere. The quantity of these emissions is three times that yielded from the traditional wastewater treatment activities (Kaluli et al., 2011). Based on Figure 2.1, recovering energy, water and nutrients and other precious materials contained in the wastewater is a good opportunity for the cities to move to a circular economy and significantly contribute towards a sustainable water security around the globe (Karanja et al., 2009).

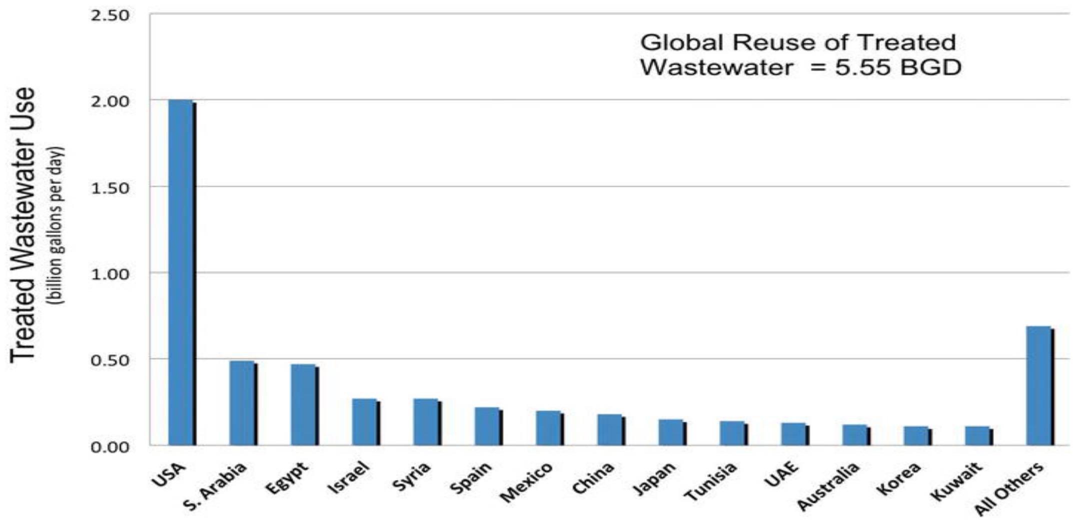

Figure 2.1: Global reuse of treated waste water (Kaluli et al., 2011).

The world market for wastewater reuse and recycling reached about $12.2 billion in the year 2016. It is further estimated that the wastewater recycling and reuse will reach $22.3 billion by the year 2021 (Kaluli et al., 2011). This exception in the market is in response to demand from towns and cities, and water industry, against a backdrop of population growth, increased urbanisation, and climate variability (Karanja *et al*., 2009).

All these factors lead to extreme water scarcity at a time when there is an increasing global demand for clean and usable water. As a resource, wastewater management is important and crucial solution to these problems (Braga, 2001). Four out of five (80%) of wastewater around the globe still finds its way to the environment without being treated at all – and this is besides the fact that it cannot be reused (Jiménez, 2009). The continent may not be in a position to continue enjoying the luxury of not treating wastewater for much longer. This supports the need to continue further research on the best methods for water treatments to achieve standards for irrigation.

California has been a leading example in the beneficial use of wastewater since 1890s, where raw sewerage was used on the 'sewer farms.' By the year 1987, over 0.899 Mm^3/d of the municipal wastewater was applied in different reuse cases (FAO, 2010). Wastewater use in agricultural sector has specifically been at the top of the rest of other sectors, with the emergence of landscape irrigation in the urban centres and the use of ground water recharge. In Kenya, more studies in this sector can help in achieving strategic goals associated with waste water recycling, with California as a case study.

On the contrary, in most of the Arabian states, there is scarcity of water resources, and this has posed serious constraints on the developments, both economic and social, negatively impacting on citizens' livelihood (Loucks et al, 2005). There is a decline in the available surface water and underground water due to over-pumping beyond the current rates of natural recharge, which has led to the reduction in water table. This leads to an increase in the salinity of underground water, depletion of underground water, and degradation of the ecology (Gorelick & Zheng, 2015).

Egypt is reported to produce municipal wastewater of about 3.5 B m^3/year, by 2010, its treatment capacity was in the level of about 1.6 B m^3/year (Choukr-Allah, 2010). Based on its 2030 Strategic Vision for Treated Waste Water Reuse, Egypt targets to add about 11.6 billion m^3 of waste water treatment capacity by the year 2030 (AbuZeid, 2014). Although there is an increase in wastewater treatment capacity, it won't be enough to effectively contain the anticipated future rise in the production of wastewater from the municipal water sources. This means that the untreated sources reaching the water bodies will continue to increase over the coming years (Choukr-Allah, 2010).

The Arabian and Gulf region reuse of treated sewerage water mainly targets the agricultural sector, specifically in Jordan and Syria (Sato et al, 2013). There is also an increase in use of irrigation for golf courses and landscaping in the Gulf Cooperation Council (GCC) member countries together with Northern part of Africa (Al-Rashed & Sherif, 2000). The main challenge for most of the Arabian countries is securing access to water that is safe to use and clean sanitation. The AWC (Arabian Water council, 2006) forecasts that by 2040, an additional 85 million people need to have access to clean and safe water. Also, another 95 million population of people require clean sanitation services for them to meet the SDGs (WHO/ UNICEF, 2015). Hence, there is need for water resource alternatives to curb the water shortage due to rising demands.

The requirements of the population that is increasing annually is estimated to have added lots of pressure on the total withdrawal of water. Jordan has used wastewater for irrigation purposes for several decades. The recognition and adoption of sewer water reuse in the country's (Jordanian) National Water Strategy as from 1998 was an indicator of putting great importance on the essentiality of water reclamation (enhance value) (Angelakis & Bontoux, 2001). Wastewater represents 10% of the country's total water provision and over 86% of Jordan's treated water is under reuse (Scot et al., 2003).

2.3.2 Africa Wastewater Reuse

So far in Africa, it's only Namibia that has successfully managed to recycle its domestic waste water to a drinkable state (Moyo, 2012). Namibia recycles its water through technology to make the water safe for domestic use (Jiménez & Asano, 2008). This program however requires creation of awareness and acceptance for the public. In regards to water reuse, in Namibia, the UN sustainable development goal (SDG) target seems to be better managed due to the current reuse doubling (Gude, 2017). Since formal reuse of water is not a very popular practice, at least in the arid Africa, the target may be attained with more ease than in the areas which already moved towards their targeted or given limits. It is however important to note that despite the SDG targets, untreated water is used directly and indirectly in the slum dwelling areas. It is posed as risks to consumable food and the farmers' health (Parween & Ramanathan, 2018), which leaves a gap in study of how to attain sustainable and safe ways to recycle the available waste water in big towns.

The developing countries are actually recycling water, and this is a reality to most of these nations. Waste water generated in the developing countries accounts for over 91% of the fresh water used (Moyo, 2012). Therefore, for most of the African states to have an existing local or informal water reuse strategy that is safe for the people, is not just a prerequisite, but has the ability to provide a chance to demonstrate the SDG reuse target progress, through expanding the formal methods of reuse of water (Mateo-Sagasta et al., 2015). The WHO is ready to provide help and assistance in this respect with several non-treatment methods too, to support mitigation of risk. The WHO 2015 program, WHO Sanitation Safety Plan Manual, provides the African countries an ample time to monitor and manage transition and risk control from unsafe forms to safe methods of water management and reuse, which is congruent to their context (Qadir et al., 2015). Hence, further research will provide recommendations on how to adopt a strategic plan among the local communities to recycle waste water for safe irrigation purposes.

2.3.3 Kenya Wastewater Reuse

In Kenya, treated wastewater can significantly contribute towards ameliorating the low levels of availability of portable water and irrigation water in the country. The Kenyan towns with over 100,000 people like Nairobi, Mombasa, Kisumu, Nakuru, Eldoret and Kericho amongst others have the capacity and possibility of yielding sufficient wastewater for use in the industries (Inoti et al., 2012). However, most of these urban centres do not have adequate sewerage system. It is therefore important and necessary that the country recognise wastewater as a potential resource and come up with specifications and requirements for recycling technology to be used in the industry, and agricultural sectors (Tran, Schwabe & Jassby, 2016). A wastewater national policy reuse and processing is essential to allow Kenya to enhance water availability for the different types of use (JICA, 1998).

NEMA (Kenya's National Environmental Management Authority) has set out the standards regarding the quality of irrigation water and the quality demands for discharge into the environment. The Environmental Management and Coordination Act 1999 (EMCA) schedules three, 8, 9 and 10 of water quality provides guidelines for the discharge of water to the environment or to be used in the recreational or irrigation purposes (Tran, Schwabe, & Jassby, 2016). Studies have however demonstrated that the quality of waste water from parts of Nairobi falls within the NEMA standards for reuse. For instance, the waste water quality in Nairobi was analysed and it was found that the levels of nitrates (100 mg/l) and TDS (630 mg/l) fall within the acceptable standards by the regulating authority, EMCA (Walls & Pilly, 2017). In the same manner, TDS (630 mg/l) and cadmium (0 mg/l) also falls within the NEMA standards. However, most of the waste water, due to a large population, does not pass through the sewage system. This makes it important that sewerage be treated for BOD removal, microbial contamination and turbidity.

2.4 Irrigation

2.4.1 Irrigation Development in Kenya

Kenyan irrigation potential has been estimated to stand at 540,000 ha and is distributed across four basins. The four basins include 200,000 ha in the Tana Basin, Ewaso Ngiro Basin 30,000 ha in Tana Basin 30,000 ha and Rift Valley basin 205,000 ha (Blank, Mutero, & Murray-Rust, 2002). Currently, the country has a potential of 1.3 million hectares when adequate water storage development is applied (Narita *et al.*, 2019). The irrigation development in the country has a long history since there are documentations showing that there were irrigation schemes in Kenya as far back as 16th century along the Kerio valley and along the coast (Davies & Moore, 2016). This system was so elaborate and advanced that conventional water management system had evolved and they featured canals longer than 15 km, and the transfer of water from one basin to another along the terrain through technology (Sivapalan, Savenije, & Blöschl, 2012).

2.4.2 Sources of Irrigation Water in Kenya

The water sources for irrigation primarily include ground water sources, surface water sources, grey water sources, municipal water supply, and other industrial and agricultural processes, and processing of the wastewater (Lanari *et al.*, 2016). The surface waters are the flowing water supplies like streams and canals. Surface waters also include stored and standing water sources like lakes, reservoirs, and ponds.

The ground water supplies may originate from wells and springs. Even though such water sources provide good quality of water, the supply is limited by the fact that the water in most cases has to be pumped and the quantity may not be enough particularly for irrigation purposes (Molle & Berkoff, 2007). Grey waters are used domestically, besides the black water like from washing machine discharge, sink drainage, or water for bathing. These already used waters are applied in watering the flower gardens, washing items in small scales (Hamdy & Lacirignola, 2005). However, the country is yet to achieve processing wastewater as an alternative to rainwater irrespective of Kenya's potential in taking control of famine and untapped agriculture potential in the ASALs (Molle & Berkoff, 2007).

Kaluli *et al* (2011) has done expansive research and given recommendations for national policy about wastewater irrigation in Kenya. This is a perfect example of scholars having contributed immensely towards helping bring ideas for water recycling in the country. The author's policy proposed provision of guidelines for the maximum limit for levels of herbicides, pesticides, heavy metals and chemicals in water reuse (Kaluli *et al*., 2011).

2.4.3 Selection of Irrigation Methods

It is necessary to pick the type of irrigation method based on the group of soil, water condition, climate of the region, crops to be grown, the ability of the farmer to manage the chosen system and the cost of the irrigation method (Lawston *et al*., 2015). Where wastewater is applied in irrigation, there is need to consider salinity levels, the environment, farm workers and toxicity hazards (Jiménez, 2006). The selection of wastewater as the source of water for farming depends on several technical factors like the choice of crops to be planted, fruits wetting, aerial and fruits, water distribution, contaminants and salts in the soil (Jiménez, 2006). Other factors to consider are the ease of maintaining high levels of soil water, availability of water for plant growth, and the reliability of the application and the ability to contaminate the environment and farm workers.

2.4.4 Irrigation Methods

The quality of industrial and domestic waste water normally limits its agricultural use to just sprinkler and surface irrigation techniques. Waste water quality also prevents it from being used in irrigation of vegetables and fruits crops (Abdel-Aziz, 2015). However, farmers adopt different methods of irrigation for their farming based on the availability and access to water. For example, farmers, like in rice planting, are supported by surface irrigation through flooding of fields. Hence, the type of irrigation system largely depends on the crop and availability of water.

Surface irrigation is where water is supplied to the field and allowed to infiltrate into the soil (Pescod, 1992 and Brouwer, 1988). There are different types of surface irrigation including border, basin, and furrow irrigation. In basin irrigation, the water is released into the farm fields surrounded by bunds. The fields are normally very small and flat. However, basin irrigation can only be used by small scale farmers. In border irrigation, water is released to the upper side of the field and it moves through a long graded trip of land surrounded by bunds (Sacks et al., 2009). Lastly, furrow irrigation is where the field features ridges used for growing crops with furrow as water drips in. The irrigation water infiltrates into the soil and goes to the crop roots. However, their suitability with waste water use is limited as the water will come in contact with crops, hence, causing contamination (Hytteborn, 2005). Also, flooding fields with waste water may lead to water borne diseases as humans will come in contact with it, hence, the need to research on the best method to facilitate use of waste water.

