ASSESSMENT OF HEAVY METAL POLLUTION AND THE PHYTOREMEDIATION POTENTIAL OF NONEDIBLE PLANTS IN MWEA IRRIGATION SCHEME, KIRINYAGA COUNTY, KENYA

EDWARD NJAGI SILAS

A Thesis Submitted to the Graduate School in Partial Fulfilment of the Requirements for the Award of the Degree of Doctor of Philosophy in Chemistry of Chuka University

CHUKA UNIVERSITY

OCTOBER, 2024

DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been submitted for an award of diploma or conferment of degree in this or any other University.

Signature: ______________________ Date: 15/10/2024

Edward Njagi Silas
SD11/38545/18

Recommendation

This thesis has been examined, passed and submitted with our approval as the University supervisors.

Signature: ______________________ Date: 16/10/2024

Prof. Ochieng Ombaka, PhD
Chuka University

Signature: ______________________ Date: 16/10/24

Prof. Eric Chomba Njagi, PhD
Chuka University

Signature: ______________________ Date: 16/10/2024

Prof. Moses Mahugu Muraya, PhD
Chuka University

COPYRIGHT

DEDICATION

This thesis is dedicated to my wife Mercy Wanja, my father Silas M'Bore Mugendi and my mother Esther Ciambaka whose prayers, encouragement, practical assistance and unwavering support sustained me all through this study.

ACKNOWLEDGEMENT

First and most important, I thank Almighty God for graciously blessing me with strength, focus, good health and all that I required during the period of study. I give special thanks to Chuka University for offering me an opportunity to study at the University and giving me favourable conditions that have enabled me complete the studies successfully. I sincerely thank my supervisors Prof. Ochieng Ombaka, Prof. Moses Mahugu Muraya and Prof. Eric Njagi for tirelessly guiding me with immeasurable support, patience and encouragement during the study period. I appreciate the sacrifices they made on their time to go through my proposal and thesis each time giving their valuable comments which made my work successful.

I am also very grateful to Prof. Joel Gichumbi and Dr. Zipporah Muthui for their suggestions, inputs and guidance at various stages of my study and during seminars. I am sincerely grateful to Mr. Andy Muchira for guiding me through the study area and assistance during sample collection even in challenging weather conditions. I specially thank Ms Juliet Mwelu for her guidance, patience, and appropriate assistance in chemistry research laboratory of Chuka university. I also thank the other laboratory technologists and staff who assisted me in one way or the other.

Special appreciation goes to my wife, Mercy Wanja who was very supportive from the onset of my study. My appreciation also goes to my sons Evan Kaugi and Ian Muthomi for their moral support, obedience and calmness that allowed me to remain peaceful, motivated and focussed during the entire course. To my parents Silas M’Bore Mugendi and Esther Ciambaka; your prayers, follow ups, encouragements and affirmations that you believed in my capabilities will always make me feel indebted to you. To everyone who contributed to my success in this study in one way or another, may Almighty God richly bless you.

ABSTRACT

A clean environment is critical for existence and development of all living organisms. The pollution of various sectors of environment are difficult to reverse and present a serious threat to humankind. Modern agricultural practices pollute soil to a large extent due to huge quantities of fertilizers, pesticides, herbicides and soil conditioning agents which are employed to increase crop yield. Long-term use of these agrochemicals has resulted to accumulation of heavy metal such as cadmium, lead, chromium, mercury, copper, nickel and arsenic which are toxic to plants and animals. Heavy metals cause deleterious effect on soil fertility because they are sorbed more strongly than alkali and alkaline earth metals making the essential metals leach from top soil which affect cation exchange of the soil and therefore affect crop production. Rice farming involves uses of agrochemicals which may contain heavy metals that can accumulate in various environmental segments and may enter the food chain. In humans, heavy metals toxicity is manifested by growth retardation, reproductive cycle changes, mortality, chronic diseases development and formation of tumours among other health effects. Therefore, there is need for continuous assessment of heavy metals in the environment. This study intended to assess the levels of toxic heavy metals in soil, rice, sediment and water from Mwea irrigation scheme in Kenya; determine the phytoremediation potential of common plants found in the rice farms; and propose a way to enhance phytoremediation potential of the plants. The study adopted descriptive survey design, CRD and RCBD. Questionnaires were used to establish the agrochemicals used in the study area. Soil, rice, water, sediment, fertilizers and plant shoots samples were collected, dried and digested then heavy metals analysed by ICP-MS. Data obtained was analysed using t-tests and ANOVA using SPSS version 26 and means were separated using Tukey's HSD test at $\alpha = 0.05$. The survey revealed that fertilizers, pesticides and other chemicals were used during rice farming with fertilizers used during planting containing high amounts of the heavy metals. Sediment from rivers Thiba and Nyamindi contained Cd, Pb, Zn, As and Se amounts below WHO and KEBS/WASREB limits but Cr, Ni and Mn amounts were above the limits; water from the rivers contained Cr and Mn amounts above set limits during rainy season but during dry season, the amounts of all the heavy metals determined were below the limits implying that the water was not polluted with the heavy metals during dry season. Paddy water had higher concentration of all the heavy metals than river water except for Pb and Mn. Paddy soil, rice straw, rice husks and rice grains from the scheme were found not to be contaminated with the heavy metals. The amount of Cd, Cr, Ni, Pb, Zn, and As in rice grains were found to be below the upper limit set by WHO and FAO. BAFs for rice grains were 0.5744, 0.0374, BDL, 0.0148, 0.0403, 0.0150, 0.0254 and 0.0049 for Cd, Cr, Ni, Pb, Zn, As, Mn and Se respectively indicating that little amount of the heavy metals were transferred from soil to rice grains. The EFs for all the heavy metals in *Cyperus difformis* (rice sedge), *Tradescantia fluminensis* (wandering jew), *Echinochloa crus-galli* (cockspur grass), *Cyperus rotundus* (nut grass), *Ludwigia adscendens* (water primrose) were below or close to 1.0 except for Ni which ranged from 10.1442 to 25.3863. Wandering jew and cockspur grass were found to be better phytoremediators than the other plant species studied. This study found that agrochemicals were the main source of heavy metal pollution at Mwea irrigation scheme although the pollution had not reached alarming level. Continuous monitoring of heavy metals situation is necessary to ensure that residents of Mwea and consumers of rice from Mwea irrigation scheme are safe from heavy metals.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA:	Analysis of variance
As:	arsenic
ATP:	Adenosine triphosphate
BAF:	Bioaccumulation factor
BDL:	Below detection limit
CAN:	Calcium ammonium nitrate
Cd:	cadmium
Cr:	chromium
CRD:	Complete randomized design
DAP:	Diammonium phosphate
DNA:	Deoxyribonucleic acid
EF:	Enrichment factor
FAO:	Food and Agriculture Organization
HSD:	Honest significance difference
ICP:	Inductively coupled plasma
ICP-MS:	Inductively coupled plasma – mass spectrometry
KEBS:	Kenya Bureau of Standards
KNBS:	Kenya National Bureau of Statistics
Mn:	manganese
MOA:	Ministry of Agriculture
MoALFC:	Ministry of Agriculture, Livestock, Fisheries & Cooperatives
MoP:	Muriate of potash
Ni:	nickel
NIB:	National Irrigation Board
NPK:	Nitrogen, phosphorous and potassium
Pb: -	lead
RCBD:	Randomized complete block design
SA:	Sulphate of ammonia
Se:	selenium
TSP:	Triple-super phosphate
UNEP:	United Nations Environmental Programme
US EPA:	United States Environmental Protection Agency

WASREB: Water Services Regulatory Board

WHO: World Health Organization

Zn: zinc

CHAPTER ONE
INTRODUCTION

1.1 Background to the Study

Due to population pressure and decreased arable land, agriculture has become intensive and involves high agricultural inputs leading to pollution that has impacted disastrously on the wider environment, ecosystem and human health (Shahnaj, 2010; Ibitayo, 2006; UNEP, 2002). Most commonly used agrochemicals contain significant amount of heavy metals which include Sr, V, Mn, Fe, Ni, Zn, Cd, Pb, Hg, Cu, Mo, Ba and As (Al-Horayess, 2013; El-Bahi *et al.,* 2004; Abdel-Haleem *et al.,* 2001). Some of these metals such as Cu, Mo, Ni, Zn, Mn, and Fe are beneficial to plants at low concentrations (Xu & Tao, 2004). The river water used for irrigation might also be contaminated with heavy metals due to geological factors, surface runoffs from agricultural land and urban centres, industrial waste water, human settlements and other human upstream activities (Marcovecchio *et al.*, 2007; Vukovic *et al.*, 2011; Javier *et al.*, 2017).

Further, the contamination of agricultural land by heavy metals can also be due to waste water irrigation, use of livestock manures from animals consuming feeds with additives containing heavy metals (Arunakumara *et al.,* 2013), aerial emissions, sewage and sludge, and other anthropogenic activities (Wuana & Okieimen, 2011). Unlike organic pollutants which may undergo degradation to substances that are less harmful by biological and/or chemical processes, heavy metals are non-degradable in nature. The heavy metals accumulate in soil and water bodies from where they may be absorbed by plants which affect quality of farm produce (Guan *et al.,* 2011; Kabir *et al.*, 2012).

To supply major macronutrients (N, P, and K) required for crop production, large quantities of inorganic fertilizers are regularly added to the soil (Reetz, 2016). These fertilizers may contain trace quantities of heavy metals as impurities which after continued fertilizer application may significantly increase their content in the soil. For instance, certain phosphatic fertilizers contain trace amounts of cadmium (McLaughlin *et al.,* 1999; Bhatia, 2002; Nicholson *et al.,* 2002). Studies have shown that inorganic fertilizers contain small quantities of metal like Cd, Pb, As, and other trace elements of environmental relevance (Ajayi *et al.,* 2012; Nicholson *et al.*, 2003).

Diammonium phosphate (DAP) used in a maize farm in Trans-Nzoia county of Kenya was found to contain 342.60 mg/kg Zn, 30.53 mg/kg Cr, 22.21 mg/kg Cu, 16.38 mg/kg Pb and 1.67 mg/kg Cd. In the same study, calcium ammonium nitrate (CAN) was found to contain 13.83 mg/kg Pb, 0.78 mg/kg Cu and 0.73 mg/kg Cd (Kananu, 2015). A study carried out in Nigeria revealed that superphosphate fertilizer contained 0.0012 mg/kg As, 2.59 mg/kg Cd, 7.80 mg/kg Cu, 5.26 mg/kg Ni, 6.65 mg/kg Pb, 1.92 mg/kg V and 15.81 mg/kg Zn. The study also found urea contained 0.0013 mg/kg As, 2.67 mg/kg Cd, 3.49 mg/kg Cu, 5.87 mg/kg Ni, 7.46 mg/kg Pb, 1.53 mg/kg V and 3.90 mg/kg Zn (Nsikak *et al.,* 2014). The continuous use of such chemical fertilizers over a long time may cause accumulation of heavy metals to high levels which might increase risk to environment and human health (Huang *et al.,* 2004; Czarnecki & During, 2015). It is important to ensure that these heavy metals do not accumulate in soils and water by removing them before they reach dangerous levels to avoid them affecting quality of food.

In addition to their toxicity, some commonly used pesticides are reported to contain significant amount of heavy metals such as Hg, Cd, Cu, Mn, Pb, Zn, As and others (Bhatia, 2002; Wuana & Okieimen, 2011). Soil micro-organisms are affected by heavy metals as a result of multiplicity of interactions that may occur between microbial cells, ions and other environmental constituents. These may result to decrease in microorganism population which may lead to decreased crop growth and reduced yield in crops such as rice (Sing & Kalamdhad, 2011: Chen *et al.,* 2014). The adverse effects of excessive Cd, Cu and Zn in the soil have been reflected in decreased microbial population, depressed respiration rates and inhibition of the activity of microbial enzymatic protein (Wyszkowska *et al.,* 2013). Cadmium is reported to be tolerated differently by soil fungi, suppress growth of micelial and also influence fungus-plant, bacteria-plant and bacteria-fungus interactivity. Some fungal types have been found to exhibit endurance to various metal concentrations surpassing acceptable international standards (Oladipo *et al.,* 2018). Cadmium and to a small extent zinc and lead have been found to inhibit growth of the nematode trapping fungi (Rosenzweig & Pramer, 1980; Bhatia, 2002). These effects on soil microorganisms as a result of presence of heavy metals affect soil productivity which may lead to food insecurity.