In sub-irrigation, water is distributed to the farms through underground and is directly applied to the crop roots using sub-surface canals and pipes. In localised irrigation method, water is supplied to the crops by wetting only a small part of soil close to the plant and not directly to the plant (Pescod, 1992), hence, most suitable for waste water. The water is applied to the crops through trickle or drip irrigation system, micro sprinklers, or bubblers (Hytteborn, 2005). The main problem with using drip irrigation method with waste water is blockages that are caused by debris. When choosing the most suitable irrigation method for waste water use, there is need to consider a number of things like the slope of the land, the climatic conditions of the region, the water supply, and type of crops to be planted, and the cost of the irrigation system (Hassan, El-Khatib & Mahmoud, 2019). It is also important to determine the capacity to hold water by the soil and the rate of water infiltration. The farmer and the workers' skills are important in getting good results when using irrigation. In case where sewer water is used in irrigation, it is also important to consider other related consideration like filtration, pumping methods, and amount required at each specific time for strategic planning (Hytteborn, 2005).

2.5 Wastewater Irrigation Risks

The concentration of salt in wastewater is normally high in comparison to other common sources of irrigation water, and this means that salt may accumulate in the soil and this could be a problem to the farmer (Ayers and Westcott, 1985). Where the soil has high salt concentration the plants need to use more energy to uptake the water (Balkhair & Ashraf, 2016). Since some crops are highly tolerant and resistant to salt effects than others, such crops could be identified and planted in wastewater irrigated fields. Salt level in water is quantified as total dissolved solids (TDS) or electric conductivity (EC) (Pescod, 1992). In case the rate of leaching is too low, then salt will accumulate in the crop root area. Hence, it is essential to understand how to regulate salt accumulation in soils.

Where the drainage, surface flow or subsurface that transport the excess water from the soil is too small then the groundwater can be contaminated by salt (Cui *et al*., 2017). In case the water table is high a secondary salt contamination of the root zone may happen from the salt contaminated water. With basin and border methods of irrigation the leaching is very good and there is no accumulation of salt in the crop root zone (Pescod, 1992). In furrow irrigation method, however, there can be some accumulation of salt in the ridges causing some difficulties for the crops. For drip irrigation, only a regulated amount of water, needed by the crop, is applied, which reduces risks of salt accumulation.

The human health risks as a result of wastewater use in agriculture irrigation are as a result of pathogen organisms like viruses, bacteria, helminthes, and toxic substances like the heavy metals. The highly exposed people are in sport fields irrigated through waste water and people visiting the parks. World Health Organization (1998) has divided the regulation demands into three areas (A, B and C) depending on the group risks (Alobaidy *et al.,* 2010). Category A is most regulated since it impacts on both consumers and the field workers. Category B constitutes consumed crops without cooking and public areas lawns. Category C on the other hand is only regulated because of the health risk it possesses to the field workers, for instance industrial crops, fodder crops, trees, cereals and pasture.

Hence, to successfully use waste water for irrigation purposes, it is essential for farmers to understand the risks they are exposed to, and how to minimise them (Hassan, El-Khatib & Mahmoud, 2019). However, use of drip irrigation has been proven to eradicate these categories of risks as crops and farmers do not come into contact with the water. Another key emerging issues is the emerging pollutants found in rivers along large cities like Nairobi. Ngumba, Gachanja, and Tuhkanen (2016) found that the concentration of these drugs was very high in the informal settlements. Hence, this poses a great risk to residents when they use the same water, without regulations and proper treatments, to plant their vegetables. More research is required to understand how the drugs end up in rivers even after waste water treatment.

2.6 Effects of Wastewater on Soil Characteristics

Potassium is considered to be one of the top most essential macro elements needed for crop and soil productivity. This mineral is normally needed for agricultural crop farming and it is supplied by the effluent. Research studies reveal that the irrigated soil through wastewater has bigger portions of potassium compared to soils irrigated through ground water irrigation (Rovira *et al.*, 2006). Additionally, some studies reveal that there is a significant difference between the types of soil in the microbial load. Soil that is irrigated through waste water over-time does have higher levels of contamination in comparison to soils irrigated through ground water (Rovira *et al.,* 2006).

Organic matter plays a critical role in terms of enhancing soil fertility through its function in chemical, physical and biological processes in supplying the plants with the needed nutrients and also helps the soil to keep its moist content (Alobaidy *et al.*, 2010). Wastewater has been scientifically proven to improve the organic matter in soils. According to studies, soils irrigated through wastewater gives optimal organic matter content in soils.

In a study, Haring et al (2017) tested the effect of waste water irrigation, biochar and fertilisation on the soil characteristics in Western Africa urban agriculture. The aim of the research was to examine how waste water that is not treated is used widely for irrigation because it is a resource with high nutrients value and is available throughout the year. However, there is uncertainty about the interactions between biochar, soil properties, and fertilisation plus sewer water with time (Haring *et al.*, 2017). From this study results, domestic waste water irrigation led to an increase in soil pH and sodium (exchangeable) overtime. The study also determined that there was an increase in fertilization N, CEC and SOC. The results for all the locations showed that the effects of waste water and biochar was lower pronounced than reported in other places. However, there is not much research studies completed in the Kenyan soils to help find out the level of waste water effect on their physical and chemical components.

Further, wastewater is associated with an increased salinity level. According to Olsson and Newell (1999), treating wastewater also aims to regulate the level of salinity owing to increasing concentration of salts. From an empirical review of the impact of wastewater on salinity, irrigated soils depicted up to 9 % increase in the level of salt content with a retention capacity of about 34 kg ha^{-} y^{-} (McCartney *et al.*, 2009). Therefore, upon irrigation using wastewater there is a dire need for the review of salinity levels to check the eventual impact on soils. Generally, this recommendation is built on the notion that increasing salinity in irrigation water will translate into adverse condition that reflect the quality of soils; hence risking the future prospects of arable farming.

In a study by Wuana and Okieimen (2011), the researchers looked at wastewater recycling with a focus on shift in soil aggregate stability when using different types of irrigation water doses. Based on this study, it has been determined that availability of freshwater, and the degradation of the soil are basically the worst critical environmental challenges in the region acerbated by improper use of irrigation for agricultural activities where the organic matter is not properly managed. This implies that there is need to use the appropriate methods for wastewater management to achieve the required results (Braga, 2001). Parween and Ramanathan (2018) argue in their study that correct management of waste water and proper use followed by legislative policies can go a huge mile as an effective strategy for saving water and for helping restore the mean properties of soil.

2.7 Impact of Wastewater on Crop

2.7.1 Crop Quality

The treated wastewater is useful in enhancing the production of urban food because effective treatment of wastewater reduces fiscal pathogens content (Alobaidy et al., 2010). Proper treatment of wastewater together with appropriate handling of the produce helps reduce the chances of contamination of the farm produce (Cheremisinoff, 2019). Good handling of wastewater from a wastewater irrigated farm helps in minimising the health risks and exposure to the farmers themselves. In his works, Cheremisinoff (2019) agrees with the idea of localised irrigation, especially in cases where plastic sheeting covers the soil, and uses water and nutrients from wastewater more effectively leading to higher yield of the farm produce and certainly give greater levels of health protection from the customers and farm employees.

2.7.2 Crop yield

Irrigation with wastewater has been seen to increase crop yield due to the increase in nutrients in the soil, organic matter and good moisture content (FAO, 1992). Balkhair and Ashraf (2016) also agree that use of treated waste water boosts plant growth due to more organic matter in the soil, which provides nutrients to plant growth. The long-term use of treated waste water for irrigation stands a chance to deter higher yields because of the effect of accumulated nutrients and increased salinity that could render the soil poor in terms of nutrient provision to nourish crop plants.

2.8 Bean Production

The world produces an average of 16.8 million tons of dry beans using about 23 million ha of land, and another 4.7 million tons of green beans from 0.8 ha of land (FAO & STAT, 2001). The common bean does very well in regions featuring medium rainfalls. The green beans also do well in places where other crops fail like places where there is heavy rainfall and hot weather that does not allow flowering for other crops and causes increase in diseases (Bryla, Banuelos, & Mitchell, 2003). The optimal daily average temperatures needed for the growth spans 15 ^{0}C to 21 ^{0}C. Additionally, the minimum average daily temperatures needed for growth is about 10 ^{0}C and a max of 26.9 ^{0}C (Pachico, 1989). It is known fact that very high temperatures lead to increase in pod fibre content.

The time period for growing different crops differs with the use of the chosen product and is basically 60 to 101 days for growing the green beans and 90 to 121 days for the dry beans (Bryla, Banuelos & Mitchell, 2003). The bean does not demand for a specific type of soil for it to grow, but it is preferred to use deep and friable soils with a pH of 5.4 to 6.0. The beans require 20 to 40 kg/ha N, 40 to 60 kg/ha P and 50 to 120 kg/ha fertilizers (Fageria, 2002). Beans have the ability to fix nitrogen to the soil which helps it meets high yield demand. For good early growth N can be used as a starter dose.

2.8.1 Common Bean Distribution in Kenya

Even though Kenya primarily has two planting seasons for the common beans, most of the farmers grow the beans once a year due to advanced and unpredictable climatic conditions. Hence, there is need to adopt a strategic plan of how to achieve an optimum bean production throughout the year. The Western and Rift Valley region which yield 22% and 33% of the national outputs, respectively, allocates land for planting common beans only once a year in the March-May season, which is another reason for low yield (Kimenju, Karanja, & Macharia, 1999). The March-May season is also referred to as the long-rains season, however, the experienced rainfall amounts have been reducing significantly, leading to lower bean harvest. Aljaloud (2010) study proposes recycling of waste water to achieve reliable yields as opposed to relying on short and long rains. The Eastern and Central Kenyan farmers, on the other hand, grow the crop twice a year with only 70% of the Eastern region farmers growing the crop during the long-rains (Katungi et al., 2011). There are still low levels of yields in the country and unstable fluctuations in rainfall amounts. With an extensive research in this area, an understanding of rainfall events can be achieved to enable formulation of a strategic tool to guide effective irrigation.

2.9 Conceptual Framework and Crop Models

The section highlights the key concepts and theories that have been used in this study to aid in gathering data and appropriately analysing it. First, the research is based on an experimental design that takes the random complete block design (RCBD). Also, several equations have been applied to calculate various parameters like the crop water requirements, reference evapotranspiration, and in the calculation of errors and significances in the ANOVA table (Appendix iv). Figure 2.2 is a flow chart diagram depicting the analysis process and the models applied to achieve the objectives.

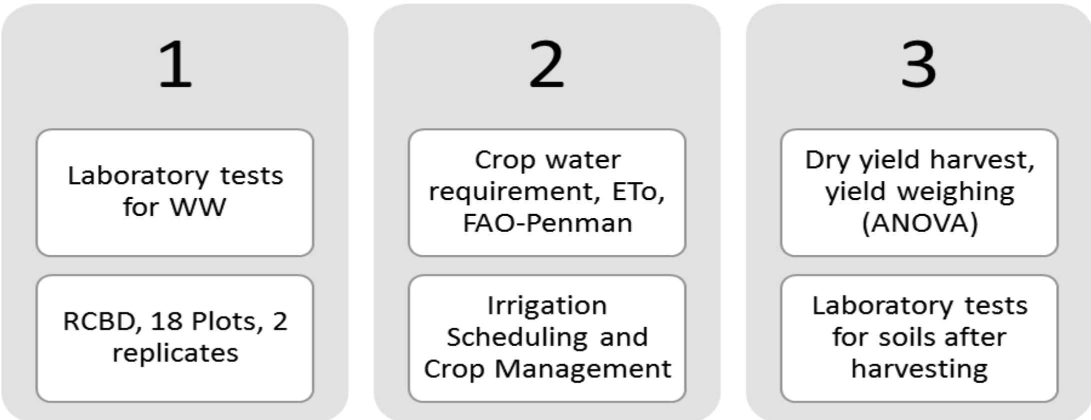

Figure 2.2: Conceptual Framework and Crop Models Flow Chart

2.9.1 FAO-Penman Monteith Equation

Several scientific methodologies and concepts have over the years been advanced to investigate and measure the rate of the evapotranspiration from various climatic data. The researchers have over time tried to test the overall accuracy of these concepts within various conditions (Córdova *et al.*, 2015). To curb this challenge, different standards have been developed and made available within the FAO research on irrigation and drainage policy paper (Djaman *et al.,* 2017). The modified penman has been credited to give the best results with respect to the reference grass crop. Different new studies in investigation and the highly advanced assessment of the requirements of the water crop and uses have identified some weak points in the techniques in the methodologies. Various studies analysed the overall performance of the four techniques for different places (Córdova *et al*., 2015). Even though the overall findings of such studies could have been impacted on by the site conditions, or by bias in gathering of the weather data, becoming obvious that the proposed techniques have different behaviours based on different parts of the globe (Djaman *et al*., 2017). Deviations from calculated to collected values were most of the time discovered to be above all parameters indicated through FAO, which is a key limitation.

2.9.2 ETo Calculator

Evapotranspiration can be defined as the mixture of crop transpiration and soil evaporation. Evapotranspiration therefore relies on the bean or crop character traits, weather characteristics, and environment and crop management characteristics (Raes *et al*., 2009). The rate of evapotranspiration from reference surface is referred to as the reference ETo and is written in short as ETo. It (ETo) involves inclusion of a huge uniform grass field as the reference surface (Van Dam *et al.,* 2008). The soil is completely covered by the reference grass crop, and it is kept short, properly watered and is continually and sustainably growing in the conditions for optimal agronomy (Raes *et al*., 2009). The ETo calculator is used to compute ETo based on FAO-Penman Monteith Equation using weather and station location data. A key limitation of using the ETo calculator is that it requires an extensive climate data base that may not be readily available. The equation used might also be complex for some researchers to comprehend within a short period of time.

2.9.3 CROPWAT

FAO developed the CROPWAT as a computer program to simulate the irrigation requirements of a crop. This is entirely based on the crop, soils data, and climatic parameters of the immediate area. Generally, the tool is used for research purposes and for developing decision making tools that can enable farmers to estimate crop water requirements and to develop the appropriate irrigation schedules (Smith, 1992). Based on various cropping patterns, the model is also suitable for simulating various supply schemes with respect to cropping patterns (Smith, 1992). The model has a user friendly interface that allows researchers to successfully use it by allowing them to input the appropriate required data effectively (Figure 2.3). Hence, one can easily create input files, do calculations, create charts, and get an output file. However, a key limitation is that the model requires dependable rainfall to be effective.

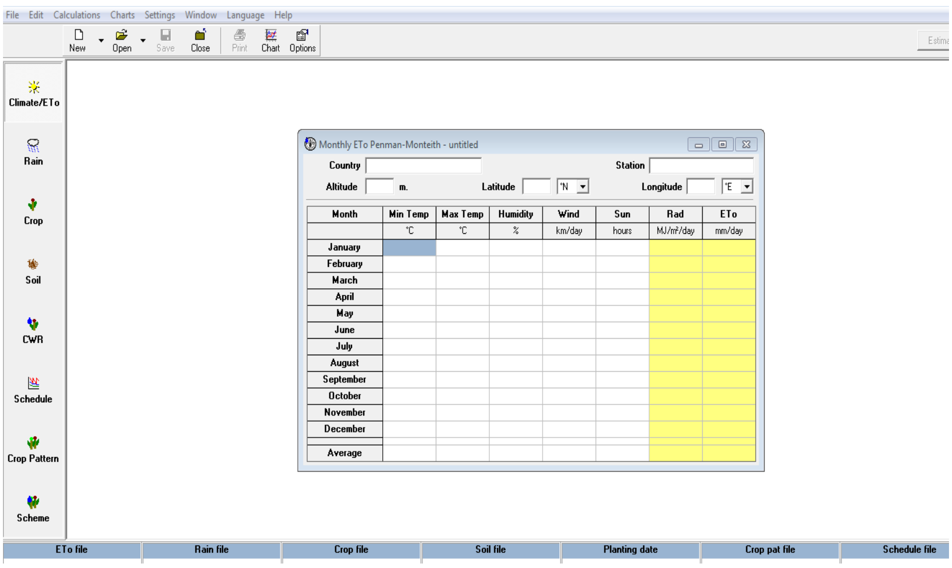

Figure 2.3: CROPWAT Model Window

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This section of the study presents the research methodologies that were adopted for the study under the following areas: Research design, study concept, population of the sample and sample size, sample size determination, sampling processes and procedures, experiments, research instruments, pre-testing research tools/instruments, and the procedures for gathering data.

3.2 Study Area

The experimental design was done at University of Eldoret main campus farm. The location has a local elevation of 2,100 meters above sea level (7000-9000 feet), and is located at 0˚31'N Latitude and 35˚17'E Longitude (Figure 3.1). The area does not experience prolonged dry season. The mean annual temperature is 16.6˚C. The mean maximum temperature for the area is 22˚C and the mean minimum temperature for the region is recorded as 9˚C, while mean annual precipitation is 1,103 mm. The driest month is January, and is 30 mm of precipitation. With an average of 172 mm, the most precipitation falls in August. For the study area, long rains are experienced from March to June and the long rains from August to October.

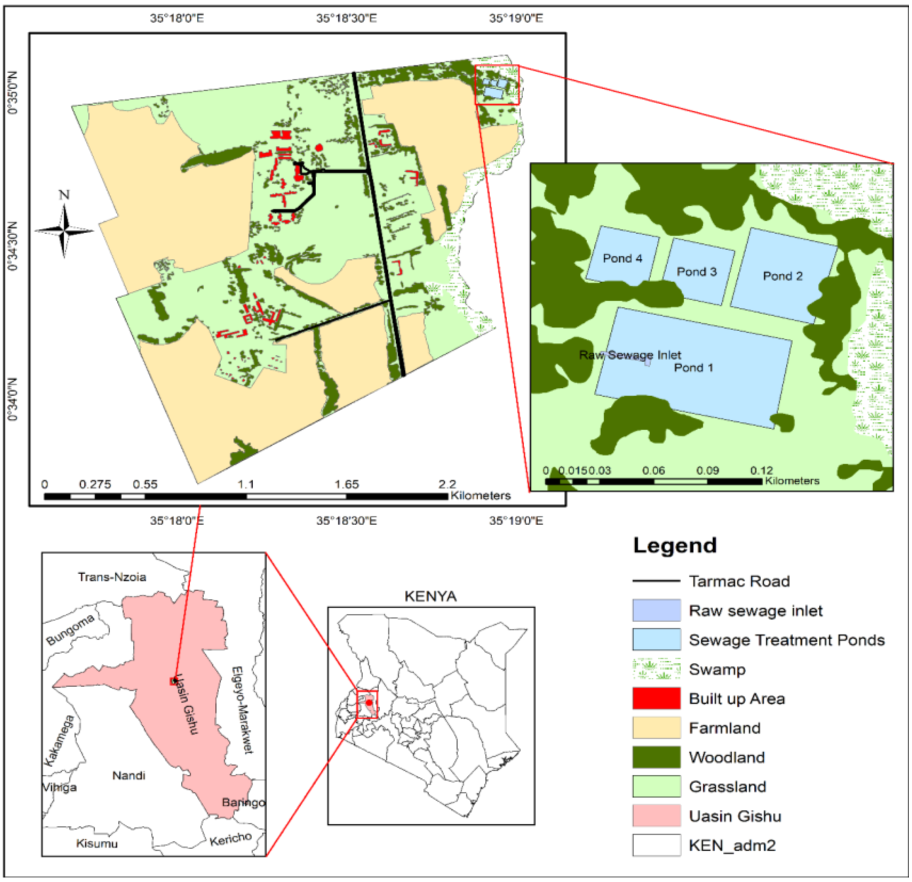

Figure 3.1: Location of the study area in Eldoret

3.3 Analysis for physical-chemical characteristics of wastewater

The research entailed collecting water samples from the third pond of the University of Eldoret wastewater treatment plant and filling it in clean bottles to determine its characteristics. These include water temperature, colour, and odour, solids that are water suspended, pH, the ratio of sodium absorption, metals like zinc, aluminium, and copper, chemical and nutrient loads and electoral conductivity. Such parameters as nitrates, bases, phosphates, and chlorides were tested in the university laboratories. The water quality criteria analysis generally varied with the planned water use measured against guidelines and standards set by NEMA (Appendix iii) and WHO. WHO guidelines used concentrate on recommending the best treatment methods to reduce contamination based on category A, B, C, as identified in literature.

Waste water temperatures, the dissolved oxygen, pH levels and the conductivity were measured at every sampling point. The sample's pH was also measured through pH meter calibration via the buffer solutions of already known pH figures. The EC (electrical conductivity) was measured through the conductivity meter which is calibrated through conductivity guidelines (0.01 m KCl with conductivity 1413 µ Scm-1). The K^+ and Na^+ ions were measured using Flame Photometer (flame have different colours when they burn), the carbonates and bicarbonates were measured through Alkalinity method. The phosphate molecule (PO_4) in water was determined through the Ascorbic Acid Method. The sample Chlorides were measured through precipitation argentometric method. For the metals like zinc, a sample of 50 ml and 5 ml concentration of HNO_3 were mixed together and stirred to have them digested.

After the samples were digested, they were filtered using the Whatman filter paper number 42. After filtering the sample, it was ensured that the volume was 50 ml using deionized water (Kimenyi, 2002). The sample was then analysed using a specified cathode lamp. The procedure then involved calibrating the Ascorbic Absorption Spectroscopy for every element through standard solution of known concentration before injection of sample. All the results were calibrated accordingly for water samples before pumping the water for irrigation purposes. All the specifications followed the National Environment Management Authority (NEMA) and World Health Organisation (WHO) guidelines for treated waste water reuse in irrigation.

3.4 Treatments and Experimental Design

The research was done as a RCBD research design (randomised complete blocks design) with two replications to generate eighteen experiment plots. Every plot size was 3 m × 1.5 m. The spacing left between each replications and plots was approximately 40 cm and 50 cm, respectively. Soil moisture and crop data were collected from these fields throughout the season. In each treatment, the bean root zone, 0.7 m, was refilled to field capacity (abbreviated as FC) where soil water in the root area came close to 45% of all the water available referred to as total available water (TAW). The readily available soil moisture content RAM, is calculated as RAM = 0.45× TAW. Also the total available water depends on the soil type, which was evaluated in the study.

Bean crop was identified for this research and was grown at a space of 20 cm between each plant and with a 10 cm raw spacing. Each plot had two lines of bean plants as guided by the two drip lines. This variety of crop was chosen due to its high levels of adaptability and it is mostly used in the area where the study was conducted. The research aimed to get sustainable policies to recycle waste water and thus improve bean yield in the dry seasons. The bean crop was irrigated using drip irrigation methods and was subjected to nine different treatments.

The crop growing season was categorised into four main growth stages including initial period, development stage, flowering period and the maturity phase. The categories were classified based on the bean growth curve. Table 3.1 depicts the application of irrigation treatments to the plants, the treatments are as follows (A to H).

Table 3.1: Irrigation treatments

SN	Waste Water (WW)	Fresh Water (FW)
1	A-0 % NPK	E-0 % NPK
2	B-25 % NPK	F-25 % NPK
3	C-50 % NPK	G-50 % NPK
4	D-75 % NPK	H-75 % NPK
5		**I -Control treatment 100 % NPK**

Treatment of fresh water at 100 % NPK concentration acts as a control experiment to have a clear observation if irrigation through treated waste water has the same significant effect as to applying fertilisers. Fresh water was collected from nearby shallow well and fed into the respective tanks that were elevated approximately 1 m from the ground surface (Appendix ii). After the plots were ready, it was essential to assign each plot an experimental treatment, which was conducted randomly. To achieve this, each plot was assigned a number (1 to 18) from one far end corner to the last as illustrated in Table 3.2. This was essential to avoid differences in a test study through accounting for spatial impact.

Table 3.2: A layout of the random complete block design

1	C-50% NPK	10	D–75% NPK
2	D-75% NPK	11	B-25% NPK
3	F-25% NPK	12	G-50% NPK
4	E-0% NPK	13	H-75% NPK
5	A-0% NPK	14	F-25% NPK
6	B-25% NPK	15	I-100% NPK
7	G-50% NPK	16	C–50% NPK
8	H-75% NPK	17	E-0% NPK
9	I–100% NPK	18	A-0% NPK
BLOCK 1		BLOCK 2	

3.5 Determining Bean Crop Water Requirement

i. Crop water needs are influenced by various factors like crop type, growth stage, soil characteristics, and climatic data. With regard to this, the first step was to define the crop and its respective growth stages up to maturity.

ii. After defining the crop growth stages, the next step was to calculate the total growth period of the crop in days. For each stage, the respective number of days was also defined.

iii. The growth stages defined have varying crop factors (K_c), which also vary based on the type of crop. This was also defined for the bean crop.

iv. Based on the historic climatic data and calculation of reference evapotranspiration ET_o, crop water need was simulated through the CROPWAT model to get the amount of water for each growth stage. Using the Penman-Monteith equation, the actual evapotranspiration was estimated and used to compute the crop water requirement.

The CROPWAT Model is a computer tool developed by FAO, department of Land and Water Development. Its key functions are the calculation of reference evapotranspiration, crop water requirements, and crop and scheme irrigation. It was adopted to the study to calculate the crop water requirements by inputting climatic, soil and crop data in various files as inputs to the model.

v. Irrigation schedules chart was generated from the CROPWAT after feeding the input files like soil, crop, crop water requirement, and climate data. With this, irrigation schedules that ensured that the required water amount was applied to the plots.

3.6 Irrigation Method

Water was supplied to the beans via a drip irrigation system. Use of a drip irrigation method was preferred as it eliminated contamination of the plant as water was directed to the soil. The system consisted of a PVC main line and sub main lines of diameters 50 mm and 32 mm respectively. Polyethylene drip lines (laterals) of 25 mm in diameter were used to irrigate the beans. The drip lines had built in emitters with a nominal discharge of 1.2 l/hr spaced 20 cm from each other. Additionally, control valves were installed at the entry of each plot to adjust and control the amount of irrigation water delivered to each plot.

It is essential to apply the right quantity of water at the correct time. Hence, the process involved the use of a soil water balance equation. First, the daily crop evapotranspiration was generated using CROPWAT and the historic climate data from CLIMWAT database using Equation 3.1. The CLIMWAT tool is used together with CROPWAT to allow the calculation of crop water requirements (FAO, 2013). It facilitates an easier access to climate data at the correct format that can be fed into the CROPWAT programme.

$$ET_C = K_C \times ET_0 \qquad (Eq.3\ .1)$$

Next, it was essential to get the depth of the application irrigation through equation 3.2 and 3.3

$$I_{T1} = (Wr_{Fc} - Wr_{T0}) + [\sum_{T0}^{T1} ET_C - \sum_{T0}^{T1} RF - I_{T0}] \qquad (Eq\ .3.2)$$

$$Wr_{Fc} - Wr_{T0} = 1000\ (\theta_{FC} - \theta_{T0})\ Zr \qquad (Eq.3.3)$$

Where:

ET_c = Crop Evapotranspiration for no water stress conditions

ET_0 = Reference Evapotranspiration

I_{T0} = Irrigation Depth at Time T_0 (mm),

I_{T1} = Irrigation Depth Required at Time T1 (mm),

K_c = Crop Coefficient

RF = Rainfall (mm),

Wr_{FC} = Soil Water Content in Root Zone at Field Capacity (mm),

Wr_{t0} = Root Zone Soil Water Content at Time T0 (mm),

Zr = Rooting Depth (m).