Rice farming involves use of large quantities of inorganic fertilizers and pesticides. It has been reported that heavy metals such as cadmium, zinc, lead, chromium, nickel, iron, copper, mercury and arsenic accumulate at different parts of rice plants but the rice grains accumulate the least amount compared to other parts (Arunakumara *et al.,* 2013). People who consume rice as staple food may therefore be exposed to toxic heavy metals through rice (Solidum *et al.,* 2012) particularly in long-term. Some heavy metals have cumulative deleterious effect which may cause chronic degenerative changes to nervous system, liver and kidneys and have teratogenic and carcinogenic effects (IARC, 1987; Ibrahim *et al.,* 2006).

Therefore, this pollution requires remediation approaches for heavy metals in order to protect human health and the environment. A remediation strategy is normally accepted if it reduces heavy metals bioavailability and only if the reduced bioavailability is equated with reduced risk that is long term. The levels of heavy metals in the soil and water should be determined to establish the type, amount and distribution before any remediation is undertaken (Karthikeyan *et al.,* 2004; Jankaite & Saulius, 2005; Wuana & Okieimen, 2011). Selection of the appropriate remediation technique depends on site characteristics, concentration, type of pollutants and the final use of the contaminated soil and water (Jankaite & Saulius, 2005). Remediation technologies that are used include physical, chemical and biological methods. Frequently mentioned as the best remediation techniques of soils contaminated with heavy metals are immobilization, soil washing, and phytoremediation because they are cost effective and environmentally friendly (Wuana & Okieimen, 2011).

In developing countries with great population density and scarce funds for environmental restoration, low cost and ecologically sustainable remedial options are required to restore contaminated lands so as to reduce the associated risks, make the land resources available for agricultural production, enhance food security and scale down land tenure problems (Karthikeyan *et al.,* 2004; Wuana & Okieimen, 2011). Among the available methods, phytoremediation is generally more accepted because it has more advantages than the others. Phytoremediation of heavy metals is use of plants to extract, immobilize or remove heavy metals from water, soil and sediment. It is an effective, fairly cheap, easy to carry out, aesthetically pleasant and is socially accepted by many people (Kumar *et al.,* 1995). Plant species that have capability of accumulating heavy metals (hyperaccumulators) may accumulate 100-500 times heavy metals in dry matter compared to soil or nonaccumulator plant species (Bhargava *et al.,* 2012; Mahar *et al.,* 2016; Sheoran *et al.,* 2016). Many of the natural plants that are used in phytoremediation especially through phytoextraction method are annual, biennial or short-lived perennial herbs; and shrubs or small trees that have low biomass and grow slowly which limits the remediation process (Fasani *et al.,* 2018).

The plants that are considered effective in phytoremediation should have efficient metal uptake and translocation; able to accumulate and tolerate high concentration of heavy metals in easy to harvest parts; and should be fast growing, have abundant biomass production and have deep root system (Dalcorso *et al.,* 2019, Fasani, 2012). Remedial capability of plants can be improved by genetic manipulation that can introduce novel traits for uptake and accumulation of heavy metals into the biomass which would improve phytoremediation significantly. Plant species that are heavy metal tolerant protect themselves from toxicity of the metal ions by using specific proteins to bind the metals which makes them nontoxic to the plants (Gratoa *et al.,* 2005; Martinez *et al.,* 2006). The proteins that are important for metal detoxification in plants are metallothioneins, phytochelatins and glutathione. Gene coding for these have successfully been used to improve phytoremediation by genetic engineering (Kramar, 2005; Martinez *et al.,* 2006).

It has been reported that some tobacco shrub species have greatly improved metal tolerance and uptake when genetically transformed through over-expression of enzymes that induce formation of phytochelatins (Cherian & Oliveira, 2005; Kramar, 2005; Martinez *et al.,* 2006). Plants that are naturally tolerant to heavy metals have been used as a source of genes for phytoremediation (Cherian & Oliveira, 2005). Methylmercury has been transformed to volatile elemental form that is 100 times less toxic by use of two bacterial genes merA and merB combined in transgenic plants such as arabidopsis, tobacco, poplar tree, eastern cotton and several others (Bizily, 2000; Gratoa *et al.,* 2005). Arabidopsis plant with tolerance to arsenic and cadmium has been engineered by introducing bacterial genes arsC and y-ECS (Cherian & Oliveira, 2005).

A popular strategy to improve phytoremediation traits using transgenesis is to introduce and overexpress genes responsible for uptake, translocation and segregation of heavy metals. These genes are those that encode metal transporters of the metal ions and metal chelators (Kozminska *et al.,* 2018; Mani & Kumar, 2014). Cation diffusion facilitator family genes are responsible for encoding various types of proteins that enable cells to exclude excessive amounts of ions from cytoplasm. Some plants overexpress cation diffusion facilitator genes which makes them produce higher amounts of thiol compounds which makes them efficient in segregating metal ions in the vacuoles by chelating them. This results in hyperaccumulation of the heavy metals in the plant biomass (Kozminska *et al.,* 2018). Furthermore, a range of harmful organic compounds such as polychlorinated biphenyls, halogenated hydrocarbons and ammunition wastes may simultaneously be removed alongside heavy metals (Peuke & Rennenberg, 2005).

Kenya produces about 229100 metric tons of rice against a much higher consumption which makes large quantity of rice to be imported (KNBS, 2024). Hence, the need to promote intensive cultivation of rice to boost its production. The Government of Kenya encourages use of various modern agricultural technologies to meet the demand of the rice to its citizens which include planting high yielding and disease resistant varieties; appropriate soil and water management in irrigated rice; high quality seed and supply system; appropriate crop rotations in rice systems; appropriate agronomic practices for different cropping systems; and appropriate pest, disease and weed control technologies (MOA, 2008). The major rice growing areas in Kenya are Ahero, Bunyala, West Kano and Mwea. Rice growing was started at Mwea Tebere in 1954 with 65 acres and currently, the area under rice irrigation is about 26000 acres. The water used for irrigation in this area mainly comes from rivers Thiba and Nyamindi (NIB, 2016) that pass through agricultural areas and near urban centres. Agricultural practices such as irrigation and use of heavy metals containing agrochemicals may contribute to the contamination of agricultural soil and water which may affect the quality of rice and safety of consumers (Aktar *et al*, 2009; Karishma & Prasad, 2014).

There are several inorganic fertilizers used in rice farming in Kenya which include Diammonium Phosphate (DAP), Triple-Super Phosphate (TSP), Muriate of Potash (MoP), Sulphate of Ammonia (SA) and Urea. DAP or TSP is applied a few days after transplanting whereas SA or urea is used for top dressing (Ngige, 2004; MOA, 2008). After over 60 years of rice irrigation at Mwea irrigation scheme where agrochemicals are always used, it was necessary to assess the levels of some selected heavy metals in the soil and rice that is grown in the scheme. It was also necessary to determine levels of heavy metals in water that is used for irrigation in this area. Soil and water that are contaminated with heavy metals pose great environmental and human health problem that requires cheap and effective remediation. The study also determined phytoremediation potential of common nonedible plants found in rice farms which will help mitigate the soil and water heavy metal pollution.

1.2 Statement of the Problem

Advancement of rice production presents a chance to enhance food security in Kenya because the consumption of rice is increasing at high rate due to consumers change in eating habits, increase in population and urbanization. Since rice is mainly consumed by humans, it is expected to be of high quality and free from any toxic substances. Modern agricultural practices that rely on intensive use of agrochemicals may introduce toxic substances to rice which may affect its consumers. These toxic substances may be pesticide residues or their decomposition products, non-metal radicals or toxic heavy metals. Continuous use of agrochemicals during rice production may build up levels of heavy metals in paddy soils resulting to their uptake by rice plants and then transferred to rice grains which are consumed by humans. Acute or chronic exposure of heavy metals affects body organs such as liver, brain, kidneys, lungs and other key organs in addition to affecting several body physiological processes.

Mwea irrigation scheme is the oldest and largest rice irrigation scheme in Kenya where rice growing has been going on for over 60 years. The main rivers feeding Mwea irrigation scheme are Thiba and Nyamindi which flows from Mount Kenya forest then though rocks and soil on the courses of the rivers, agricultural lands, residential areas and urban centres. Weathering, surface runoffs and seepage of waste water to these rivers may be contributing to water pollution with heavy metals before being used for irrigation. Since paddy rice irrigation involves use of fertilizers, pesticides and irrigation water that may be containing heavy metals, soils in this scheme may have accumulated high quantities of heavy metal which could be finding their ways in rice.

It was therefore necessary to investigate the levels of heavy metals in water and soils of Mwea irrigation scheme and also find out if these metals are absorbed and translocated to rice grains which may affect their human health.

Soils and water that is contaminated with heavy metals requires an effective and affordable remediation technique. It is generally accepted that phytoremediation is efficient, fairly cheap, easy to carry out and environmentally friendly method that could be applied to restore contaminated soil and water. There are naturally growing plants that may be used in phytoremediation of soils and water polluted by heavy metals. Isolation and use of phytoremediator plants from naturally growing plant species in a given locality may be important in phytoremediation of nearby soils and water polluted by heavy metals since such a plant would grow well in the said ecological conditions. Since natural plants that are used for phytoremediation are slow growing and have low biomass which limits phytoremediation, development of plants which have better qualities of phytoremediation should be the long-term plan.

1.3 Objectives

1.3.1 Broad Objective

The broad objective of this study was to assess the levels of toxic heavy metals in soil, sediment, water, rice and also to determine phytoremediation potential of nonedible plants growing in Mwea irrigation scheme in Kenya.

1.3.2 Specific Objectives

The specific objectives for this study were:

i. To assess sources of heavy metal contamination at Mwea irrigation scheme and its water catchment.
ii. To determine the levels of heavy metals in water and sediment of rivers Thiba and Nyamindi which feed Mwea irrigation scheme.
iii. To determine the concentration of selected heavy metals in the paddy water, soil, rice straws, rice husks and rice grains from Mwea irrigation scheme.
iv. To determine heavy metal phytoremediation potential of common non-edible plants growing in Mwea irrigation scheme.

1.4 Research Questions

To achieve objective (i), the study sought to answer the following question:

i) What were the sources of heavy metal contamination at Mwea irrigation scheme and its water catchment?

1.5 Hypotheses

To achieve objective (ii), (iii) and (iv) the following hypotheses were formulated and tested at 0.05 significance level:

H_{01}: There is no statistically significant difference in the concentration of the selected heavy metals in water and sediment from rivers Thiba and Nyamindi.

H_{02}: There is no statistically significant difference in the concentration of selected heavy metals in the paddy water, soil, rice straws, rice husks and rice grains from different sections of Mwea irrigation scheme.

H_{03}: There is no statistically significant difference in phytoremediation potential of the selected nonedible plant species commonly found in Mwea irrigation scheme.

1.6 Justification of the Study

Copper, mercury, cadmium, lead, nickel and arsenic are some of the elements that can accumulate in the soil if they get entry through agrochemicals, sewage, smoke from automobiles and other sources resulting in severe biological and chemical contamination (Bhatia, 2002; Wauna & Okieimen, 2011). Heavy metals get absorbed by soil particles, taken up by plants and may be concentrated in crops posing health threats that may be manifested in disorders such as growth retardation; decrease in longevity; and detrimental changes in reproductive cycles that may lead to mortality of offspring, morbidity, pathological changes, symptoms of chronic diseases and formation of tumours (Bhatia, 2002; Shayler *et al.,* 2009; Dara & Mishra, 2010). Paddy rice has been found to scavenge heavy metals from the soil with arsenic commonly found in higher concentration than in other cereal crops (Williams *et al.,* 2009). A study carried out in Malaysia paddy soils found 3.87 mg/kg Cu, 1.82 mg/kg Ni, 6.64 mg/kg Pb, 17.1 mg/kg As and 0.06 mg/kg Cd (Rudzi *et al.,* 2018). In another study, Pb and Cr were the most abundant heavy metals in paddy soils and the highest bio-accessible heavy metal in rice grains were Cr, Cu, Pb, As and Cd (Zulkafflee *et al.,* 2019).

This study came at an appropriate time because after over 60 years of rice farming at Mwea irrigation scheme, it was necessary to find out if heavy metal pollution had reached alarming levels. Little had been reported on heavy metal levels in soil, water and rice from Mwea irrigation scheme. Arsenic content in locally produced rice (Ahero and Mwea) was reported to be 0.059043 mg/kg and 0.037124 mg/kg in sindano and pishori/basmati types of rice respectively. This was less than that of rice imported from Thailand, Pakistan and India but was below World Health Organization (WHO) maximum allowable level of 1.0 mg/kg (Njue *et al.*, 2019). This study determined the levels of heavy metals in soil, water and rice; compared them with the accepted levels of WHO; then appropriate advice will be given to relevant government agencies so that mitigation measures can be undertaken. Appropriate soil remediation method has been recommended to the relevant government agencies so that appropriate action will be taken whenever need arises. This study was generally aimed at ensuring that general population health as a result of heavy metal soil and water pollution is well taken care of and will provide a long term solution to heavy metal pollution of soil and water.

CHAPTER TWO

LITERATURE REVIEW

2.1 Consumption and Growing of Rice

2.1.1 Rice Consumption

Rice is the most important food crop of the developing world and the staple food of more than half of the world's population (Jayaprakash *et al.*, 2022; Arnarson, 2017). Farming of rice was introduced in Kenya from Asia in the early 20th century and it has become the third most important staple food after maize and wheat. Over three quarters of rice is grown in irrigation schemes and the rest is grown during normal rainy seasons in Kenya (MOA, 2008). Unlike maize and wheat that are consumed by humans and livestock, rice is mainly consumed by humans. Development of rice presented an opportunity to reduce the number of gravely food insecure people that stood at 850 million by half by 2015 according to the World Food Summit 1996-Millenium Development Goals (MOA, 2008; FAO, 2006). Rice growing areas in Kenya include Mwea, Ahero, Bunyala and West Kano. In Mwea, rice growing was started at Mwea Tebere section in 1954 with 65 acres, growing to 2478 acres in 1960 and currently, the area under irrigation is about 26000 acres (FAO, 2006; MOA, 2008; NIB, 2016).

Rice is the most important food crop of the developing world and the staple food of more than half of the world's population. It is rich in vitamins, minerals and complex carbohydrates. Rice ranks high in nutritional quality among cereals; protein content is good and contains relatively high levels of essential amino acid lysine (Tripathy *et al.*, 2017; Arnarson, 2017, Jayaprakash *et al.*, 2022). The annual consumption of rice, maize and wheat which are Kenyan staple foods has been increasing at a rate of 12 %, 4 % and 1 % respectively which is attributed to gradual changes in eating inclinations especially for urban inhabitants (MOA, 2008). In Kenya, per capita consumption of milled rice rose from 12.7 kg in 2016 to 20.6 kg in 2018 increasing rice consumption to 949, 000 metric tonnes and is expected to increase to 1, 292, 000 metric tonnes by the year 2030 (MoALFC, 2020). Everyone in a family is involved in rice production at various stages with men mainly being involved in land preparation (ploughing, rotavation and leveling) and transportation whereas women and children are involved in planting, weeding, bird scaring, threshing and drying. Rice marketing is done by both men and women but women dominate the local retail rice businesses (MOA, 2008).

Rice is harvested, threshed then dried under the sun until it gets ready for hulling. Hulling is done by shelling machine that loosens the hulls from rice by rolling them between two sheets of metal coated with abrasives which removes kernel hulls. This hulled rice grains is known as brown rice. Since the brown rice retains the outer bran layer of the rice grain, it needs no further processing. However, the bran layer contains vitamins, minerals and oils that makes it spoil faster than milled white rice. This makes further milling necessary which also produces a more visually appealing white rice. The light-coloured grain is then cooled and polished by a brush machine (Sinkovic *et al*., 2023; Rickman & Gummert, 2010).

2.1.2 Rice Growing Using Agrochemicals

Rice growing involves using agrochemicals such as fertilizers and pesticides at different stages of growth. A high phosphorus fertilizer such as diammonium phosphate (DAP), triple-superphosphate (TSP) or any other NPK is applied 0-5 days after transplanting for early crop establishment. Some potassium is also required so if an NPK is not used, Muriate of potash (MoP) is added to provide potassium. At tillering stage (21-25 days after transplanting), a nitrogenous topdressing fertilizer is applied which could be from a high NPK (with micronutrients and sulphur preferably) or straight nitrogen fertilizer. Final topdressing is done at panicle initiation (45-60 days), with preferably a nitrate-N fertilizer, sulphur and micronutrients applied together with MOP to boost the potash for better grain filling and better protein content (Wafula, 2017; MOA, 2008; Ngige, 2004).

The major rice diseases are blast, rice yellow mottle virus and brown spot whereas main rice pests include stem borers, leaf miners and cutting insects. These diseases and pests are managed using pesticides that include organophosphorus thiolate fungicides, tricyclazole, ediphenphos and mancozeb (Rola & Pingali, 1993; Parveen *et al.,* 2003; Gianessis, 2014).

2.2 Effects of Heavy Metals on Human Health

2.2.1 Physiological Roles of Toxic Heavy Metals

Trace elements with densities above 5 g/cm^3 are classified as toxic heavy metals and include mercury, lead, copper, cadmium, nickel among others (Wuana & Okiemen, 2011). In addition, metalloids such as selenium, arsenic and antimony are also considered under this category (Tchounwou *et al*., 2012). The biological significance of these elements is confirmed by their toxic properties at relatively low concentrations. However, this classification has little general application because all the trace elements are toxic if ingested at sufficiently high levels and for a long enough period (Dara & Mishra, 2010). Elements that can accumulate into the soil if they get entry either through sewage, industrial wastes, mine washings, fertilizers or fungicides include copper, mercury, cadmium, lead, nickel and arsenic (Bhatia, 2002).

Trace elements find their way into humans either by dermal contact, inhalation or ingestion (Jaishanker *et al*., 2014). An indispensable link in the food chain is the terrestrial or marine plant life from which humans receive their quota of trace elements directly or indirectly by feeding on herbivorous animals which depend on plants for their nutrition. Plants absorb trace elements either via the root system or by foliar absorption (Rewat *et al*., 2024; Dara & Mishra, 2010). Some of the heavy metals in traces are considered to be essential for plants and animal nutrition and they serve some useful biological functions. Thus, copper, cobalt, manganese, selenium and zinc are essential to both animals and plants (Tuorma, 2002). Minute traces of arsenic, chromium, nickel and tin have been found to be essential for animals but not for plants. Although some essential physiological roles have been inferred for arsenic, cadmium and lead recently, mercury and silver have not yet been confirmed to be essential for both plants and animals since they do not seem to serve any useful biological function (Alloway, 2013; Tchounwou *et al*., 2012; Dara & Mishra, 2010).

All heavy metals have been found to be toxic when present in excess amounts in both animals and plants (Afzal & Mahreen, 2024). In fact, the toxicity of all the essential trace elements follow the general trend; under supply leads to deficiency, optimum supply helps in healthy growth, and over-supply leads to toxicity and even death to the organisms (Dara & Mishra, 2010). The adverse effects of heavy metal toxicity in biological systems may result from interaction of the metal with protein leading to denaturation, interaction with DNA leading to mutation, effects on cell membrane and effect on regulatory enzymes. These adverse effects on mammals may manifest in disorders such as retardation of growth, decrease longevity, detrimental changes in reproductive cycle leading to mortality of offspring, morbidity, pathological changes, symptoms of chronic disease and formation of tumors (Tchounwou *et al*., 2012; Sirotkin & Kolesarova, 2022). The toxicity due to the metals and their compounds is mainly determined by the delivery of the metal to the cell to attain a critical concentration level at the site of action and the cellular biochemical defense mechanism (Jarup, 2003). Although the toxic action of the different metals may be different, most of them involve binding to the metabolically-active groups such as amino-, imino-, sulphurdry-, carboxyl-, phenolic- or phosphoryl groups (Dara and Mishra, 2010).

Studies have shown that Cr, Ni, Cd and Be are potentially carcinogenic (Mulware, 2013). Elements like Be, Cr, Sr-90 and Pu -239 have been found to be potentially mutagenic. Furthermore, metals like Cd, Cu, Pb, Hg, Mo, Ni and Se in excessive amounts have been found to be potentially teratogenic (Tchounwou, *et al*., 2012). Some arsenic compounds have been found to be carcinogenic, mutagenic as well as well as teratogenic (Balali-Mood *et al*., 2021). The heavy metal pollutant, like some other pollutants on acute or chronic exposure severely affect different body organs. Some of the body organs are affected more severely in poisoning situation by different chemical pollutants (Rodrigues & Romkens, 2018). Table 1 shows some heavy metals and their target organs.

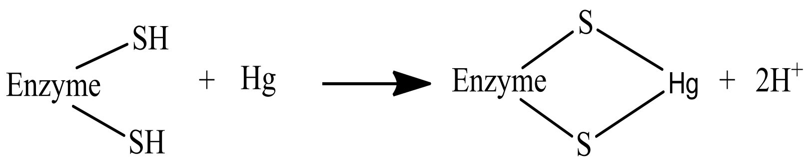
Table 1: Target Organs Affected by Heavy Metal Pollutants

Heavy metal/ metalloid	Target organ
As, Hg, Mo, Se	Liver
As, Hg, Pb, Cd	Blood
As, Hg, Pb	Brain
As, Hg, Pb, Cd	Kidneys
As, Hg, Cd	Lungs
Cd, Se	Bones and teeth

Source: Dara & Mishra, 2010

Heavy metals form stable coordination complex with a variety of sulphur and nitrogen-donor ligands compared to those of oxygen-donor. Although most heavy metals are known to exert biological effects through combination with sulphydryl groups, they can also combine with other groups especially in chelate configuration. For example, Hg and Ag can combine with amino-imidazole, phosphate and carboxylate groups; Pb can also combine with carboxylate and phosphate groups (Rubino, 2015; Dara & Mishra, 2010). Quite a good number of heavy metals apply toxic effects on tissues such as gastrointestinal mucosa, bone marrow, highly specialized cells such as neurons and renal tabular cells, and can also lead to excessive damage due to oxidative stress induced by formation of free radicals (Balali-Mood *et al.*, 2021; Jaishanker *et al.*, 2014, Dara & Mishra, 2010).

Heavy metal ions such as Pb^{2+}, Hg^{2+} and Cd^{2+} acts as enzyme inhibitors. They attack ligands like –SH and -SCH_3 in cysteine and methionine amino acids in the enzyme structure as shown in equation 1.



………… Equation 1

Quyoom, 2014; Dara & Mishra, 2010, Heavy metal ion can also replace the right metal ion of similar charge and size from metalloenzymes and inhibit normal activity or induce toxicity for example, Cd^{2+}can displace Zn $^{2+}$ and lead to cadmium toxicity (Jaishanker *et al.*, 2014). Cd^{2+} can inhibit activity of enzymes such as amylyse, carbonic anhydrase, adenosine, triphosphatase, alcohol dehydrogenase and carboxy peptidase. Pb^{2+} can inhibit activity of enzymes like carbonic anhydrase, cytochrome oxidase, alkaline phosphatase, adenosine triphosphatase and some important enzyme in the synthesis of “heme” (Dara & Mishra, 2010; Day & Cohen, 2013).

2.2.2 Biochemical, Toxicological and other Effects of Selected Heavy Metals

Heavy metals have many biochemical, toxicological and other effects. Some of the heavy metals that can get in soil and water as a result of natural or human activities include Cd, Cr, Ni, Pb, Zn, As, Mn and Se (Michalak *et al.*, 2021; Hariharan & Dharmaj, 2020; Goldman, 2013; Pemmer & Streli, 2013; Dara & Mishra, 2010).

2.2.2.1 Cadmium

Due to the similarity in atomic structure and chemical properties, Cd and Zn are usually found together in nature. However, whereas zinc is an essential element in human body, cadmium is considered as a toxic element (Tang *et al.*, 2014; Yu *et al.*, 2021). It is not a neurotoxin but has deleterious effects on bone structure and kidneys (Jumba & Likimani, 2001) and acts as inhibitor of sulphydryl enzymes. It has high affinity for other ligands in cell such as hydroxyl, carboxyl, phosphatyl, cysteinyl and histidyl side chains of proteins, purines and porphyrin and can also disrupt pathways of oxidative phosphorylation (Dara & Mishra, 2010; Manahan, 2010). Cadmium interacts/competes with other metals such as Cu, Fe, & Zn and induces the deficiency symptoms of these essential metals. Cadmium is highly toxic because of the absence of homeostatic control for it in the human body (Rajakumar *et al*., 2020; Dara & Mishra, 2010; Brzoska & Moniuszko-Jakoniuk, 2001). About one-third of the absorbed cadmium is stored in kidney and liver which is the target organs. When excessive amounts of Cd are ingested, it replaces Zn^{2+} at key enzyme site and induces metabolic disorders (Dara & Mishra, 2010; Jumba & Likimani, 2001). It is a carcinogen and its other long term effects include increased blood pressure, liver, kidney and lung disease (Qu & Zheng, 2024; Girard, 2014).