Θ_{FC} = Moisture Content at Field Capacity (Vol %),

Θ_{T0} = Moisture Content at Time T_0 (Vol %), To determine the duration of water application in seconds (s), the irrigation depth in (mm) and the area of wetted surface area was used. First, the area of the soil surface wetted by the drip system was measured using a tape measure and the area calculated. This value, combined with the rate of discharge of the emitters enabled conversion of the amount of irrigation water applied (Eq.3.4).

$$Ta = d * A\, q^{-1} * 3600 \qquad (Eq.3.4)$$

Where:

Ta = duration of irrigation (s)

A = area of wetted soil surface (m^2)

q = emitter discharge (l/hr)

d = irrigation depth (mm).

3.6.1 Soil Input File for crop water requirement

To compute water retention characteristics, the soil physical parameters like the moisture holding characteristics were evaluated. Also, the textural class was determined from samples collected strategically from the field. It involved the excavation of three profile pits from random points in the field. Undisturbed soil was collected from 0.5 m depth using the Kopecky ring that is 100 cm^3 in volume. Next, the total mass of the soil samples was dried in the oven at 110 °C for 24 hours and later weighed. From this, the bulk density of the soil was calculated using equation (3.5), which was used to get the soil water holding characteristics.

$$P_b = \frac{Ms}{Vs} \qquad (Eq\ 3.5)$$

Where:

P_b = Bulk Density

Ms = Total dry mass of sample

V_s = Bulk Volume of dry Soil

The next step involved getting the soil texture using the soil separation method into its relative proportions of clay, sand, and silt. This was done after collecting soil samples from the farm, air drying them, and separating their particle sizes using the hydrometer approach. In hydrometer method, the soil particles are dispersed with calgon followed by agitation. After it is dispersed, the amount of every particle group is measured (Rossi *et al*., 2008). After obtaining the relative proportions of clay, sand, and silt, the next step was to use the pedo-transfer function to extract other soil physical characteristics like the textural class, water content at saturation (θ_{SAT}), field capacity (θ_{FC}) and permanent wilting point (θ_{PWP}) (Rossi *et al*., 2008).

The initial soil water content (SW_0) and the soil water content during the planting period were measured, recorded, and eventually monitored throughout the experiment. SW_O was calculated using the gravimetric methods while SW_c was taken at 50 cm of the root zone to determine the moisture content.

$$\Theta_m = \frac{M_{s+w} - M_s}{M_s} \times 100 \qquad \text{(Eq. 3.6)}$$

Where:

Θ_m = mass water content (mass %)

M_{s+w} = mass of wet soil sample (g)

M_s = total dry mass of sample (g)

Also, moisture content in volume is calculated through,

$$\Theta vol = \Theta_m * (P_b \times \rho) \qquad \text{(Eq. 3.7)}$$

Where

Θvol = Volumetric moisture content

Θ_m = Mass water content (mass %)

P_b = Soil Bulk Density

ρ = Water density (Kg/m^3)

3.6.2 CROPWAT Simulation

In order to determine the crop water requirement and irrigation schedule simulations, there are various input data that is required. This ranges from crop data, climate data, rainfall data, and soil data. Based on the climatic data, the model used the monthly climate data in estimating the reference evapotranspiration. The CLIMWAT model for CROPWAT was used to collect the historic climatic data for the University of Eldoret for a period of 20 years. Using the RAINBOW software, it was possible to plot the probability of occurrence of rainfall amounts for the growth period, which helped in generating irrigation schedules for wet, normal or dry conditions. CROPWAT also uses maximum and minimum temperatures, relative humidity, sunshine hours, and wind speed. For the bean crop, the input data included the planting date, K_c values at each growth stage, number of days for each growth stage, and depletion factor. For the soil input file, it was essential to include the maximum rain infiltration rate, total moisture content, initial soil moisture content, and the maximum rooting depth.

3.7 Irrigation schedule

In all experiments, a three-day irrigation interval schedule was generated, and the volume of water to be used on each interval derived from the computed crop water requirement in the CROPWAT (Jiménez *et al*., 2009). From this, time and the application depth of the irrigation events were also specified. The equivalent in volume basis was found and applied to the plants according to the various treatments.

The CROPWAT model was used to develop an irrigation schedule to be used on bean crop under the predetermined climatic conditions, which give maximum yield. According to FAO, influence of rain should be taken into account in an accurate manner to give accurate results (Jensen and Allen, 2016).

3.8 Soil characteristics due to irrigation with treated waste water

After the crop growth period, undisturbed soil samples from the plots were collected strategically from every horizon up to 50 centimetres in depth using an auger. This was done to test the soil in regards to physical features like textural class, EC, pH, the average bulk density, and organic matter. The above mentioned soil parameters were analysed at the university's chemistry laboratory. The analysis involved organising the samples depending on the plots and blocks, and labelling them with respect to plot and block numbers. Further, it involved taking two samples of soil from each plot to have uniformity. The study then determined the sampling depth of the sample to represent the root zone of the crop, which also needed to be consistent with the sampling depth that was used in creating the calibration data set that was to be used to interpret the soil tests.

3.9 Waste water effect on crop yield

After the growth period of the crop, beans were harvested from each experimental plot, and their dry mass taken using a weighing scale and recorded in Kilograms per hectare. The yield data was then analysed to determine any sources of error by using the F critical factor. Figure 3.2 below shows the flow chart of the key methodological processes. To analyse the null hypothesis and test it, yield from the fresh and treated waste water at 0 % NPK treatment results were then adopted where freshwater treatment was used as the control experiment. The use of the ANOVA statistical method in the study helped in making a comparison of the treatment samples while determining the difference between these samples (Kawulich, 2004).

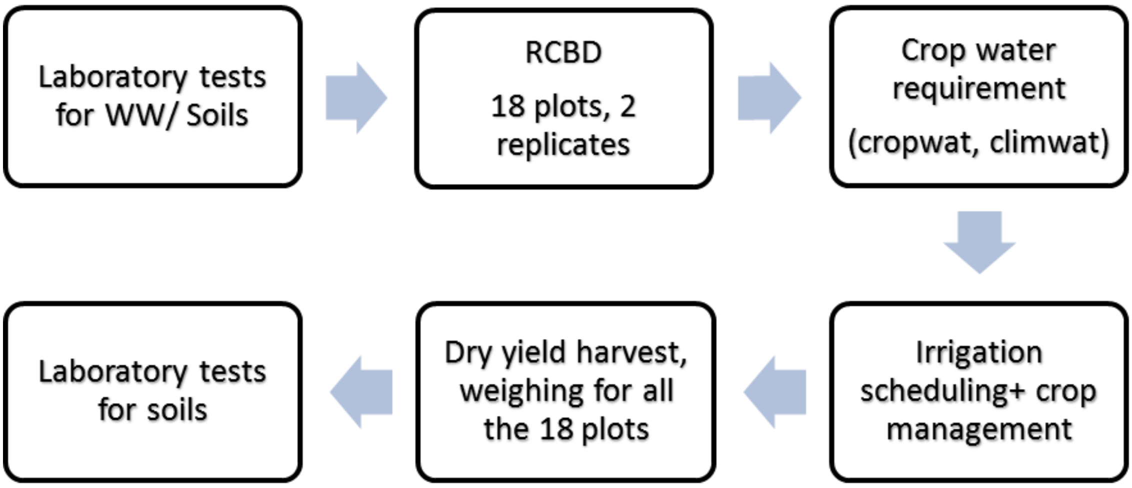

Figure 3.2: A flow chart of the key methodological processes

3.10 Data analysis

The research involved collecting data about soil properties from two soil samples taken from each plot; before and after the 95-110 days' growth period. Data was analysed using Minitab and Analysis of variance (ANOVA). The research has two sources of unique variations in the number of observations (n) retrieved from the RCBD trial. The size of the two sources is used to show whether the differences observed is due to chance or is real. The data gathered from the crop yield from all the treatments was then tested to determine levels of significance. The data was then analysed statistically using standard-deviations and mean. Variance analysis between the treatments was done and used as indicators for significance levels for the treatments.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Treated Waste Water Physical and Chemical Traits

After collecting treated waste water samples from the last pond and taking them to the chemistry laboratory for analysis, the following results were recorded in Table 4.1.

Table 4.1: Treated Wastewater Physical-Chemical Traits

Physical-Chemical Characteristics	Sample 1	Sample 2	Average	Standard Deviation
Ph	8.0	6.2	7.1	1.3
Electrical conductivity(mS/cm)	432.0	458.0	445.0	18.4
Total Dissolved solids(mg/L)	307.0	313.0	310.0	4.2
Chlorine mg/l	81.0	79.0	80.0	1.4
Free and saline ammonia (N) mg/l	0.64	0.57	0.62	0.0
Albuminoidal ammonia (N) mg/l	-	-	-	-
Nitrate (N) mg/l	13.2	14.2	13.7	0.7
Nitrite (N) mg/l	0.026	0.028	0.027	0.0
Phosphates PO_4 mg/l	6.1	3.9	5.0	1.6
Suspended Solids	17.4	16.6	17.0	0.6
Permanganate value (4 hrs at 27 degrees) mg/l	7.0	12.0	9.0	3.5
Biochemical Oxygen demand (5 days at 20 degrees mg/l)	14.1	12.9	13.5	0.8
Chemical Oxygen Demand	-	-	-	-
Chloride (mg/l)	0.007	0.003	0.005	0.0
Chromium (mg/l)	0.27	0.33	0.3	0.0
Cobalt (mg/l)	0.09	0.07	0.08	0.0
Copper (mg/l)	0.032	0.038	0.035	0.0
Aluminium (mg/l)	3.3	3.7	3.5	0.3
Arsenic (mg/l)	0.0	0.0	0.0	0
Boron (mg/l)	0.0	0.0	0.0	0

NB: These parameters were compared with the NEMA guidelines for irrigation water. The guidelines are available in the 2018 NEMA strategic report.

Table 4.2: NEMA Guidelines for Irrigation Water (NEMA, 2018).

Parameter	NEMA Allowable limits	Observed value from waste water
Ph	6.5-8.5	7.1
Chloride	0.010 (mg/L)	0.005 (mg/L)
Arsenic	0.10 (mg/L)	0.00 (mg/L)
Boron	0.10 (mg/L)	0.00 (mg/L)
Cadmium	0.50 (mg/L)	-
Aluminium	5.0 (mg/L)	3.5 (mg/L)
Chromium	1.50 (mg/L)	0.5 (mg/L)
Iron	1.00 (mg/L)	-
Copper	0.05 (mg/L)	0.035 (mg/L)
E.coli	Nil/100 ml	-
Fluoride	1.00 (mg/L)	-
Total Dissolved Solids	1200 (mg/L)	310 (mg/L)
Lead	5 (mg/L)	-
Selenium	0.19 (mg/L)	-
Sodium Absorption Ratio (SAR)	6.00 (mg/L)	-
Cobalt	0.10 (mg/L)	0.08 (mg/L)
Zinc	2.00 (mg/L)	-
Biochemical Oxygen Demand (BOD)	30.00 (mg/L)	13.5 (mg/L)

4.1.1 Discussion

From table 4.2, it is clear that the waste water used for irrigation in this research study falls under the NEMA acceptable limits for the elements indicated. Based on this, these limits enabled the determination of the type and amount of nutrients that were present for soil and crop use. Waste water has a high electrical conductivity due to presence of dissolved ions. However, there are very low traces of metals that could cause significant harm to the crops.

This can be attributed to the three levels of wastewater treatment method used (Alghobar & Suresha, 2016). Based on literature, BOD occurs on releasing biodegradable substance into the water body, microorganisms depend on the wastes as their food, breaking them down into simpler inorganic and organic matter (Berti & Jacobs, 1996). On decomposition in the aerobic environment the process yields stable and non-objectionable products like SO_4, CO_2, and NO_3 amongst others. The municipal wastewaters primarily contain the biggest percentage of water (say 99.9% is water), and a small concentration of dissolved and suspended inorganic and organic substances. Similar to this, waste water contains organic substances like fats, lignin, soaps, proteins, carbohydrates, together with their decomposition products (Tak, Inam & Inam, 2010). The water also contains synthetic and natural organic chemicals especially wastes coming from the washrooms and kitchens, respectively. The wastewater pH stands at 7.1, which is within the allowable limits as NEMA recommends that it should be in the range of 6.5 to 8.5 pH to be used in irrigation. In this case, pH could be attributed to the soaps and detergents in the water from the hostels.

4.2 Physical-Chemical Characteristics of Fresh Water

To differentiate the characteristics of fresh and waste water, fresh water samples from the nearest source were also taken for laboratory analysis and results tabulated in Table 4.3.

Table 4.3: Physico-Chemical Characteristics of Fresh Water

Parameter	**Characteristics**
Colour	Clear
Deposit	Organic Matter
Taste	-
pH	7.2
Turbidity	Clear
Odour	None
Electrical Conductivity at 25 degrees (mS/cm)	145.6
Chlorine (mg/l)	-

Fresh water is identified to have no chlorine. It is also clear of any odour or suspended solids. From research, fresh ground water has little to no traces of Nitrogen, Phosphorous, and Potassium, which makes it most suitable for use in the control experiment. This is in concurrence with Kanoti *et al.* (2019) study that argues that ground water from a shallow well may contain some pollutants and contaminants that may have some effects to crops.