The symptoms of cadmium toxicity produced by enzymatic inhibition include hypertension, respiratory disorders, damage to kidneys and liver, aminoaciduria (urinary excretion of aminoacids), hypecalciurea (urinary excretion of excessive calcium), glycosuria (excretion of blood sugar in the urine), proteinuria (urinary excretion of proteins), osteopororis (decalcification of the skeleton), formation of kidney stones and others (Yan & Allen, 2021; Suturug *et al*.,2017). Carcinogenic and teratogenic effects have also been observed in epidemiological studies on animals (Dara & Mishra, 2010; Duggal, 2007). Due to cadmium high toxicity and relative ease with it gets into solution, the upper limit of this element is recommended to be 10 mg/l in drinking water (Jumba & Likimani, 2001), 0.8 mg/kg in soil (Osobamiro *et al.,* 2019) and 0.6 mg/kg in sediment (Ameh *et al.,* 2016).

2.2.2.2 Chromium

In human, chromium improves insulin sensitivity, enhances carbohydrates, lipids and protein metabolism. Deficiency of chromium leads to impaired glucose tolerance and less efficient control of cholesterol (Lewicki *et al.,* 2014; Pechova & Pavlata, 2007). Chromium toxicity depends on its oxidation state with Cr (VI) being much more toxic than Cr (III). Infact, Cr (VI) is more easily absorbed than Cr (III) through oral or inhalation routes (Genchi *et al.,* 2021; Desmarais & Costa, 2019). The primary target for inhaled Cr is respiratory tract if exposure is acute (Caglieri *et al.,* 2006). However, other effects have been reported on liver, gastrointestinal tract and kidney (Chakraborty *et al.*,2022).

Ingestion of Cr (VI) in high doses results to acute effects on cardiovascular, respiratory, hepatic, haematological and even death (Hessel *et al.,* 2021; Ray, 2016). Chronic exposure to some Cr (VI) compounds may cause allergic behaviour in sensitive people. Chronic exposure to Cr (III) has been found to result in liver malfunction, renal failure, anaemia and weight loss (Balali-Mood *et al.,* 2021; Hessel *et al.,* 2021; Ray 2016). Cr (III) has not been shown to be mutagenic or carcinogenic but Cr (VI) has shown positivity in both. There is no evidence showing that Cr (III) compounds are reproductive or developmental toxicants but potassium dichromate may be teratogenic (Wang *et al.,* 2017; Mamyrbaev *et al.,* 2015).

2.2.2.3 Nickel

Studies have indicated that nickel is essential to animal nutrition and has been shown to be present in RNA and DNA (Samal & Mishra, 2011). Significant concentrations of nickel have been shown to be present in RNA and DNA (Cameron *et al*.,2011). Nickel is to be essential for some micro-organisms and animals but not to plants. It is associated with bacterial synthesis of vitamin B12 in humans but it is toxic at higher concentrations (Pieczynska *et al*., 2021; Dara and Mishra, 2010). Nickel is believed to inhibit various enzymes such as cytochrome oxidase, isocitrate dehydrogenase and maleic dehydrogenase. Nickel dust is also believed to be carcinogenic (Samal & Mishra, 2011; Dara & Mishra, 2010).

2.2.2.4 Lead

Lead is considered as a general protoplasmic poison which is cumulative, slow-acting, subtle and like other heavy metals, it has high affinity for sulphur (Wani *et al*., 2015). Although lead exerts much of its activities through sulphydryl inhibition, it also interacts with carboxyl and phosphoryl groups (Dara & Mishra, 2010). The major biochemical effects of lead is its interference with heme synthesis leading to hematological damage. It also inhibits utilization of iron in the body (Jumba & Likimani, 2001). Lead inactivates delta-aminolevulinic acid (ALAdehydrase) and thus obstructs its conversion to porphobilinogen (PBG) which is an important step in heme synthesis (Ogun *et al*., 2023). It also impairs the activity of porphobilinogen decarboxylase. These effects disrupts synthesis of haemoglobin and other respiratory pigments such as cytochromes which require heme (Phillips, 2020). Lead also obstruct the utilization of oxygen and glucose for the life-sustaining energy production (Singh & Kalamdhad, 2011). The interference with normal metabolic functions starts when the blood-lead level reaches about 0.3 ppm. When the blood-lead level reaches about 0.8 ppm, symptoms of anemia will be observed due to the deficiency of haemoglobin (Dara & Mishra, 2010). High levels of lead in the blood can cause kidney dysfunction and brain damage because it is toxic to the central peripheral nervous systems (Collins *et al*., 2022; Wani *et al*., 2015).

One of the most insidious effects of inorganic lead is its ability to replace calcium in bones and accumulate there as a reservoir for long-term release (Wani *et al*., 2015). This lead is subsequently remobilized along with phosphates from the bones and exert toxic effects when transported to soft tissues (Dara & Mishra, 2010). On average, only about 10% of inorganic lead that is ingested is absorbed, and distributed to various tissues such as liver, bones, kidney and brain. About 90% of this lead is immobilised in bones (Wani *et al*., 2015). The bone-lead concentration goes on increasing and accumulating with age until it reaches toxic levels (Thompson, 2012). Chronic exposure to lead causes renal damage, interfere with fertility, causes female menstrual disturbances, weight loss, constipation and loss of teeth (Qu & Zheng, 2024; Dara & Mishra, 2010). Organic lead such as tetraethyl lead and tetramethyl lead is 10-100 times more acutely poisonous than inorganic lead (Wani *et al*., 2015). Inorganic lead is mainly absorbed by ingestion or inhalation whereas tetraethyl lead is absorbed through inhalation of volatile compounds or by dermal entry into the body (Dalefield, 2017). Inorganic lead mostly causes gastrointestinal and hematological disturbances whereas tetraethyl lead selectively attacks the central nervous system (Wani *et al*., 1015; Clarkson, 1987). Organolead compounds are also suspected to cause genetic modification (Dara & Mishra, 2010).

The most severe clinical form of lead poisoning is brain damage which produces clumsiness, subtle changes in mental attitude, sluggishness, poor memory, inability to concentrate, restlessness and hyper irritability (Jumba & Likimani, 2001). Lead is particularly toxic to young children, who are at greater risk for lead poisoning than adults because they cannot excrete as much lead; consequently, they retain a higher percentage of ingested lead than adults (WHO, 2010). Also children's growing bones do not absorb lead as rapidly as full-grown bones; the lead remains in blood stream longer and has more opportunity to damage developing organs (Wani *et al*., 2015). Exposure to lead can stunt a child's intellectual, behavioural and physical development (WHO, 2010). Studies have shown that infants exposed to lead have IQ scores that are 5 % lower by age 7 than unexposed ones; the affected children are 6 times more likely to have reading disabilities and seven times more likely to drop out of school (Girard, 2014). Cattle have been observed to eat lead paint off fences and so farmers should not paint fences with lead paints (Girard, 2014).

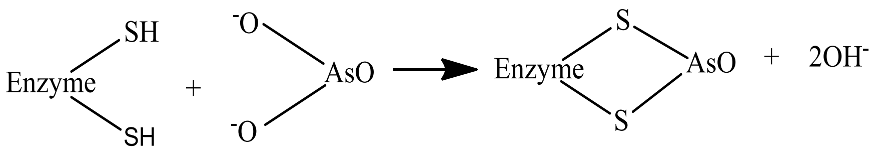
2.2.2.5 Zinc

Zinc is essential in human body and its requirements increases during pregnancy, lactating period and growth age period (Roohani *et al.,* 2013; Donongelo & King, 2012). Moderate deficiency of zinc leads to retarded growth, delayed puberty, male hopogonadism, rough skin, poor appetite, slow wound healing, taste abnormalities and mental lethargy (Prasad, 2013; Siklar *et al.,* 2003). Severe cases of zinc deficiency are diarrhoea, weight loss, pustular dermatitis, emotional disorder and intercurrent infections (Prasad 1985). Zinc is a growth factor which is required in protein synthesis, DNA synthesis, cell division, testicular size and functions and hormonal functions of various endocrine organs (Fallah *et al.,* 2018; Wessels *et al.,* 2017).

Under normal dietary conditions, zinc toxicity is not encountered. However, acute toxicity of zinc leads to nausea, gastric distress and disorientation (Fosmire, 1990). Just like zinc deficiency, elevated zinc levels may compromise immunity and lead to low food intake in chicken possibly due to defective pancreatic acinar cell function. Decreased bone mineralization, joint deformities and lameness in horses has been observed which has been associated with Zn-induced Cu deficiency rather than zinc itself (Grungreiff *et al.,* 2020; Fallah *et al.,* 2018; Siklar *et al.,* 2003). This is attributed to metallothionein-copper interaction which leads to hypochromic anaemia (Wahab *et al*., 2020). It has been found that if there is persistence of zinc intoxication, both copper and iron absorption are interfered with which may lead to anaemia as a result of iron deficiency (Wahab *et al.,* 2020; Zahra *et al.,* 2017). Abdominal cramps, vomiting and diarrhoea sometime with blood have been noted after ingestion of zinc sulphate. (Plum *et al.,* 2010; Goldman, 2013).

2.2.2.6 Arsenic

Arsenic is a general protoplasmic poison which affects all systems in the body and is a cumulative poison (Hughes *et al*., 2011). The major biochemical effect of arsenic are complexation with co-enzymes, uncoupling of phosphorylation and coagulation of proteins (Thakur *et al*., 2021). Trivalent arsenicals reacts with sulphydryl (-SH) groups in cells and thus inhibit the sulphydryl containing enzyme systems essential to cellular metabolism as indicated in Equation 2.



...... Equation 2

(Thakur *et al.,* 2021). The pyruvate oxidase system gets inactivated by complexation with As(III) and thus generation of adenosine triphosphate (ATP) that is an important energy source is inhibited. The enzymes generating cellular energy in the citric acid cycle are also adversely affected (Dara & Mishra, 2010; Manahan, 2010).

Arsenic interferes with some biochemical processes involving phosphorous due to the similarities in their chemical properties. For instant, a vital step in generation of ATP is enzymatic synthesis of 1,3-diphosphoglycerate from glyceraldehyde-3-phosphate (Sadiku & Rodrigues, 2022; Garbinoki *et al*., 2019)). As(III) interferes in this reaction by producing 1-arseno-3-phosphogylcerate instead of 1,3–diphosphoglycerate. The former compound undergoes spontaneous hydrolysis forming 3-phosphoglycerate and arsenate. Thus, instead of phosphorylation, arsenolysis takes place (Dara & Mishra, 2010; Girard, 2014). Arsine (AsH_3) combines with hemoglobin and is oxidized to a hemolytic compound that does not appear to act by sulphydryl inhibition (Rael *et al*., 2006). Low chronic doses of arsenic ingested tend to accumulate in lipid rich tissues (Jaishanker *et al.*, 2014). In man, high arsenic levels are usually found in hair, nails and skin (Katz, 2019). When arsenic is inhaled, it is deposited in lungs and retained there for a long time. Soluble arsenicals are absorbed from mucus membranes (Muzaffar *et* *al*., 2023). Arsenic containing ointments or lipids soluble vesicants are absorbed through the skin. Inhalation of arsenic dusts for a long period may cause perforation of the nasal septum, as is the case with chromium and other metallic dusts (Dara & Mishra, 2010).

Chronic ingestion of inorganic arsenic causes peripheral arteriosclerosis commonly known as 'black foot disease' (Tseng *et al*., 1996). It may also cause peripheral neuritis resulting in motor and sensory paralysis of the nerve extremities (Staff & Windebank, 2014). Arsenic is toxic to liver and it produces fatty infiltration and causes central necrosis and cirrhosis. It also affects bone marrow and cellular elements of blood (Dara & Mishra, 2010). It is also a known carcinogen and greatly increases the risk of bladder cancer (Girard, 2014). Arsenic can cross placental membrane and is known to be teratogenic to animals (Kaya-Akyzuzlu *et al*., 2016). Arsenicals are also known to be carcinogenic to lungs in humans and may lead to skin cancer through the initial skin lesions (Dara & Mishra, 2010). Background arsenic levels in both fresh and salt water are found to be about 2 µg/l. The recommended upper limit in water is 50 µg/l (Jumba & Likimani, 2001; Duggal, 2007).

2.2.2.7 Manganese

Manganese is a trace element that is found in bones, pancreas, kidneys and liver in little amounts (Soetan *et al.,* 2010; Wada, 2004). It helps in formation of connective tissues, clotting factors, bones, sex hormones and is necessary in brain and nerve functions (Avila *et al*., 2013; Soetan *et al*., 2010). Manganese is an antioxidant enzyme superoxide dismutase (SOD) component (Michalak *et al.,* 2021; Asif, 2017; Avila *et al.,* 2013). Low quantities of manganese in the body may lead to bone malformation, infertility, weakness and seizures. However, large amounts of manganese in diet may lead to elevated manganese in body tissues (Sriram & Lonchyna, 2013; Thompson *et al.,* 1991). Manganese presents neurotoxicity that is unique because it begins with early psychiatric abnormalities and ends up with parkinsonian syndrome (Wada, 2004; Avila *et al.,* 2013). It seems as an inducer of a pro-inflammatory situation in glial cells through producing interleukins and Tumor Necrosis Factor-Alpha (Kirkley *et al.,* 2017; Jana *et al.,* 2007). The ordinary levels of manganese in the blood is 4-15 µg/l although organs like liver, bone, pituitary glands, pancreas and adrenals have higher amounts (Martin *et al.,* 2020; O'Neal & Zheng, 2015).

High levels of manganese triggers mitochondrial disruption by promoting influx of calcium leading to functional loss and terminal permeability of mitochondrial membrane (Roa & Norenberg, 2004). It has also been found that manganese leads to production of reactive oxygen species in mitochondria which results to elevation in apoptotic protein expression and an increase in intracellular antioxidant proteins which attenuate the cascade (Zorov *et al.,* 2014; Martinez-Finley *et al.,* 2013). Chronic exposure of manganese leads to largest amount of mitochondria infiltration and acute exposures leads to sequester within nucleus and nucleolus (Warren *et al.,* 2020).

2.2.2.8 Selenium

Selenium, which is a component of amino acids that are found in active sites of enzymes in animals (including humans) is required in trace amounts (Wada, 2004). At high amounts, it is toxic because it replaces sulphur in enzymes (Hariharan & Dharmaj, 2020; Maroney & Hondal, 2018). In humans, selenium deficiency can lead to muscle necrosis, hypothyroidism, cardio-cerebrovascular, male infertility and also may increase risk of development of cancers of lung, skin, colon, esophagus and stomach (Genchi *et al.,* 2023; Kieliszek *et al.,* 2011). Selenium has been associated with pathogenesis of type two diabetes melitus liver damage, increased serum liver enzyme levels, higher hepatic insulin resistance, and high triglyceride levels (Ogawa-Wong *et al.,* 2016; Yang *et al*, 2016).

Chronic exposure to selenium compounds affects synthesis of thyroid hormone, impairment of natural killer cells activity, hepatotoxicity and also gastrointestinal disturbances (Ventura *et al.,* 2017; Kieliszek & Blazejak, 2016; Vinceti *et al.,* 2001). Acute exposure of environmental selenium has been found to lead to dermatological effects which includes nail loss, hair loss and dermatitis (Vinceti *et al.,* 2001). Extreme cases of selenium poisoning can result to liver cirrhosis, pulmonary edema and death (Hadrup & Ravn-Haren, 2020; Stroikova *et al.,* 2020)

2.3 Sources of Heavy Metals in Soil

2.3.1 Natural Sources of Heavy Metals in Soil

Background concentration of heavy metals in the soil of an area is related to the pedo-geochemical fraction and the dynamics of the environment that led to the formation of the soil. Soil forming parent materials are natural sources of heavy metals as well as other elements. For instance, arsenic natural source includes volcanic release and weathering of As-containing minerals and ores (Eugenio *et al.*, 2018; Dara & Mishra, 2010). High levels of heavy metals such as chromium, mercury, copper, nickel and zinc have been identified in some volcanic soils (Anda, 2012; Eugenio *et al.,* 2018). Even though toxic heavy metals are present in the earth's crust in trace levels, anthropogenic activities such as industrial processing, agricultural applications, use of these metals as well as their alloys and compounds distributes them into the environment increasing these metals to their natural quantities (Dara & Mishra, 2010).

2.3.2 Heavy Metal Pollution in Agricultural Soils

Some of the agents responsible for agricultural soil pollution include fertilizers, pesticides, soil conditioners, farm wastes, irrigation water, fumigants and other chemical agents. Fertilizers use has increased tremendously because soil has either become deficient in a number of nutrients or the total nutrient value is naturally low (Kihara & Huising, 2016) but they may be contaminating the soil with their impurities (Bhatia, 2002). Studies have demonstrated that phosphorous fertilizers contain among others on average; 13 mg Cd, 60 mg Cr, 26 mg Cu, 13 mg Pb and 236 mg Zn per 1 kg of fertilizer (Ghambus & Weiczorek, 2012). During chemical processing of fertilizers, cadmium passes into soluble phase of the fertilizers which favours mobility of this element and leads to its entering the food chain (Gambus & Weiczorek, 2012; Zhong & Zhao, 2016).

Pesticides contain significant amount of heavy metals since they are manufactured using chemical compounds of mercury, cadmium, copper, manganese, lead, zinc, arsenic and others (Wuana & Okieimen, 2011; Bhatia, 2002). Pesticides that contain heavy metals include lead arsenate, dimethylarsenic acid, arsenic trioxide (rat poison), cadmium fungicides and organomercurials (for seed dressing) (Bhatia, 2002; Duggal, 2007; Dara & Mishra, 2010; Girard, 2014). Pesticides have been found to undergo bioaccumulation and this may lead to biomagnification at higher trophic levels (Harnung & Johnson, 2012).

Farm yard manures are important source of organic fertilizers that are applied in farms for improving soil fertility and therefore increase crop production (Zhang *et al.,* 2012). Since the demand for animal products (eggs, meat, milk and other dairy products) have increased, livestock are frequently given feed additives to increase production (Arunakumara *et al.,* 2013; Al-Jaf *et al.,* 2019). These feed additives may contain heavy metals such as copper, cadmium, zinc and arsenic which lead to the manures produced by these animals to contain the heavy metals (Sager, 2007). Arsenicals are used at low concentrations as growth stimulants for poultry and swine and also to prevent dysentery in swine (Jumba & Likimani, 2001). Roxarsone (3-nitro-4-hydroxyl-phenylarsonic acid), an organoarsenic compound is added to some poultry feed to control coccidiosis, enhances the efficiency of feeds utilization, stimulates growth and egg production and improve meat appearances. Roxarsone and its degradation products have been found in chicken litter and arsenic has been detected in soils fertilized with this chicken litter (Manahan, 2010). Continuous application of such manures in farms may lead to accumulation of some heavy metals in the soil (Nicholson *et al.,* 2002; He *et al.,* 2009).

Heavy metal pollution of farm soils with Zn, Pb, Cu, Co, Cd, Ni and V has been found to be as a result of irrigation with polluted water from river in vicinity of a steel plant (Fang *et al.,* 2011; Zhang *et al.,* 2013). Irrigation with water that has high concentration of heavy metals leads to soils being polluted with the heavy metals which have been found to be absorbed by crops sometimes beyond the acceptable levels (Liu *et al.,* 2005; Makino *et al.,* 2010; Ahmed *et al.,* 2018). In addition to these sources, soil conditioners, fumigants and other chemical agents are also employed in agricultural systems to increase and protect the soil fertility as well as kill hazardous insects. They contain several toxic metals like Pb, As, Cd, Hg and Co which may accumulate in soil thereby introducing these heavy metals into the growing crop (Bhatia, 2002).

On release to environment, some heavy metal cations such as Zn^{2+} occur as free cations; others such as Cu^{2+} are bound to organics; while others such as chromium, molybdenum and tungsten form oxyanions CrO_4^{3-}, MoO^{2-} and WO_4^{3-} respectively (Pilon-Smits &

Pilon, 2002). It has also been reported that most cations of transition elements such as Pb^{2+}, Cu^{2+}, Cr^{3+}, Ni^{2+}, Co^{2+}, Fe^{2+} and Mn^{2+} are sorbed more tightly on soil than alkaline earth metal cations (Violante *et al.,* 2010) which makes the essential alkaline earth metals released from exchange sites that makes them leach. Availability of heavy metals in soil solution modifies intake of nutrients by plants, especially those of cationic micronutrients such as Mn^{2+}, Fe^{2+}, Zn^{2+} and Cu^{2+} because they may compete for the same uptake sites located in the roots (Zang *et al.,* 2014), or competes (such as As and Cd competes with P and Zn) for absorption (Sharma & Dietz, 2009; Dalcorso *et al.,* 2013). Indirectly, heavy metal ions exert toxicity by replacing essential nutrients at cation exchange sites of plants (Taiz & Zeiger, 2002; Chibuike & Obiora, 2014). Heavy metals at high concentration have negative influence on growth and activities of beneficial soil microorganisms. This happens by changing their population, diversity and overall activity of microbial communities of the soil which may lead to slow organic matter decomposition causing a decline in soil nutrients (Schaller & Diez, 1991; Chibuike & Obiora, 2014).

2.3.3 Bioaccumulation Factor (BAF) of Toxic Heavy Metals

Bioaccumulation factor (BAF) of a heavy metal in a plant is the ratio of the amount of the metal accumulated in above ground part of a plant relative to the amount it the growth medium (Sultana *et al.,* 2022). It is determined by the formula;

$$\text{BAF} = \frac{\text{Cpp}}{\text{Cs}}$$

Where, Cpp is amount of heavy metal in plant part and Cs is amount in soil (Agarwal *et al.,* 2022).

BAF measures the degree of accumulation of the heavy metal in a specific plant tissue relative to its ambient environment (Agarwal *et al.,* 2022). It is used to determine the level of uptake and final accumulation of a metal in a given part of plant (Shingadgaon & Chavan, 2019). BAF has been calculated to show relatively how much heavy metal has been uptaken from the soil and accumulated to various parts of rice (Satpathy *et al.,* 2014).

2.4 Remediation of Soil that is Contaminated with Heavy Metals

Soil is the major sink for heavy metals that are released into the environment by anthropogenic activities. Unlike organic contaminants which could be oxidized to carbon dioxide by microbial activity, most metals rarely undergo microbial or chemical degradation, and their concentration in soils persists for many years after they are added though their speciation and bioavailability may vary (Adriano, 2003; Kirpichtchikova *et al.,* 2006). To sufficiently protect and restore soil ecosystems polluted by heavy metals, their characterization and remediation is necessary. Remediation of soil is broadly classified into three categories; physical, chemical and biological.

2.4.1 Physical Remediation of Soil

Many physical remediation methods involve excavating and transporting soil for ex situ treatment or in situ treatment where soil is treated in its natural location (Eugenio *et al.,* 2018). Some of the physical methods include soil replacement, soil isolation, vitrification and electrokinetics. Soil replacement is done by partly or fully removing the polluted soil and replacing it with nonpolluted one (Yao *et al.,* 2012). Vitrification involves treating heavy metal polluted soil with high temperature which leads to formation of vitreous material which makes heavy metals immobile (Mallanpati *et al.,* 2015). Electrokinetics involves application of electric field gradient of suitable intensity between two sides of electrolytic tank containing saturated contaminated soil, the heavy metals present are separated through electrophoresis, electric seepage or electro-migration which reduces heavy metal contamination (Evanko & Dzombak, 1997). Soil isolation technique is used to separate polluted soil from unpolluted one by restricting the polluted soil to a specific area when the other physical methods are not feasible or economical (Zhu *et al.,* 2012).

2.4.2 Chemical Remediation of Soil

Chemical remediation methods are fast and effective methods that use chemicals and chemical processes to reduce heavy metals in the soil. These methods involve oxidation, reduction, hydrolysis, solubilization, pH manipulation and other chemical processes. The methods include soil washing, immobilization and encapsulation (Khalid *et al.,* 2016; Eugenio *et al.,* 2018). Soil washing involves making heavy metals leach from soil by chemical means (Ferraro *et al.,* 2015; Guo *et al.,* 2016; Park & Son, 2016). Immobilization techniques aim at decreasing mobility, bioavailability and bioaccessibility of heavy metals in the soil by adding some binding agents to the contaminated soils that immobilizes them by forming more chemically stable constituents (Wuana & Okieiman, 2011). Encapsulating involves mixing heavy metal polluted soil with some substances that fixes the heavy metals into manageable solid blocks which prevents contamination to the surrounding (Khalid *et al.,* 2016).

2.4.3 Biological Remediation

Biological remediation techniques are non-invasive and cheap remediation methods that employ plants and microorganisms to remove heavy metals from the soil (Khalid *et al.,* 2016). The methods are aesthetically pleasant, environmentally friendly and use little energy to remediate soils with low to moderate levels of heavy metal contamination (Sabir *et al.,* 2015). These methods include phytoremediation, chelate assisted phytoremediation and microbial assisted phytoremediation. Phytoremediation of heavy metals is the in situ use of green plants to extract, immobilize or remove heavy metals from water, soil and sediment. Phytoremediation is classified into various categories that include phytovolatilization, phytostabilization, rhizoremediation, phytofiltration and phytoextraction (Prasad & Freitas, 2003; Fulekar *et al.*, 2008; Ali *et al.,* 2013).