4.3 Crop water Requirement and Irrigation Schedules through CROPWAT

4.3.1 Soil Input File

After the soil analysis from the farm was done, it was determined that its composition was 28% clay, 60% sand, and 12% silt. With these respective results, it was found that the soil's classification was that of sandy clay loam based on the USDA system (Khurana & Singh, 2012) (Appendix v). The physical characteristics of the soil and its texture were also determined based on the pedo-transfer function described by (Wagner *et al*., 2011). From the soil analysis, the bulk density was found to be 1.4 g/cm^3. However, the soils portrayed the same physical characteristics between the profile layers. A basic chemical analysis depicts that the soil had a high content of phosphorous and potassium, but low in calcium and magnesium. Table 4.4 below presents information on soil input profile.

Table 4.4: Soil input file

Soil Depth	Soil Texture	Field Capacity (FC) (vol %)	Saturated hydraulic conductivity (mm/day)	Permanent wilting point (WP) (vol %)	Point of Saturation (vol %)	Total Available water mm/m	Bulk Density g/cm^3
20 cm	Sandy clay Loam	24	270	15.4	40.3	86	1.4

For the Sandy Clay soil, the total water holding capacity (TAM) is 10 ×(Θ_{FC} - Θ_{WP}) per meter depth of soil.

Hence, TAM = 10 × (24 - 15.4)

= 86 mm/m-soil depth

The Allowable Depletion (AD) or Readily Available Soil Moisture (RAM) = p.×TAM, where p is the fraction of total available soil moisture that a crop can extract from the soil without suffering water stress.

Hence, RAM = 0.45 × (86) = 38.7 mm/m-soil depth

Considering the maximum root depth of the bean crop is 0.7 m, hence, the RAM at this depth is; 38.7× 0.7 = 27.1 mm

4.3.2 Climatic Data Input File

The planting period of the bean crop occurred from 18th June to 2nd October 2018. The probable rainfall pattern for this period had been predetermined and used to generate the irrigation schedule. This was essential to monitor the use of wastewater and freshwater in supplemental irrigation. From the CROPWAT model, rainfall, minimum and maximum temperatures were used to indicate the most relevant aspects of irrigation that could be captured in the course of using an ET_0 analytical tool. This is to evaluate the consequences of using wastewater in supplemental irrigation of beans.

Figure 4.1 is the generated historic data for the study area that was captured from the CLIMWAT

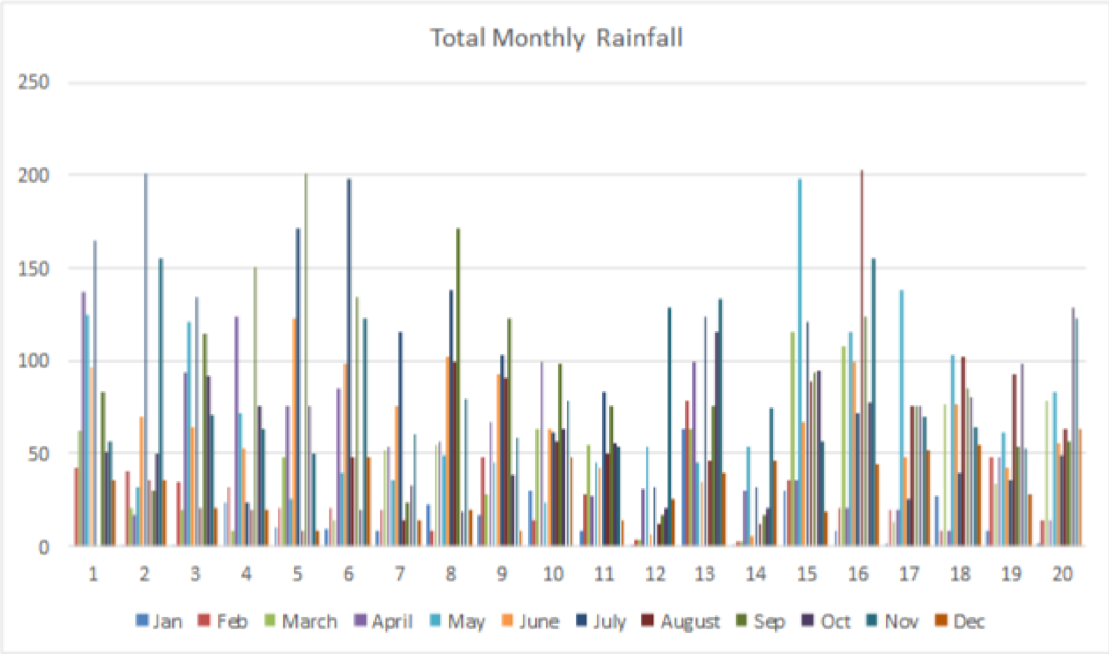

Figure 4.1:Historic rainfall data for the 20 years in Chepkoilel from 1996 to 2015

There is need to present the frequency analysis of the entire rainfall data from which one can determine the rainfall amount for the growth period. Using the Rainbow software, the frequency analysis for the rainfall amount that was collected for 20 years was analysed and the charts presented. The rainbow software offers statistical tests that investigate whether the rainfall data follow a certain distribution (Raes, Willems, & Gbaguidi, 2006). It was initially designed to test the homogeneity of hydrologic records, and to execute a frequency analysis of rainfall and evaporation data (Houessou-Dossou *et al.*, 2019). With this, one can be able to predict the occurrence of a certain rainfall event. For example, in this case, the annual rainfall that had the probability of 80% event occurrence (the dry year) was derived to be 536 mm (Figure 4.2). From the CROPWAT model and use of the ETo calculator, the mean ET_0 and rainfall for this period was derived to be 786.0 mm and 706.4 mm respectively.

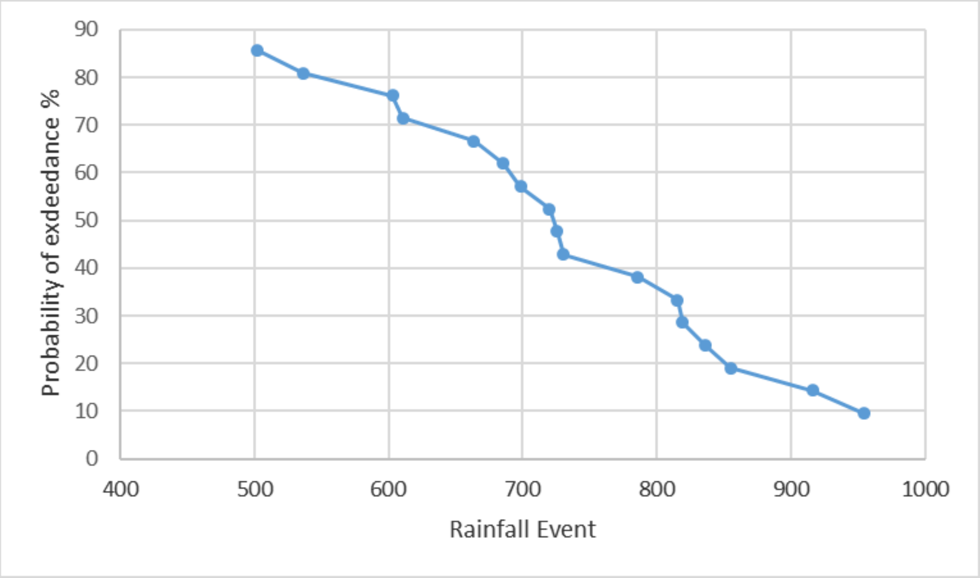

Figure 4.2 Probability of exceedance for the rainfall events

From the rainbow probability analysis, it is easy to predict the chance of a specific event happening within the planting season. From the probability plot (Figure 4.2), it is certain that the rainfall events were justified. Based on this reason, the rainfall events were used in the CROPWAT to generate the irrigation schedules based on crop water requirements. As indicated in the rainbow probability analysis, one can detect the dry, normal, and wet period (Table 4.5). Supplemental irrigation is recommended for the dry period, which occurs at 80% of exceedance. From Table 4.5 the event at 80% of exceedance is identified as 536 mm.

Table 4.5 Probability of Exceedance and respective rainfall events.

Probability of Exceedance	**Rainfall Event (mm)**	**Year Identified**
Wet 20 %	855	1996
Normal 50%	720	2004
Dry 80%	536	2006

After identifying typical wet, normal, and dry years as 2006, 2005, and 2003 from the frequency, the monthly rainfall data is plotted for the normal, dry, and wet years (Figure 4.3). Also, the monthly ET_o is also plotted as a line graph. The figure is a combination of the normal, wet, and dry years based on the 50 %, 20 %, and 80 % probability of exceedance.

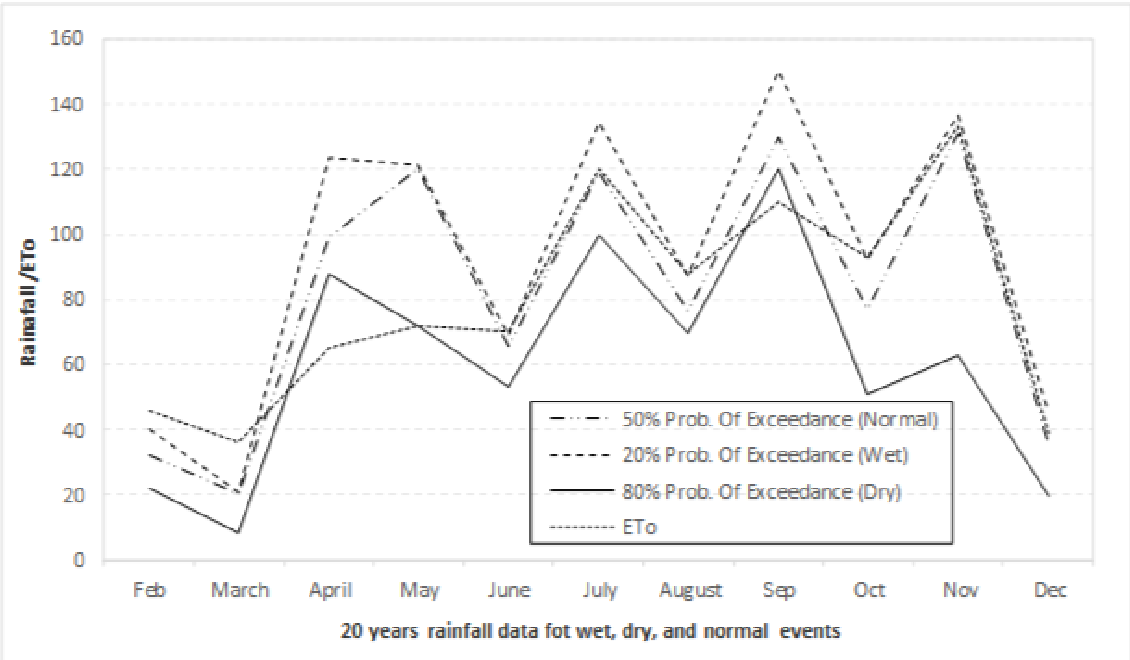

Figure 4.3 Mean monthly reference evapotranspiration and dependable rainfall amounts for each of the months of the rainy period in University of Eldoret with series 3-20%, 1-50%, and 2-80% probability of exceedance representing a wet, normal, and dry year.

Figure 4.3 helps in designing and planning for the irrigation schedule. From the probability analysis, it was possible to get the event that is expected for a specific return period. The key interest is to supplement the rainfall amounts during the dry event. A comparison of the ETo, dry, wet, and normal plots shows that ETo amount exceeds the dry event amount, meaning there is need to add water to meet crop water requirement.

4.3.3 Crop Input File

The approximate growing period for the bean crop is 95 to 110 days. The bean growth period was selected as June to October, during which, ET_o was 426.4 mm. The initial planting date was set as 18th June 2018. Bean crop has four growth phases including the following: initial stage, crop development stage, flowering stage, and the ripening stage (Table 4.6) (Gibson & Nolan, 1974). For each growth stage, a predetermined number of days is allocated as the Table 4.6 shows together with the crop coefficients.

Table 4.6: Bean crop growth stages Food and Agricultural Organisation (2009)

	Initial Stage	Crop Development	Flowering	Ripening
Length (Days)	15	25	45	20
Kc	0.35	0.70	1.10	0.30

Reference evapotranspiration is calculated using the 20 years' historic data and crop water need using the equation $ET_{crop} = ET_o \times K_c$. These parameters were fed into the CROPWAT model as input files to generate an irrigation schedule as illustrated in the next section.

4.4 Developing irrigation schedules

4.4.1 Results

The crop file, climate file, and the soil files were fed into the CROPWAT model to simulate the crop water requirement. Also, further calculations ensured with the development of a suitable irrigation schedule for the beans. The water level in the root zone was fed into the CROPWAT as the reference for determining when to begin the irrigation and end it. During the initial periods of bean growth, it was essential to start at Field Capacity. The soil-water-atmosphere balance equation was applied throughout the bean growth season to enhance irrigation scheduling. During the initial days of growth, or at the beginning of the season, soil moisture content was very close to the permanent wilting point SW_0 = PWP. During the irrigation treatment, it was critical to refill the root zone to field capacity. Hence, the analysis derived an irrigation schedule of 23 irrigation events. The interval was derived to be after every three days based on the crop water requirements. The highest irrigation water demand was found to be during the flowering stage, also referred to as the mid-season stage and the yield formation period. Hence, Table 4.6 presents its respective growth stages per number of days.

Irrigation water was added every three days as of the crop water requirements calculations (Figure 4.4). FAO (2013) highlights that water demand is often highest during the mid-season growing stage when the crop is in its flowering and yield formation stages of growth. After feeding the crop file, soil file, climate file, and the rainfall input files into the CROPWAT, the calculation option for an irrigation scheduling produced the chart (Appendix vi). Water was added through irrigation at an interval of three days until the late growth stage when the beans were almost ready for harvesting.

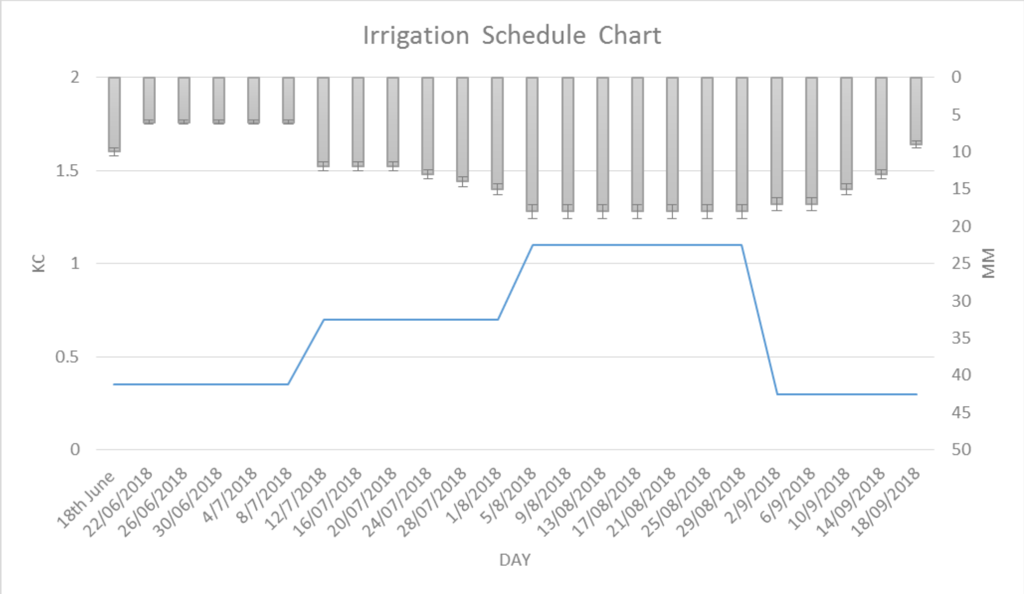

Figure 4.4: Irrigation Schedule Chart

4.4.2 Discussion

It is evident that rainfall variation comes about due to a wide range of factors, which intensify over time. The irrigation schedules were entirely designed using the CLIMWAT and CROPWAT software. In this case, a particular depth of rainfall was expected within the season based on a particular probability and a return period. The rainfall depths were predetermined through the frequency analysis of a 20-year historic rainfall data. This was obtained through the CROPWAT software that also generated the irrigation schedule. A similar study by Hashem *et al*. (2016), concentrated on the use of CROPWAT to generate irrigation schedules where the model is found to be an effective tool.

Crop water requirements are essential in planning, design, and operation of an irrigation method. This is specifically essential in drip irrigation to determine an application schedule (Khurana & Singh, 2012). For the bean crop, water requirement can be determined by identifying the crop factor. The highest, best and most recommendable crop water requirements reside in hot areas, and areas that are windy and dry. The lowest crop growth requirements in water are on the other hand found in cool areas, areas that are humid and cloudy, and do not have wind or very little wind (Allen *et al*., 1989). During hot periods, the evapotranspiration from the crops is higher, which raises the crop water requirement consecutively. On the other hand, cool periods lower the evapotranspiration. This is evident from choosing the dry event for supplemental irrigation as the evapotranspiration was higher, which raises water requirement.

4.5 Effect of Treated Waste Water Irrigation on Crop Yield

4.5.1 Results

Yields from all the treatment plots were recorded in Tonnes per hectare as shown in Table 4.7. The ANOVA model was used to test if there was any significant difference between yield from Block A and yield from Block B (Kothari, 2004). Also, the same statistical model was used to illustrate the significance in difference between yield from waste water treatments and that from fresh water treatments.

Table 4.7: Crop yield in Tonnes per hectare per plot

Treatment	**Block A**		**Block B (replicate)**	
	Biomass (Ton/ha)	**Yield (Ton/ha)**	**Biomass (Ton/ha)**	**Yield (Ton/ha)**
Waste water 0% NPK	1.80	1.47	1.76	1.37
Waste water 25% NPK	1.90	1.55	1.99	1.21
Waste water 50% NPK	1.31	0.71	1.35	0.80
Waste water 75% NPK	1.00	0.50	1.10	0.55
Fresh water at 0% NPK	0.90	0.70	0.98	0.78
Fresh water at 25% NPK	1.20	0.90	1.23	0.85
Fresh water at 50% NPK	1.41	1.20	1.43	1.10
Fresh water at 75% NPK	1.62	1.50	1.60	1.43
Fresh water at 100% NPK	1.70	1.65	1.67	1.59

The bean yield was presented in graphical form to show a clear indication of the variation of yield obtained from all the treatments and their replicates (Figure 4.5)

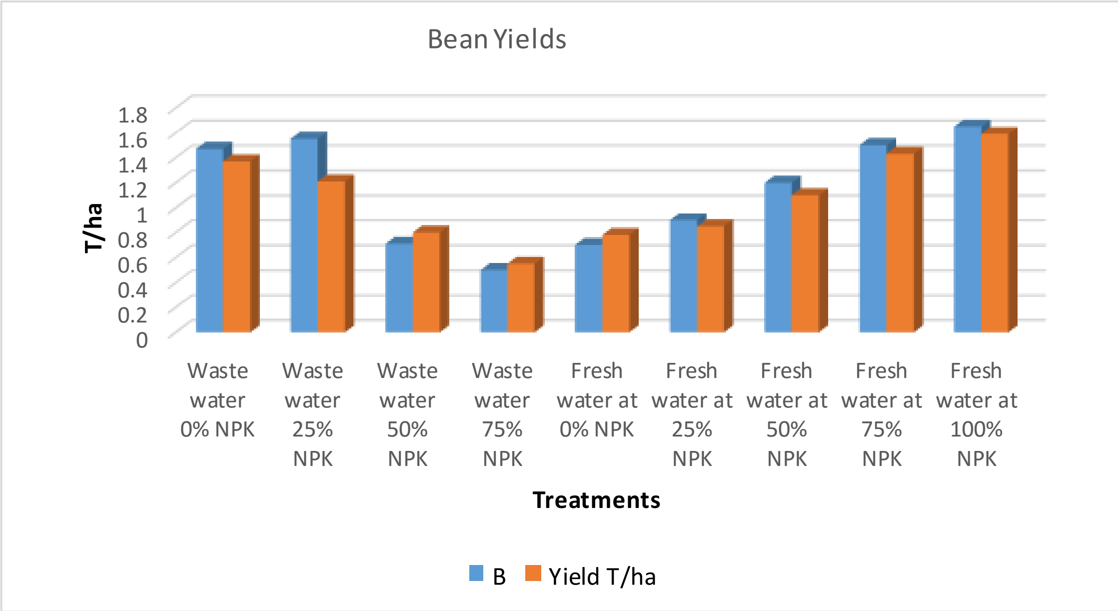

Figure 4.5: Graphical presentation of the bean yields

From the graph, it is evident that adequate presence of NPK leads to a higher yield of bean crop up to an optimum level. For the fresh water, this optimum level was identified as 100 % NPK, however, for the waste water, the optimal NPK for the crop growth occurred at 25 %. Above this, the yield decreases abruptly, which can be attributed to excess presence of Nitrogen, Potassium, and Phosphorous. This can be described as 'nutrient pollution', which is a form of water pollution (Lupi *et al.*, 2019). It refers to contamination by excessive inputs of nutrients. It is a primary cause of eutrophication of surface waters, where excess nutrients, usually nitrogen or phosphorus, stimulate algal growth that blocks crops from accessing adequate sunlight.

As a recap, the formulated hypothesis was generated from the following details: Four similar methods that can determine the bean yields from the irrigation treatments were compared. There were two different types of irrigation methods used, which is irrigation with waste water, and irrigation with fresh water. It was assumed that the two types of irrigation gave varying results from each other. Also, from the RCBD, the blocking factor is the type of irrigation, hence Table 4.8 is generated.

Table 4.8 Two Way ANOVA Analysis

	Waste Water (WW)		**Fresh Water (FW)**	
0% NPK	1.47, 1.37	∑=2.84	0.70, 0.78	∑= 1.48
25% NPK	1.55, 1.21	∑=2.76	0.90, 0.85	∑= 1.75
50% NPK	0.71, 0.80	∑=1.51	1.20, 1.10	∑= 2.30
75% NPK	0.50, 0.55	∑= 1.05	1.50, 1.43	∑= 2.93
100% NPK			1.65, 1.59	∑= 3.24

The main question for the hypothesis is whether there is any evidence at 5 % level of significance, which one of the treatments will give higher yields? Tables 4.9 and 4.10 shows the generation of ANOVA based on data.

Table 4.9 Generation of the ANOVA Model based on data

	Methods of fertiliser application %				
Type of Irrigation (Supplement)	**0% NPK**	**25% NPK**	**50%NPK**	**75%NPK**	**∑**
Irrigation with freshwater	0.70, 0.78 ∑=1.48	0.90, 0.85 ∑=1.75	1.20, 1.10 ∑=2.30	1.50, 1.43 ∑=2.93	**8.46**
Irrigation with waste water	1.47, 1.37 ∑=2.84	1.55, 1.21 ∑=2.76	0.71, 0.80 ∑=1.51	0.50, 0.55 ∑=1.05	**8.16**
∑	**4.32**	**5.51**	**3.81**	**3.98**	**16.62**

<u>Model</u>

$$Y_{ijk} = \mu + ح_i + \beta_j + (ح\beta)_{ji} + \epsilon_{jik}$$ (Eq. 4.1)

I = 1, 2...a

J = 1, 2...b

K =1, 2…n

Where: Y_{ijk} = observation taken under the i_{th} level of factor A and j_{th} level of factor B in the k_{th} replicate

μ – Overall mean

iح- effect of the i_{th} level of factor A

β_j – effect of the j_{th} level of factor B

ij – effect of the interaction between $ح_i$ and β_j

ε_{ijk} – Random error component

a= 2, b=4, n = 2, which are number of treatments, methods, and replications.

Critical factor (C_F) $= \frac{(\Sigma y_{ij})^2}{(abn)}$ (Eq. 4.2)

$$= \frac{16.62^2}{2 \times 4 \times 2} = 17.26$$

Critical Factor (CF) =17.26

$SS_{Total} = \sum \bar{y}_{ij}^{\,2} - CF$ (Eq. 4.3)

$$= (0.7^2 + 0.78^2 + 0.9^2 + \cdots + 0.8^2 + 0.5^2 + 0.55^2) - 17.26$$

$$= 19.18 - 17.26 = 1.917$$

$$SS_T = 1.917$$

Source of variation within treatments (SS_A) = $\sum_{j=1}^{r} \frac{y_i{}^2}{b \times n}$ – CF (Eq. 4.4)

Where b = 2

Therefore, SS_A = $\sum_{j=1}^{2} \frac{y_i{}^2}{4 \times 2}$ – CF

$$= \frac{(8.46^2 + 8.16^2)}{4 \times 2} - 17.26$$

=17.269 – 17.26 = 0.01

$$SS_A = 0.01$$

Source of variation between treatments (SS_B) = $\sum_{r=1}^{c} \frac{y_i{}^2}{a \times n}$ – CF (Eq. 4.5)

$$= \frac{4.32^2 + 4.51^2 + 3.81^2 + 3.98^2}{2 \times 2} - 17.26$$

$$= \frac{69.359}{2 \times 2} - 17.26$$

$$SS_B = 0.08$$

$SS_{Error} = SS_T - SS_A - SS_B$ (Eq. 4.6)

$$= 1.917 - 0.01 - 0.08$$

$$= 1.827$$

Table 4.10: ANOVA table analysis

Source of Variation	**SS**	**DF**	**MS**	**F_{OB}**	**$F_{critical}$**
Treatments (A)	SS_A =0.01	(a-1) $2-1=1$	$\frac{SS_A}{a-1}$ $=\frac{0.01}{1}=0.01$	$\frac{MS_A}{MS_E}$ $=\frac{0.01}{0.609}=0.0164$	F $(1,3)_{0.05}$ = 10.13
Methods (B)	SS_B =0.08	(b-1) $4-1=3$	$\frac{SS_B}{b-1}$ $=\frac{0.08}{3}=0.0267$	$\frac{MS_B}{MS_E}$ $=\frac{0.0267}{0.609}=0.0438$	F $(3,3)_{0.05}$ = 9.28
Error	SS_E =1.827	(a-1) (b-1) $1\times3=3$	$\frac{SS_E}{(a-1)(b-1)}$ $=\frac{1.827}{3}=0.609$		
Total	SS_T =1.917	(ab-1) $(2\times4)-1=7$			

For both cases of the irrigation types, waste water and fresh water, F Critical is greater than F observed. That is 10.13 > 0.0164 and 9.28 > 0.0438. Hence, one can accept the alternative hypothesis and deduct that all the treatments result in different crop yields.

4.5.2 Discussion

The Fresh water at 100% NPK irrigation treatment had the highest yield as compared to the other treatments. This is due to availability of the required nutrients at optimum level for plant growth. However, the waste water at 0% NPK and waste water at 25% NPK treatments had significantly equal yield to the 100% NPK irrigation treatment using fresh water. The residual effect of waste water application significantly led to increase in bean yield. According to Drewa *et al*. (1993), sewage nutritional contents increase chlorophyll content and oxygen evolution, hence, the crops grow well to maturity.