Phytovolatilization involves uptake of heavy metals from soil by plants, converting them to less toxic organic compounds vapours then releasing them to atmosphere as biomolecules through transpiration (Marques *et al.,* 2009; Sakakibara *et al.,* 2009). Phytostabilization technique uses plants to decrease bioavailability and mobility of the heavy metals in the soil by restricting them within the rhizosphere (Bolan *et al.,* 2008; Sylvain *et al.,* 2016). Rhizoremediation is the treatment of inorganic and organic pollutants in soil by bacterial or fungal activity in the rhizosphere (Kuiper *et al.,* 2004) which prevents the uptake of heavy metals by plants (Velmurugan, 2012). Phytofiltration is use of plant roots (rhizofiltration) or seedlings (blastofiltration) to absorb or adsorb metals from ground water and aqueous waste streams (GWRTAC, 1997; Garbisu & Alkorta, 2001). Phytoextraction involves use of plants to take up heavy metals, translocate and concentrate them in above ground harvestable plant parts which in effect reduces the heavy metal content in the soil (Khalid *et al.,* 2016).

2.4.4 Choice of a Soil Remediation Technique

Appropriate soil remediation technique that is chsen depends on the cost implication, length of time available for remediation, concentration of the metal in the soil, long term effectiveness of the technique and applicability to multi-metal contaminated soil. In terms of cost, physical remediation is the most expensive and bioremediation is cheapest. It has been reported that phytoremediation is the most cost-effective soil remediation (Cunningham & Ow, 1996; Schnoor, 1997; Marques *et al.,* 2009).

2.4.5 Heavy Metal Phytoremediation Potential and Enhancement Factors

2.4.5.1 Plants with Phytoremediation Potential

Some plants have high potential of remedying heavy metals from environment by various phytoremediation techniques but the rate of remediation depends on the rate of plant growth (Fulekar *et al.,* 2008). Most of the plants used in phytoremediation especially through phytoextraction are biennial or short-lived perennial herbs, shrubs or small trees that have low biomass and grow slowly which limits the phytoextraction method (Fasani *et al.,* 2018). Plant species that have capability of accumulating heavy metals (hyperaccumulators) accumulate 100-500 times heavy metals in dry matter compared to soil or nonaccumulator plant species (Bhargava *et al.*, 2012; Mahar *et al.,* 2016; Sheoran *et al.,* 2016). Some plant species can hyperaccumulate and hypertolerate more than one heavy metal., For instance, *Thlaspi coerulescens* hyperaccumulate nickel, lead, cadmium and zinc; *Thlaspi ochroleucum* and *Thlaspi goesingense* can hyperaccumulate zinc, nickel and lead (Keller & Hammer, 2004; Vogel-Mikus *et al.,* 2006, Ali *et al.,* 2013).

2.4.5.2 Heavy Metals Enhancement Factors

Phytoremediation of soils polluted with heavy metals through phytoextraction process involves uptake of the heavy metals to above ground harvestable plant parts (Suman *et al.,* 2018). The concentration of a heavy metal in a plant shoots relative to the concentration of the metal in the soil where the plant in anchored may be used as an indicator of the phytoextraction potential of the plant. The ratio of concentration of the heavy metal in plant shoots and the soil is used to determine the heavy metal enhancement factor (EF) (Haddad *et al.,* 2023; Shingadgoan & Chavan, 2019). It is a ratio of heavy metal amount in shoots to the heavy metal amount in soil on which the plant is growing (Garba *et al.*, 2018) and is determined by;

$$EF = \frac{C\ shoots}{C\ source}$$

Where C_{shoots} is the heavy metal concentration in shoots and C_{source} is the heavy metal concentration at the source (which is soil in this case) (Shingadgoan & Chavan, 2019)

A value of EF greater than one (1) indicates higher concentration of the metal in the plant than in the soil (Sabo & Iadan, 2018) implying that the plant is a potential phytoextractor of the metal in question. The greater the value of EF, the better the phytoremediation potential of the plant through phytoextraction process.

2.4.5.3 Molecules Responsible for Phytoremediation

Various plants show molecular mechanisms related to cell wall composition, plasma membrane properties and vacuolar compartmentalization that may be involved in detoxification of various pollutants (Hall, 2002; Cherian & Oliveira, 2005). Assumptions of many scientists is that key ligands that play a role in hyperaccumulation include histidine, nicotianamine, organic acids (mainly citrate and malate), glutathione, phytochelatins and metallothioneins (Verbruggen *et al.,* 2009). Histidine is taken as the most important free amino acid involved in hyperaccumulation since it forms stable complexes with some heavy metals and is found in fairly high concentration in the roots of hyperaccumulator plants (Persans *et al.,* 1999; Callahan *et al.,* 2006). Nicotianamine form strong complexes with many transition metals which appears to aid transportation of micronutrients within the plant (Stephan & Scholz, 1993). It also appears to be involved in metal hyperaccumulation and detoxification in some plants (Douchkov *et al.,* 2005; Kim *et al.,* 2005; Callahan *et al.,* 2007). Organic acids such as citrate and malate in hyperaccumulators are assumed to play a major role in vacuolar sequestration by formation of metal-organic acid complexes in shoots (Kramer *et al.,* 2000; Sarret *et al.,* 2002; Haydon & Cobbett, 2007). Glutathione form complexes with several metals, is a cellular antioxidant and is a precursor of phytochelatins (Freeman *et al.,* 2004). Phytochelatins are synthesized enzymatically from glutathione in presence of certain metals and metalloids leading to some metal detoxification but not for Cu, Cd, Zn, cobalt and Ni (Ebbs *et al.,* 2002; Schat *et al.,* 2002; Clemens, 2006). Metallothioneins in plants are associated with variations in copper tolerance (Jack *et al.*, 2007) and seem to function in copper accumulation and phloem transport (Guo *et al.*, 2008).

2.4.5.4 Improvement of Phytoremediation Capacity of Plants

Efficiency of phytoremediation capacity of a plant can be improved by traditional plant selection or by biotechnology methods (Dalcorso *et al.,* 2019). In the traditional approach, native non-edible plant species that grow in heavy metal contaminated sites have been identified for reclamation purposes (Roccotiello *et al.*, 2015; Dalcorso *et al.,* 2019). To improve their efficiency, the genetic determinants of heavy metal accumulation and tolerance can be introduced by introgression into the genome of other plants with high biomass (Dushenkov *et al.,* 2002). For instance, phytoremediation of wild *B. juncea* has been improved by fusing its protoplasts with those of *N. caerulescens* to transfer the metal-resistant ability of *N. caerulescens* into the high biomass of *B. juncea* (Brewer *et al.,* 1999). Use of tissue culture for selecting genes that have enhanced ability for assimilation of metals helps in development of phytoremediation plant varieties (Fulekar *et al.*, 2008).

Even though these classical breeding and genetic approaches have given positive results, genetic engineering techniques may accelerate development of plants with higher phytoremediation capacity. Recombinant DNA technologies coupled with availability of genome sequences for different plant species allows the transfer of desirable determinant from hyperaccumulator species to sexually incompatible and high-biomass crops that are appropriate for phytoremediation (Fazani *et al.,* 2018; Dalcorso *et al.,* 2019). Metal hyperaccumulating plants with high abilities to tolerate, accumulate and detoxify heavy metals possess unique genes (Danika & LeDuc, 2005) which could be transferred to fast growing plant species for enhanced Phytoremediation (De Souza *et al.*, 1998). Candidate plants for genetic engineering for phytoextraction should be high biomass plants which grows fast, have inherent capability for phytoextraction and be amenable to genetic transformation (Fasani, 2012; Dalcorso *et al.,* 2019). In these candidate plants, metal accumulation and tolerance may be improved by overexpressing natural or modified genes encoding antioxidant enzymes or those that are involved in the biosynthesis of glutathione and phytochelatins (Gratoa *et al.*, 2005). For instance, the gene YCF1 (yeast cadmium factor protein) has been introduced into *B. juncea* and the resultant transformants exhibit enhanced tolerance to cadmium and lead which improved their accumulation in shoots 1.5 to 2 times higher than the wild types (Bhuiyan *et al.,* 2011). Compared to natural hyperaccumulators, transgenic plants are highly efficient, have higher biomass, can accumulate and decontaminate pollutants for longer period and, reduce treatment cost (Rugh *et al.,* 1998; Dhankher *et al.,* 2002; Dimkpa *et al.,* 2017).

Plants that are naturally tolerant to heavy metals have been used as a source of genes for phytoremediation (Cherian & Oliveira, 2005). Methylmercury has been transformed to volatile elemental form that is 100 times less toxic by use of two bacterial genes merA and merB combined in transgenic plants such as Arabidopsis, tobacco, poplar tree, eastern cotton and several others (Bizily, 2000; Gratoa *et al.,* 2005). Arabidopsis plant with tolerance to arsenic and cadmium has been engineered by introducing bacterial genes arsC and y-ECS (Cherian & Oliveira, 2005). Among the compounds that are main metal chelators in plants, only metallothioneins are direct products of gene expression and in contrast, the amount of phytochelatins and organic acids depends on the activity of enzymes involved in their biosynthesis and therefore genes encoding these enzymes should be manipulated (Kozminska *et al.,* 2018). Some of the genes encoding metallothioneins that have been found to improved heavy metal tolerance and accumulation in plants are EhMT1, SpMT1, BcMT1, SaMT2 and ThMT3 (Yang *et al.*, 2011; Xia *et al.*, 2012; Zhang *et al.*, 2014; Lu *et al.*, 2015; Peng *et al.*, 2017).

2.4.5.5 Phytoextraction as Carried out in Agricultural Farms

Phytoextraction is done by planting hyperaccumulators in contaminated soil then harvesting them once mature. Depending on the targeted soil concentration after remediation, repeating planting and harvesting of the hyperaccumulators is done until concentration reach the acceptable levels (Ghosh & Singh, 2005; Wuana & Okieimen, 2011). After each cropping, the plants are harvested and disposed appropriately (Ghosh & Singh, 2005; Fuksova *et al.,* 2009). In medium and low contaminated soils where farming cannot be avoided, co-cropping hyperaccumulators with low accumulating agricultural crops is done (Wei *et al.,* 2011).

2.4.5.6 Phytoremediation Investigations Done in Kenya

In Kenya, little investigations on phytoremediation has been reported. A study carried out using bamboo at a chromium contaminated site identified *D. asper, B. vulgaris, D. membranaceus* and *B. blumecana* as bamboo species suitable for restoration of chromium-contaminated tannery sites (Were *et al.,* 2017). In another study, *P. senegalensis*, *A. hybridus* and *E. Crassites* were found to have capability to uptake Cu, Zn and Cd from contaminated water in Nairobi river (Owiti, 2015). Studies also showed that turnip, sunflower and mustard plant accumulated high amount of Fe, Mn, Zn and Cu when grown in sludge but turnip and sunflower were more effective in phytoremediation (Kilongi, 2017). A study carried out in Nairobi dam showed that free floating *Eichhornia crassipes* absorbs and concentrates Cd, Pb, Cu, Zn and Ni so it could be used for their removal from polluted water (Ndeda & Manohar, 2014).