It is evident that waste water application increased germination percentage of bean seeds to become 93% compared with control experiments seeds (84 %). Table 4.11 highlights the number of seeds planted and number of seeds that germinated in plant treated with waste water at 25% NPK and freshwater at 100% NPK, which were considered the ideal treatment applications for optimum plant growth. Seeds irrigated with waste water at 25% were less due to the last drip emitters being at the edge of the plot where planting could not be done.

Table 4.11: Germination rate for the planted beans

	Seeds Planted	**Seeds that germinated (no. of crops)**	**Germination Percentage**
Waste Water at 25% NPK	46	43	93.5%
Fresh Water at 100% NPK.	50	42	84 %

Figure 4.6 shows the data presented in graph to have a comparison of the yields from two plots. The bar chart in the secondary axis gives a comparison of the germination percentages for the wastewater at 25% NPK and fresh water at 100% NPK.

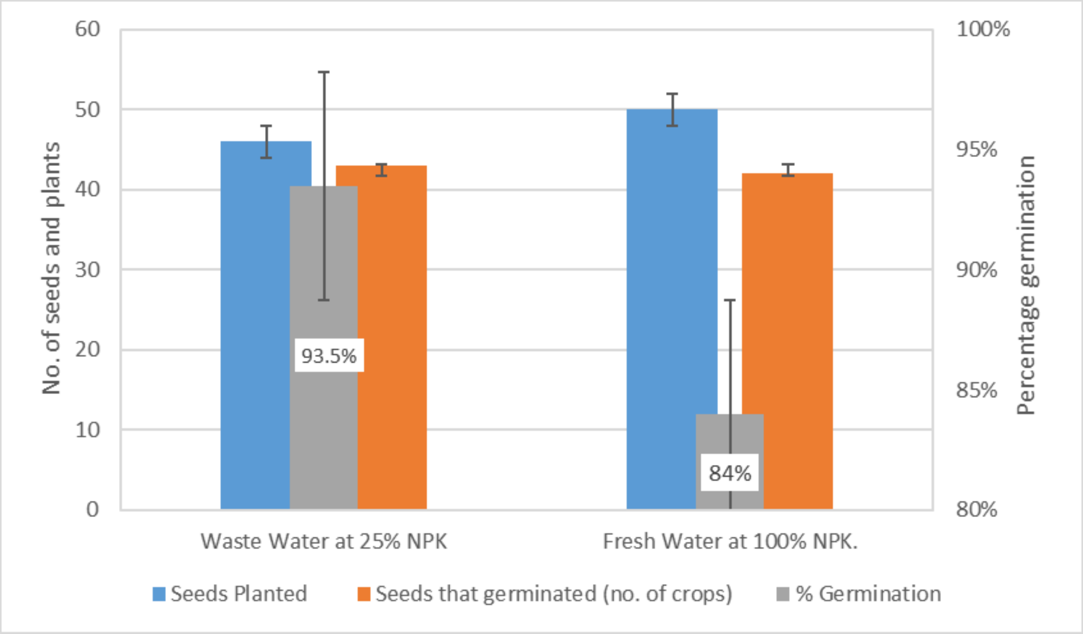

Figure 4.6 Germination percentage for waste water and fresh water

When wastewater from University of Eldoret is properly planned and used, it helps significantly to reduce surface and water pollution challenges. It also helps conserve valuable water sources and allows farmers to take advantage of the nutrients found in the sewerage system to grow and irrigate their crops. The Phosphorous and Nitrogen residual in the sewerage system may help minimise or get rid of the need to purchase fertilisers (Al-Hamaiedeh & Bino, 2010). It is beneficial to consider the reuse of effluent water and also consider wastewater collection and treatment. Also, disposal planning is essential to optimise sewerage system design in regards to effluent treatment and transport methods. Further, due to the reducing rainfall amounts, water harvesting may not be an effective approach compared to water recycling. Water collected is very low compared to the amount of water being disposed into lakes and rivers (Aljaloud, 2010). Further, waste water production is continuous whether the rains are there or not, hence, there can never be a ‘dry’ period when using wastewater for irrigation. Other than this, with correct guidance from the local government, the farmers will harvest more yields that can significantly contribute to a higher GDP.

4.6 Effect of waste water irrigation on physical-chemical characteristics of soil

4.6.1 Results

Physical-chemical properties of the soil samples from different plots used for bean production around the University of Eldoret are shown. These results are presented in Table 4.12; a graphical presentation is generated as shown in Figure 4.7.

Table 4.12: Physical and Chemical Soil Characteristics

Soil properties	**Soil from the freshwater plot**				**Wastewater irrigated Soils**			
Plots	Plot E 0% NPK	Plot G 50% NPK	Plot H 75% NPK	Mean Value for Freshwater	Plot A 0% NPK	Plot C 50% NPK	Plot D 75% NPK	Mean Value for Waste water
Potential Hydrogen (pH)	8.26	8.09	8.13	8.16	7.67	7.53	7.72	7.64
Total organic matter (%)	0.81	0.14	0.68	1.21	2.19	2.14	1.73	2.02
Electrical conductivity (EC) (μScm^{-1})	666	601	709	658.67	894	941	926	920.33
Total Dissolved Solids (TDS) (mgl^{-1})	431.1	370.9	465.25	422.42	550.7	620.7	601.2	590.87
Na mg/kg	443	520	551	471.33	402	451	520	457.67
K mg/kg	106	119	120	115	474	520	560	518
P mg/kg	6.1	6.3	8.31	6.90	27.76	29.62	25.30	27.56
N mg/kg	9	15	21	15	38.53	36.31	46.34	40.39

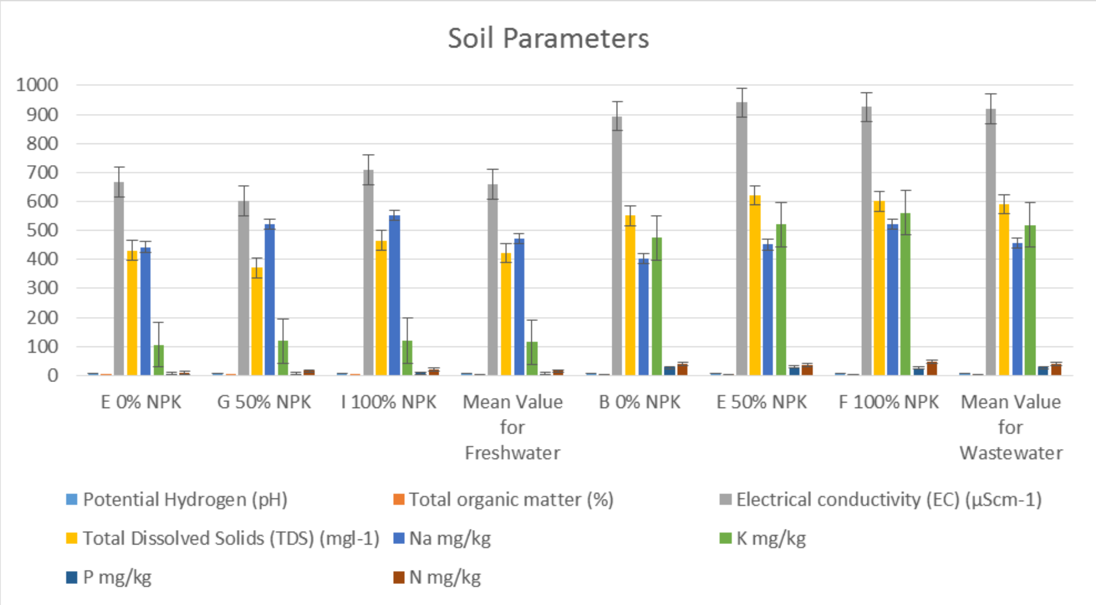

Figure 4.7 Physical-chemical properties of the soil sample

4.6.2 Discussion

(i) Potential Hydrogen (pH)

The varying pH value of the soil samples from irrigated plots represents the acidity or alkalinity degree. It is a significant parameter of soil quality owing to the fact that plant lives and growths often depend on the availability of the necessary nutrients, especially for their nourishment. The analyses revealed that pH values for the irrigated soils ranged from 8.09 to 8.26 for freshwater irrigation and between 7.53 and 7.72 for wastewater irrigated soil samples. A universally recognized pH standard of between 6 and 6.5 optimally favours a wide spectrum of crops because of the wide ready availability of most plant nutrients.

These findings concur with Dalahmeh *et al.* (2016) who reveals that treated wastewater for irrigation can lead to detrimental impacts on soil quality. In this case, a reduction in the soil pH value and an elevation of the soils' salinity are prevalent. The reasoning behind the reduction in soil pH revolves around the abstraction of the hydrogen ion from the acidic components of the wastewater. Therefore, the extensive use of treated wastewater for irrigation could eventually lower the soil pH beyond the survival point of a bigger assortment of relevant soil nutrients (Alghobar & Suresha, 2016). Key to note, pH values that were registered in soil samples after irrigating with freshwater and wastewater, to supplemental natural sources, are less than FAO's 8.4 recommendation.

(ii) Electrical Conductivity

Irrigation with wastewater led to an increasing EC value for soils from 894 to 926 µS/cm and a mean of 920.33 µS/cm whereas the average for the freshwater irrigation ranged between 601 and 709 and a mean of 658.67 μScm^{-1}. According to the changes in the value of electrical conductivity of irrigated soil samples from the wastewater and freshwater plots, it is clear regarding the presence of salinity, which stands out as an imperative indicator of success or failure regarding the state of fields that were previously irrigated for supplemental purposes (Berti & Jacobs, 1996). The values are slightly above the anomalies benchmarked by the Kenyan National Environment Management Authority (NEMA). As a result, for the electrical conductivity ranges in the UoE soils irrigated by waste and fresh waters could be triggered off by the moderate degrees of the salinity issue. Technically, this finding infers that the salinity issue could be addressed through the use of excess clean water in relation to the needs and requirements of plants like beans to induce leaching, which alleviates salts from root zones such as the topsoil layer.

(iii) Organic matter

Organic matter content is considered one of the imperative determinants of soil fertility. Its position emanates from the activity fostered in the chemical, physical, and biological processes that aim to readily avail the necessary plant nutrients and sustain moisture content levels.

Notably, treated wastewater registered remarkably high organic matter contents of about 2.02 % as compared to a mean rate of 1.21% in freshwater irrigated soils. It is a vivid implication that wastewaters significantly contain more organic matter compounds compared to freshwaters. The findings concur with many scholars who argue that treated wastewaters prolifically contributes to the levels of organic matter content in soils (Dalahmeh *et al*., 2016; Bougnom & Piddock, 2017, Valipour & Singh, 2016).

(iv) Phosphorous

Phosphorous (P) is an imperative chemical component of soils, which influences the growths and productivity of plants. Mean ranges of Phosphorous were found to be high ($\bar{x}$ = 27.56 mg kg^{-1}) in soils irrigated with wastewater as compared to the $\bar{x}$ value of 6.90 mg kg^{-1} for soils irrigated with freshwater. These findings are in line with the study by Orlofsky *et al*. (2016) that treated wastewaters lead to an anticipation of growing concentrations of Phosphorous in soils.

(v) Nitrogen

Nitrogen (N) was adversely improved in the soils around the University of Eldoret farm when wastewater was initially used in supplemental irrigation. The figures show a high mean of 40.39 mg kg^{-1} for the treated wastewater and 15 mg kg^{-1} for the soils irrigated with freshwater. Similar results were registered by empirical studies by Khurana and Singh (2012) and Berti & Jacobs (1996). Evidently, Phosphorous (P) and Nitrogen (N) are considered necessary macronutrients for ample development and growth of crops like beans (Orlofsky *et al*., 2016). Notably, the study's analysis reveals that the total composition of N was more than 0.1% for both freshwater and wastewater irrigated soils. Key to note, these findings fall below FAO's Guidelines where by soils with less than 0.1% Nitrogen are deemed poor.

(vi) Sodium

Sodium (Na) and its salts Na^{+} in soils irrigated by treated wastewater was 457.67 (parts per meter) ppm (mg/kg) on average as compared to 471.33 ppm for soils that underwent supplemental irrigation by freshwater. Similar results were reported by Oliveira *et al*. (2016). Sodium brings about considerations in arable farming as one of the specific toxic ions. Elgallal, Fletcher, and Evans (2016) inferred that sodium can directly influence the availability of crop water leading to adverse physical-chemical properties of the soil, specifically to soil structure. Sodium has the capacity to disperse soil; hence causing permeability decrease, higher compressibility, and reduced shear strengths. For the case of the UoE-based study, sodium concentration levels are still below the toxic levels despite the introduction of either wastewater or freshwater in the supplemental irrigation practice.

(vii) Potassium

Potassium (K) is among the most imperative macro elements that play a key role in soil and crop productivity. The use of water from effluents guaranteed the supply of potassium in the soil. The analysis results show that the use of wastewater in irrigation led to soils with significantly large amounts of potassium. It was found out that soil that was irrigated using wastewater showed a relatively high value of potassium concentration (518 ppm) in comparison to the soil that was irrigated with freshwater (115 ppm). It is evident how the introduction of wastewater influences the physical-chemical properties of the soil, which also matter to soil quality (Elgallal, Fletcher, & Evans, 2016). Therefore, it is logical for farmers around the University of Eldoret in Kenya to discern and adopt irrigation techniques and conditions that guarantee leveraged unfolding consequences regarding soil quality owing to the physical-chemical properties of the soil.

(vii) Total Dissolved Solids

Initially, the waste water has a high content of total dissolved solids, when used for irrigation, these dissolved solids are added to the soils. When the soils are tested after the growth period, the TDS will be available in the water that soil is suspended in. From Figure 4.7 it is evident that total dissolved solids are higher in content in the soils that were irrigated with waste water and low in soils irrigated with fresh water. This shows that waste water has higher dissolved solids, which were added into the soils. This is in agreement with Elgallal, Fletcher, and Evans (2016) study that depicts that waste water, due to dissolved solids, can lead to soil contamination with salts.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Background

The section highlights a recap of the whole research based on the key objectives and findings. It also presents the recommendations that are directed to farmers and policy makers.

5.2 Conclusions

The primary aim of the research was to analyse the effect of waste water irrigation on crop yield and soil physic-chemical characteristics. Field experiments were set up from June to October 2018 at University of Eldoret Farm. Essential data collected before and during the experiment period include climatic data, physical soil & waste and chemical soil & waste characteristics, above ground biomass, number of seeds and plants per plot, and final dry yield. The 100% fresh water irrigation treatment was used as the control experiment. The conclusions below have been deducted from the research:

1. It was evident that waste water from the University of Eldoret's wastewater treatment plant had varying physical and chemical characteristics. Some of the available nutrients include Nitrogen, Phosphorous, and Potassium. Other than these, a significant amount of total dissolved solids and organic matter was observed. The tests carried out for the simple metals showed some traces of zinc, aluminium, copper, and cobalt. However, there were no traces of boron and arsenic. In comparison to NEMA 2018 guidelines on irrigation water. The

waste water collected at the University of Eldoret plant was found to fall within these standards, and hence, could be used for irrigation.

2. Bean crop water requirement is dependent on its four growth stages, initial, development, flowering, and ripening. Each stage was found to have a different crop factor, and hence, varying crop water requirement. More water was required for the flowering and ripening stages. Through the historic climatic data collected for 20 years, and using CROPWAT, a frequency analysis enabled one to get the probability of exceedance for the wet, normal, and dry periods. Hence, a good decision making tool was formulated to guide farmers on effective waste water irrigation scheduling.
3. Waste water has a significant effect on crop yield. Waste water at 25% NPK yields more beans. It can be concluded that waste water can be used as an alternative to the inorganic fertilisers due to the availability of nutrients required for plant growth. However, a suitable policy should be formulated to achieve acceptance by the community of waste water use in the farms.
4. Apart from improving bean productivity, waste water is also essential to the soils as it improves structure and adds the required nutrients for soil fertility.

5.3 Recommendations

From the research results and discussions, several recommendations were generated:

1. It is essential for the local authorities, and farmers, to understand the components found in waste water before using it for irrigation purposes. Hence, they will be able to estimate the nutrients available to supplement the inorganic fertilisers for optimum plant growth.
2. When planting beans, farmers should understand the four growth stages and how each stage influences the crop water requirement. With this, they should

adopt the crop water requirement and irrigation scheduling guidelines in their decision-making involving waste water irrigation.

3. Farmers should adopt waste water irrigation with an aim of improving bean yield. Through this, they will be able to approach the bean yield potential for the country with a strategic support from the local government.
4. Based on the study, waste water irrigation improves soil structure and fertility, hence, it is recommended that farmers should adopt waste water recycling in their farms to supplement the inorganic fertilisers that are expensive, and often degrade soils. The waste water should be used where the soils have low pH, have a low organic matter content, or a low water holding capacity for subsequent improvement.

5.4 Implications for Future Research

It is evident from literature that many countries globally have attained a successful strategy to recycle their waste water into reusable state. In some countries like Namibia, the country has managed to recycle its waste water into a reusable state. From this research, further research is required in terms of health implications to the end-users when consuming foods irrigated with waste water. Although the waste water was found to be within the NEMA allowable limits for irrigation, more research should be carried out to derive better methods to eliminate all the trace metals in the waste water. Also, there should be research on how industrial and domestic waste water can be separated to use different treatment plants. Industrial waste water has a high amount of pharmaceutical that can cause water pollution. There is an emerging technology with Diageo- East Africa Breweries Ltd., which aims at treating industrial waste water to drinkable levels. Hence, more research and innovation should be channelled towards making this a reality also in irrigation. Also, there is a dire need for studies on the long-term use of treated waste water, especially regarding the impacts on crop yield and soil particles.

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APPENDICES

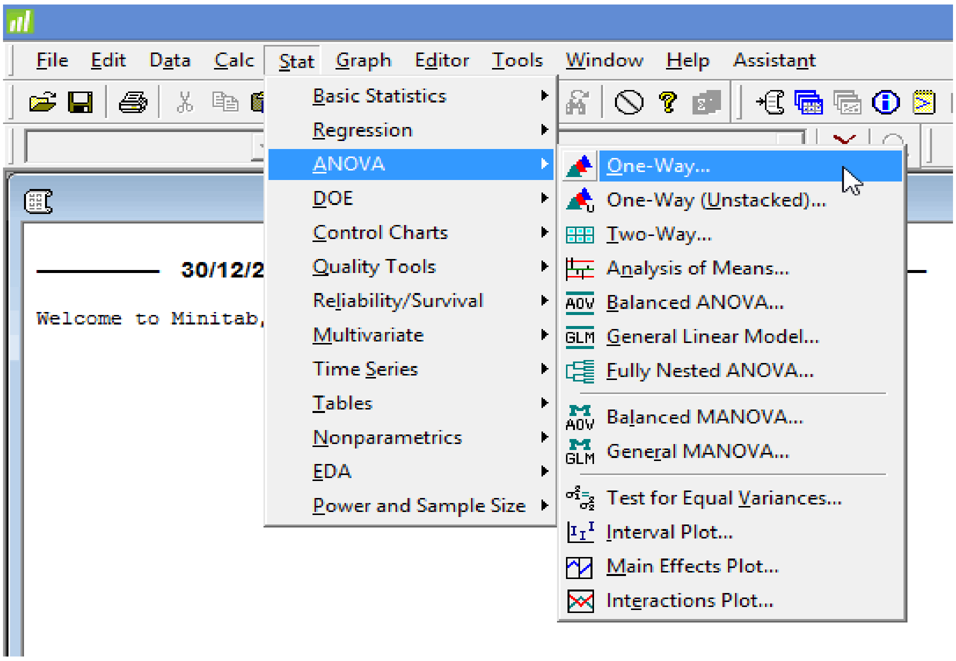
APPENDIX I: WASTEWATER FLOW INTO RIVER CHEPKOILEL

APPENDIX II: GROUND WATER COLLECTION FROM SHALLOW WELL

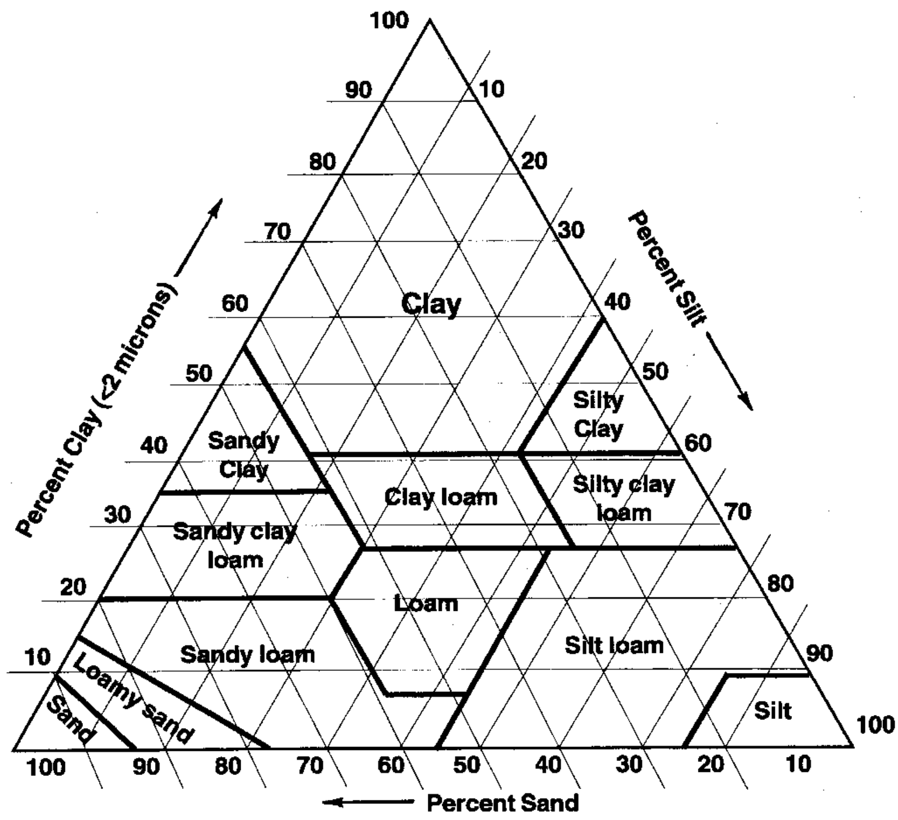
APPENDIX III: PARAMETER PERMISSIBLE LEVEL (NEMA, 2006).

pH	6.5-8.5
Aluminum	5 (mg/L)
Arsenic	0.1 (mg/L)
Boron	0.1 (mg/L)
Cadmium	0.5 (mg/L)
Chloride	0.01 (mg/L)
Chromium	1.5 (mg/L)
Cobalt	0.1 (mg/L)
Copper	0.05 (mg/L)
E.coli	Nil/100 ml
Fluoride	1.0 (mg/L)
Iron	1 (mg/L)
Lead	5 (mg/L)
Selenium	0.19 (mg/L)
Sodium Absorption Ratio (SAR)	6 (mg/L)
Total Dissolved Solids	1200 (mg/L)
Zinc	2 (mg/L)

APPENDIX IV: PHOTOGRAPHIC REPRESENTATION OF ANOVA SOFTWARE FOR VARIANCE ANALYSIS



APPENDIX V: THE USDA SYSTEM



APPENDIX VI: IRRIGATION SCHEDULE CHART

Dates	K_c	Growth Stage	Interval (days)	Amount added for supplemental (mm)
18th June		Initial	0	10
22/06/2018	0.35		3	6
26/06/2018	0.35		3	6
30/06/2018	0.35		3	6
4/07/2018	0.35		3	6
8/07/2018	0.35		3	6
12/07/2018	0.70	Development	3	12
16/07/2018	0.70		3	12
20/07/2018	0.70		3	12
24/07/2018	0.70		3	13
28/07/2018	0.70		3	14
1/08/2018	0.70		3	15
5/08/2018	1.10	Maturity	3	18
9/08/2018	1.10		3	18
13/08/2018	1.10		3	18
17/08/2018	1.10		3	18
21/08/2018	1.10		3	18
25/08/2018	1.10		3	18
29/08/2018	1.10		3	18
2/09/2018	0.30	Late season	3	17
6/09/2018	0.30		3	17
10/09/2018	0.30		3	15
14/09/2018	0.30		3	13
18/09/2018	0.30		3	9

APPENDIX VII: HISTORIC RAINFALL DATA FOR THE 19 YEARS IN CHEPKOILEL FROM 1996 TO 2015

	Jan	Feb	March	April	May	June	July	August	Sep	Oct	Nov	Dec
1996	0	42.34	62.10	137.22	125.10	96.76	164.45	172 .56	83	51	57	36
1997	0.5	40	20.13	17.07	31.46	69.46	200.91	35.5	29.8	50.12	154.95	35.5
1998	0.45	35	19.56	93.8	121.5	64.06	134.5	20.13	114.12	92.07	70.46	20.13
1999	23.12	32	8.27	123.92	71.92	53.12	22.99	19.56	150.14	75.77	63.06	19.56
2000	10.11	20	48.22	75.1	25.02	123.29	171.02	8.27	200.91	75.13	50.12	8.27
2001	8.8	20.13	13.44	85.09	39.12	98.61	197.53	48.22	134.5	19.13	123.29	48.22
2002	8.5	19.56	51.43	53.55	35.6	75.09	115.76	13.44	22.99	32.56	60.13	13.44
2003	22.3	8.27	54.94	56.66	48.97	102.28	137.97	99.28	171.02	18.27	79.56	19.56
2004	16.7	48.22	27.83	67.11	45.6	92.8	102.85	90.8	123.29	38.22	58.27	8.27
2005	30	13.44	63.07	98.92	23.56	62.78	61.32	56.78	98.61	63.44	78.22	48.22
2006	8.1	28.22	54.35	27.22	45.32	42.15	82.85	50.12	75.09	55.67	53.44	13.44
2007	0.11	2.99	3.09	30.8	53.62	5.99	31.46	11.65	17.07	20.56	128.22	25.02
2008	63.44	78.22	63.07	98.92	44.89	34.89	123.76	45.87	75.09	115.76	132.99	39.12
2009	0.01	1.99	2.09	29.8	53.62	4.99	31.46	11.65	17.07	20.56	75.02	46.45
2010	29.72	35.5	115.18	35.5	197.53	67.11	121.5	88.91	93.8	94.07	56.63	19.05
2011	8.22	20.13	107.97	20.13	115.76	98.92	71.92	202.83	123.92	77.77	154.95	44.19
2012	1.58	19.56	13.27	19.56	137.97	47.65	25.02	75.09	75.1	75.13	69.46	51.43
2013	26.99	8.27	76.62	8.27	102.85	76.79	39.12	102.28	85.09	80.18	64.06	54.94
2014	8.1	48.22	33.35	48.22	61.32	42.15	35.6	92.8	53.55	98.61	53.12	27.83
2015	1.87	13.44	78.64	13.44	82.85	56.07	48.97	62.78	56.66	129.06	123.29	63.07