2.5 Methods for Analysis of Heavy Metals

Analytical methods used to analyze heavy metals include atomic absorption spectrophotometry (AAS), inductively coupled plasma (ICP), x-ray fluorescence (XRF) and microwave plasma-atomic emission spectroscopy (MP-AES) among others (Skoog *et al.,* 2017; Narayanan, 2014). AAS is easy to operate, highly sensitive (up to ppb detection), free from inter-element interference, has high accuracy, offers wide application across industries and low cost per analysis. On the other hand, AAS has limitations because it cannot detect non-metals, it is more applied in analysis of liquids, the sample is destroyed during analysis and acquiring the equipment is expensive (Visser, 2021; Oti, 2016). ICP is fast, has low detection limit, gives clean mass spectra, offers high spectral resolution, has multielement analysis capability and has ability to quantify all elements except argon. However, ICP has poor tolerance of non-volatile total dissolved solids and has high initial and operation cost (Wilschefski & Baxter, 2019; Warra & Jimoh, 2011). Inductively coupled plasma- mass spectrometry (ICP-MS) offers very high sensitivity and is suitable for multielement analysis at parts per trillion (ppt) which enables obtaining much information about the examined sample whereas inductively coupled plasma- optical emission spectrometry (ICP-OES) has poor precision, sample drift, non-ideal detection limit and sometimes inaccurate identification (Douvris *et al.,*2023; Khan *et al.,*2021; Gan *et al.,* 2019; Wilschefski & Baxter, 2019; Masson *et al.,* 2010). XRF is non-destructive, fast, highly accurate and has simple spectra line with no interference but requires large samples, has difficulty in quantifying elements lighter than sodium, has difficulty in distinguishing isotopes and ions of the same element and has high cost of acquiring the instrument (Margui *et al.*, 2022; Oti, 2016). MP-AES is cheap because it uses nitrogen and not argon, safer to use and work with, highly sensitive (limits below ppb), fast, can deal with difficult matrices and can be located at sampling point because it only requires electricity. However, MP-AES has poor detection limits for elements such as As, Se and Hg; matrix interference for complex samples; and small linear range (Balaram, 2020). In this study, ICP-MS was used because of its high sensitivity, accuracy, simplicity in sample preparation, small sample requirement and was available.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Site

The study was carried out at mainly Mwea irrigation scheme which is located in Mwea west subcounty of Kirinyaga County in Kenya. This subcounty had a population of 114, 660 people in 2019 (KNBS, 2019) and some of its towns include Wanguru, Mutithi and Kimbimbi. Mwea irrigation scheme is situated about 100 km from Nairobi within latitude of 37^o 13´ E and 37^o 30´ and longitude 0^o 32´ S and 0^o 46´ S on the south eastern slopes of Mount Kenya (Mburu & Ngucia, 2022; Gicheru, 2016; Mati *et al.,* 2011). The scheme consists of regions with black cotton soil (paddy sections) intercepted with other clay soils (used for settlement and growing of other crops) and is classified as tropical with semi-arid climate (Mburu & Ngucia, 2022; Gicheru, 2016). The upland soils are weathered on intermediate igneous rocks including trachytic and phonolites or rhyolitic phonolites whereas plain soils are weathered on basic igneous rocks including nephaling basalts and basaltic agglomerates (Wanjogu *et al*.,2006; Kamoni, 1992)

The annual amount of rainfall experienced in this area ranges from 356-1625 mm with an average of about 950 mm and has bimodal rainfall season, that is, long rains (April-May) and short rains (October-November) (Akoko *et al.,* 2020; Gitonga *et al.,* 2019; Mati *et al.,* 2011). This area has air temperature ranging from 14-31^o C with a mean of 24^o C and a relative humidity of 55-70 % (Akoko *et al.,* 2020; Ndiiri *et al.,* 2012; Mati *et al.,* 2011). The irrigation scheme has a gazetted area of 12000 hectares of which 6500 hectares is already under paddy irrigation and the rest comprises of amenities, subsistence crops and horticultural farming (Gicheru, 2016; NIB, 2016; Muhunyu, 2012; Mati *et al.,* 2011).

The water used for irrigation mainly comes from rivers Thiba and Nyamindi. These rivers originate from Mount Kenya forest and flows from forest boundary through cultivated and settled land up to the point water is abstracted. The irrigation water is abstracted from the rivers by gravity using fixed intake weirs then distributed on the scheme through unlined open channels. There is a link canal that joins the two rivers that transfer water from river Nyamindi to river Thiba (Akoko *et al.,* 2020). The study site is shown in Figure 1.

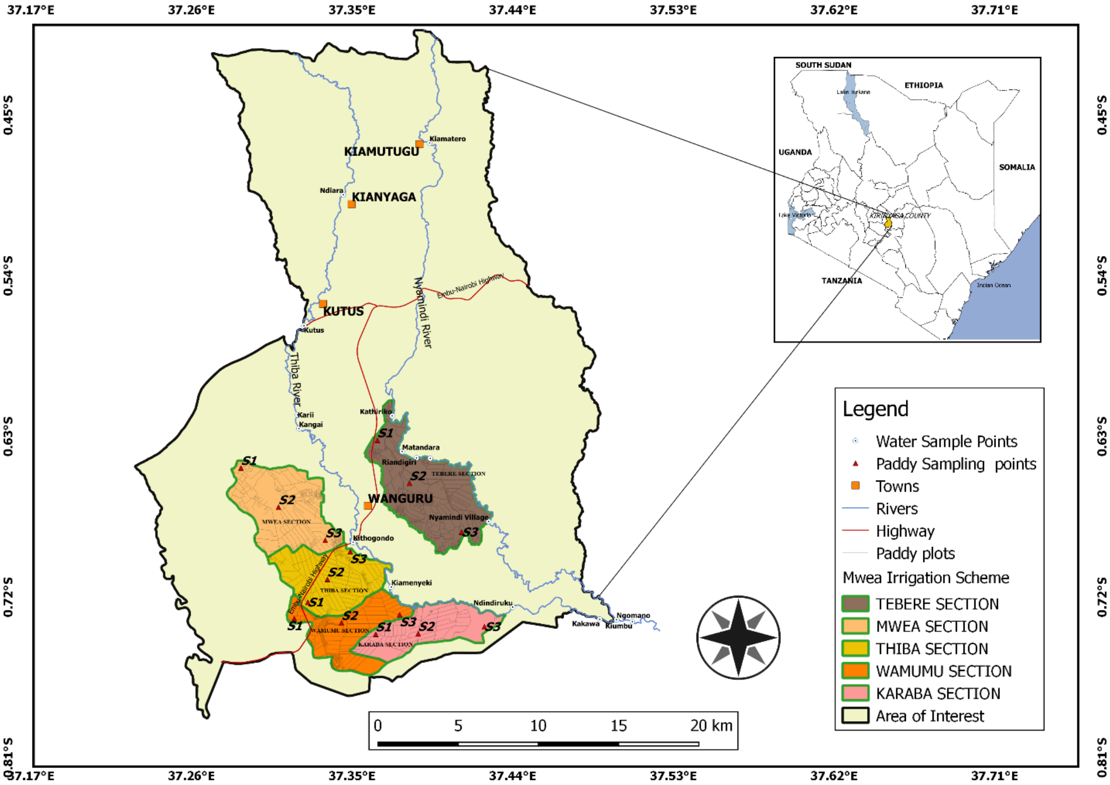


Figure 1: Map of Study Site

[Source: Galaxy GeoServices Inc. Thematic map showing Mwea irrigation scheme and its surrounding. Map generated using Quantum GIS software version 3.8 (July 17, 2024)]

The area where rice is grown is made up of five main sections namely Tebere (T), Mwea (M), Thiba (H), Wamumu (W) and Karaba (K). However, there are other areas outside these main sections that are known as '*Jua kali*' where rice is grown (outgrowers). Further information about size, when rice growing begun and duration of rice farming on the five sections is summarized in Table 2.

Table 2: Main Rice Growing Sections in Mwea Irrigation Scheme

Section	Approximate acreage	Year established	Approximate years of rice farming
Tebere (T)	3285	1954	70
Mwea (M)	3110	1956	68
Thiba (H)	3019	1966	58
Wamumu (W)	2880	1971	53
Karaba (K)	2650	1984	40

Source: Abdulahi et al., 2003; JICA,1988; Farmers interview

Rice farming at Tebere section was started first in 1954 followed by Mwea section around the same time. Thiba section was established in 1966, Wamumu section in 1971 and Karaba by 1984. Tebere and Mwea sections have been in place for about 68 years whereas Thiba, Wamumu and Karaba sections have been in place for about 58, 53 and 40 years respectively.

3.2 Research Design

In this study, descriptive survey research design, complete randomized design (CRD) and randomized complete block design (RCBD) were adopted. A descriptive survey research design was well-suited for collecting both qualitative and quantitative data through questionnaires, focusing on social-demographic distribution, food commonly consumed, agrochemicals used and plants commonly found in rice farms at Mwea irrigation scheme. A descriptive survey research design is particularly appropriate for studies aiming to gather detailed information about a population's characteristics, behaviours, and experiences (Kombo & Tromp, 2006; Manjunatha, 2019;). This design allows researchers to collect both qualitative and quantitative data, providing a comprehensive understanding of the subject matter (Creswell, 2014). The CRD (a one factor approach) was employed to design a suitable method to gather and analyse data on amounts of selected heavy metals in different types of fertilizers, different sections of the scheme, different parts of rice, different nonedible plants and in the two main rivers providing water for irrigation at the scheme. The CRD is a statistical design used in experiments to assess the effects of one or more factors on a response variable. The RCBD (a two-factor approach) was utilised to design suitable methods to collected and analyse data on the concentration of the selected heavy metals in water and sediment in the two main rivers feeding Mwea irrigation scheme during rainy and dry season. The RCBD allows for straightforward comparisons between treatments within blocks, enhancing interpretability of results. The RCBD is a powerful tool for researchers looking to obtain reliable and valid results in experiments where variability needs to be accounted for (Montgomery, 2017).

3.3 Research Instruments

Data and information were collected by use of questionnaires (Appendix II) and analytical instruments.

3.3.1 Questionnaires

The questionnaires were carefully developed and tested in a pilot study at Ahero irrigation scheme. After the pilot study, the questionnaires were revised to become well validated. The questionnaires were administered to 350 rice farmers from the five main rice growing sections of Mwea irrigation scheme. The questionnaires (Appendix II) contained two sections: Section I was designed by the researcher to obtain demographic information about farmers who were involved in rice farming whereas Section II was designed to obtain information on the agrochemicals used in rice farming and plants commonly found in rice farms. The information obtained from questionnaires was cleaned, coded, and analysed appropriately.

3.3.1.1 Validity

The content validity of the questionnaires was improved by supervisors and experts in the field of social sciences who offered expert judgement (Borg & Gall, 1989).

3.3.1.2 Reliability

Before administering the questionnaires in Mwea irrigation scheme, they were pre-tested after administering them to respondents from Ahero irrigation scheme to determine their reliability. This was done to remove ambiguity and enable respondents in the study area to understand and to respond to the questions accurately. The reliability coefficient was 0.76 which was above 0.70 that is reported to be sufficiently acceptable for studies (Bryman, 2012; Borg *et al.*, 2003).

3.3.2 Analytical Instruments

The analytical performance of the various instruments used for analysis was done. The reproducibility test was done by analysing a known standard five times then the standard deviation and coefficient of variation calculated. The values obtained from different sets of standards were used to plot calibration curves.

3.4 Sampling Techniques

Preliminary survey was done in the study area to identify the experimental zones, naturally growing plants when no cropping was taking place or in any abandoned farms, towns, industries, dumping sites and agricultural activities upstream. Five species of nonedible plants that are common in rice farms at Mwea irrigation scheme were identified (through a questionnaire item). Eleven commonly used fertilizers in rice farming were bought from five most busy agrovets shops (identified from questionnaires) serving Mwea irrigation scheme to determine their heavy metal content. The fertilizers were NPK 23:23:0, triple superphosphate (TSP), diammonium phosphate (DAP), muriate of potash (MoP), Mavuno plant, Baraka plant, sulphate of ammonia (SA), urea, calcium ammonium nitrate (CAN), Amidas top and Mavuno top.

Water and sediment samples from the rivers were collected in triplicates during dry and wet season along rivers Thiba and Nyamindi. The sampling points along the rivers were from Kiumbu (about one kilometre downstream from Ngomano; the confluence of rivers Thiba and Nyamindi) and coded as C2. The next sampling point was Ngomano (at the confluence of river Thiba and river Nyamindi) and coded as C1. The other sampling points along river Thiba (upstream) were Kakawa (T1), Ndindiruku (T2), Kiamanyeki (T3), Kithogondo (T4), Kangai (T5), Karii (T6), Kutus (T7) and Ndiara (T8). The sampling points upstream of river Nyamindi from Ngomano were Nyamindi village (N1), Riangeci (N2), Riandigiri (N3), Matandara (N4), Kathiriko (N5) and Kiamatero (N6). Water samples from rice paddies at M17, H6, W6 and K8 subsections were collected in dry season four weeks after planting of rice.

Water samples were collected at a depth of 30 cm below water surface (to avoid scum collection) using depth sampler/grab sampler then stored in plastic bottles. Relevant details such as sample collection date, sample code and sampling site were noted. The sampling bottles were pre-soaked overnight (to avoid unpredictable changes in characteristic as per standard procedure) with 10% HCl, rinsed with distilled water and rinsed again using the waters from collecting points. The water samples were preserved by adding 2 drops of concentrated HNO_3 to each sample (in order to preserve metals and avoid precipitation) before storing below 4^{o} C until they were digested (Kar *et al.,* 2008; Mwegoha & Kihampa, 2010; Reza & Sign, 2010). The paddy water samples were treated the same way as river water samples.

Sediment samples were collected (at the same point and time with water samples) using auger sampler. Stones and plant materials were removed by hands then samples were stored in plastic containers that had previously been cleaned with 10% nitric acid and rinsed with distilled water. The samples were labelled appropriately as described in water sample collection, recorded and transported into laboratory where they were dried in an oven at 105^{o} C. To obtain analytical samples of sediment, coning and quartering technique was done (Nyakairu & Koeberl, 2000) thereafter, the samples were stored at a temperature below 4^{o} C.

Sampling of soil was done in the dry season before ploughing land in preparation of planting. In each of the five main rice growing sections (Tebere- T, Mwea- M, Thiba- H, Wamumu- W and Karaba- K), three sampling points were identified along a transect. Soil samples were collected from each sample collection point at a depth of 0-15, 15-30 and 30-45 centimetres. The three samples from each sampling point were mixed to form a composite sample which was then put in a bag (Hoogsteen *et al.,* 2015) and labelled immediately. Similarly, soil samples were collected from three school's playground (Tebere secondary school, Karaba primary school and Kiandegwa primary school) where rice farming has never taken place (to show the natural levels of heavy metals) and were handled the same way as the other soil samples then coded 'C'. The samples were then transported to the laboratory in a cool box and kept in a refrigerator to minimize chemical reactions (Fransen & Cihacek, 1998). In the laboratory, coning and quartering technique was used to come up with analytical samples (Nyakairu & Koeberl, 2000). The analytical samples were then stored at a temperature below 4^{o} C (Okalebo *et al.,* 2002; Narayanan, 2014) in clean, nitric acid treated plastic bottles (Czarnecki & During, 2015) in the laboratory.

After rice crop matured and was ready for harvest in the season following soil sampling, rice plant (complete with straws and grains) samples were collected (from the same locations where soil samples were collected). Rice plant samples were dried under the sun, winnowed (to obtain grains), washed with distilled water then rinsed with deionized water, grains threshed (to separate edible part of rice grains from husks) then the different parts (straw, husks and grains) were stored separately at temperature below 4^{o} C (Okalebo *et al.,* 2002; Ogunkule *et al.,* 2014). About 500 g of plant shoots from each of the five common nonedible plant species identified [*Cyperus difformis* (rice sedge), *Tradescantia fluminensis* (wandering jew), *Echinochloa crus-galli* (cockspur grass), *Cyperus rotundus* (nut grass) and *Ludwigia adscendens* (water primrose)] were picked from each of the section where soil and rice samples were collected, mixed thoroughly, put in paper bags, sealed and then labelled appropriately. At the laboratory, the leaves were washed with distilled water then dried under a shade. Soil and sediment samples were dried at 40^{o} C using Memmert oven for two days. For plant shoots, drying in the oven was done at 70^{o} C for two days. Then, the samples of soil, sediment, rice straw, rice husks, rice grains, plant shoots and fertilizers were ground to fine powder using soil Deagglomerator Pulverisette 8.

3.5 Data Collection

3.5.1 Survey

Structured questionnaires were administered to the farmers identified through random sampling in the five rice growing sections. Where the sampled farmer had challenges in filling the questionnaire, interviews were conducted to collect the information. A total of 350 farmers were involved in the responding to the questionnaires

3.5.2 Digestion of Samples

Each soil/sediment/rice straw/rice husk/rice grain/plant shoots/fertilizer dry ground sample of 0.5±0.025 g was weighed out using Top pan Sartorius balance into an ultra-clean and dry inert polymeric microwave vessel. A volume of 9±0.5 ml of concentrated nitric acid was slowly added under fume extraction hood. After this, 4±0.05 ml of perchloric acid was added slowly followed by 1±0.05 ml of concentrated hydrochloric acid. The samples were left to react for 5±1 minutes prior to sealing the vessels to allow any gases to escape. The vessels were placed on the rotor then placed in the microwave digester (High performance microwave digestion system, ETHOS UP). The microwave digester was gradually heated to 150 ^{o}C in not less than 20 minutes then held at that temperature for another 20 minutes. After the last 20 minutes, the microwave automatically began cooling the samples and indicated when cooling was complete. After the cooling, the samples were quantitatively transferred into 250 ml volumetric flasks then filled to the mark using distilled de-ionised water (Fabjola *et al.,* 2015; Mangun, 2009; Kingston & Walter,1998).

The water sample was shaken thoroughly in their plastic containers by use of hand. A volume of 45 ml of the sample was measured into an ultra-clean and dry inert polymeric microwave vessel. A volume of 9±0.5 ml of concentrated nitric acid was then slowly added under fume extraction hood followed by 4±0.05 ml of perchloric acid. The vessels were placed on the rotor then placed in the microwave digester (High performance microwave digestion system, ETHOS UP) then digested with topping up with distilled water to 250 ml as was done during soil digestion.

3.5.3 Preparations of Standards

Multi element standards of 10 ppm from Agilent Technologies was used as the stock solution. A calibrated micro pipette was used to transfer 0, 100, 200,300, 500 and 1000 µL of stock solution into well labelled 100 ml volumetric flasks to prepare 0,10, 20,30, 50 and 100 ppb standards, respectively. Each of these volumetric flasks was topped up to the marks using 5% nitric acid solution. These standards were used for preparing calibration curve.

3.5.4 Analysis of Heavy Metals from Digested Samples

Heavy metal (Cd, Cr, Ni, Pb, Zn, As, Mn and Se) analysis was done at Chemistry laboratories using inductively coupled plasma-mass spectrometry (Agilent Technologies 7900 ICP-MS).

3.5.5 Determination of Phytoremediation through Phytoextraction

Heavy metal content values in soil and plant shoots of five nonedible plants commonly found in Mwea irrigation scheme rice farms were organized and tabulated in order to obtain the average value for each then heavy metal enrichment factor (EF) for each plant was determined (as described in section 2.4.5.2). The plants whose phytoremediation potential was determined were *Cyperus difformis* (rice sedge), *Tradescantia fluminensis* (wandering jew), *Echinochloa crus-galli* (cockspur grass), *Cyperus rotundus* (nut grass) and *Ludwigia adscendens* (water primrose). The heavy metal enrichment factors (EFs) were then used to identify heavy metal phytoremediation potential of each of the selected nonedible plant studied.

3.6 Data Analysis

The data was analysed using statistical package for social sciences (SPSS) Version 26. To determine whether there was significant difference in concentration of heavy metals in water, sediment and soil from different sections, ANOVA was used. Student t-test was used to compare the concentration of heavy metals in sediment and river water. To determine whether there was significant difference between heavy metal concentration in water during dry and wet season in the two rivers, two-way ANOVA was used. For the determination if there were differences in concentration of the heavy metals in different parts of rice and the soil, one-way ANOVA was used. One-way ANOVA was used to determine significant differences of heavy metals in different plant shoots growing in Mwea irrigation scheme and different fertilizers used by farmers. For identification of hyperaccumulators, ANOVA was used to determine if there were significant differences in the concentration of heavy metals in shoots of different plants growing in Mwea irrigation scheme. Tukey's Honest significant difference (HSD) was used for mean separation.

3.7 Ethical Consideration

The research proposal was submitted to Chuka University Ethics Committee for ethical considerations and evaluation. After this, the researcher sought for permission from National Commission for Science, Technology & Innovation (NACOSTI) before commencing the research. During the research, methods that were used, results and data were reported honestly. In cases where particular information has been obtained from other people's work, it has been acknowledged and only new findings have been published for purpose of dissemination of knowledge and to enable further research. The questionnaires had an introduction to assure the respondents that the information that they were to give was only to be used for academic purposes and would be treated confidentially. The respondents were enlightened and persuaded on the importance of their participation in the study and were not coerced in any way. The identity of people that gave information through questionnaires, interviews or any other way has not been revealed. Throughout the research, laws and regulations governing environmental pollution, handling and disposal of toxic materials were followed strictly to avoid health hazards.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Sources of Heavy Metal Contamination at Mwea Irrigation Scheme and its Water Catchment

4.1.1 Results from Questionnaires

The results obtained from questionnaires are presented and discussed in this section.

4.1.1.1 Social-demographic Characteristics Information of the Respondents

The social-demographic characteristics of the respondents such as gender, age, highest level of education, size of their rice farm and the time spent growing rice in the said piece of land are given in Table 3.

Table 3: Social-demographic Distribution of the Respondents (N=350)

Variables	Respondents	Percentage (%)
Gender		
Male	212	60.57
Female	138	39.43
Age (years)		
Up to 30	66	18.86
31-40	104	29.71
41-50	95	27.14
51-60	43	12.29
61 and above	42	12.00
Highest education level		
Primary	116	33.14
Secondary	161	46.00
Tertiary	41	11.71
None	32	9.14
Farm size (acres)		
Up to 1	99	28.29
1.1-2.0	153	43.71
2.1-3.0	40	11.43
3.1-4.0	27	7.71
Over 4.0	31	8.86
Farming time (years)		
0-9	176	50.57
10-19	102	29.31
20-29	40	11.49
30-39	29	8.33
40 and above	1	0.29

Out of all the respondents, 60.57 % were males whereas 39.43 % were females. This study found that more men are involved in rice farming compared to women. This study corresponds with Nzonzo (2016) and Abura *et al*. (2019) who reported that more men than women were involved in rice farming. This may be due to the fact that men being heads of families have to work hard so that they provide for their families. Rice farming is strenuous which makes more men get involved in it than women with men being involved in land preparation and transportation whereas women carry out lighter chores such as planting, weeding, birds scaring, threshing, drying and selling of rice (MOA, 2008; Medagbe *et al.,* 2020). Other studies have reported that social and cultural issues hinder women in rice production; women have less technical knowledge in rice farming; and men make day-to-day decisions on rice production (Okumu, 2020; Medagbe *et al.,* 2020; Kuria, 2004).

The percentage of respondents aged up to 30, 31-40, 41-50, 51-60 and over 60 years were 18.86 %, 29.71 %, 27.14 %, 12.29 % and 12.00 % respectively. Majority of the farmers were aged between 31-40 and 41-50 years which translates to 56.85 %. This represents middle aged people who have many responsibilities such raising their children, paying school fees, taking care of aging parents, working to gain wealth and other society social demands which pushes them to be serious in rice farming. It was observed that about three-quarters (75.71 %) of rice farmers were aged up to 50 years which is close to prime productive age of 25-54 years that was alluded by Zane (2023) and also closely agrees with Nzonzo (2016) who found that rice farmers of ages 20-49 years were 74%. This study concurs with studies carried out by Obwa (2016) and Abura *et al.* (2019) in Ahero irrigation scheme who found similar distribution of ages of rice farmers.

The education levels of rice farmers of Mwea irrigation scheme varied from those who had no formal education to those who had attained tertiary level training. The farmers with primary school level, secondary school level, tertiary level and those with no formal education were 33.14 %, 46.00 %, 11.71 % and 9.14 % respectively. It was observed that 90.85 % of the farmers had sufficient education (primary school level and above) so they may have reasonable capacity to access extension information as well as in adopting new agricultural innovations which improves farming systems. The present study closely agrees with Nzonzo (2016) who reported 85.5 % as the farmers who had primary school to tertiary level education. However, this study differs with Abura (2016) who reported that majority of farmers in Ahero irrigation scheme had primary school level education which may be attributed to persons with secondary school level education and above seeking white collar jobs; seeking employment opportunities in nearby towns or industries; venturing in self-employment at nearby urban centres; and the believe among locals that farming (as well as fishing) are jobs for people who do not have any education. In this study, the farmers who had no formal education were 9.14 % which is slightly less than 14.6 % that was reported by Nzonzo in 2016 (about 8 years ago) and far much less than 47.5 % that was reported by Kuria in 2004 (about 20 years ago) as the illiterate farmers in Mwea irrigation scheme. The present study shows that currently, more literate people are involved in rice farming than was in the earlier cases which may be attributed to educated children of the original rice farmers taking up the rice farming; free primary school education launched in 2003; and free day secondary education started in 2008 that has significantly reduced levels of illiteracy in Kenya (Ndolo *et al*., 2016; Lucas & Mbiti, 2012).

The rice farmers who had farm sizes of up to 1 acre were 28.29 %, those with farms greater than 1 acre up to 2 acres were 43.71 %, those with farms greater than 2 acres up to 3 acres were 11.43 %, those with farms from 3.1 acres up to 4 acres were 7.71 % and those with rice farms greater than 4 acres were 8.86 %. Majority of farmers (72 %) had small pieces of rice farms which was up to 2.0 acres and only 8.86 % of farmers had rice farms greater than 4.0 acres. On inception of the irrigation scheme, original rice farmers were allocated 4-5 acres with an average of 4.09 acres (Kuria, 2004) but due to maturing of the original rice farmers' children, land has been subdivided to smaller portion to the heirs. However, this subdivision is done informally due to close monitoring of land use and ownership by National Irrigation Board (NIB) management (Kimari, 2019) which is keen in preventing subdivisions to small uneconomical pieces of land and that the farmers do not actually own the land but are tenants (Munyua, 2020; MOA,2008; Kimari, 2019). Subdivision of the originally allotted land to several heirs explains why majority of farmers (72 %) have small pieces of rice farms measuring up to 2.0 acres. Since the pieces of land are small, rice farmers have to intensify farming by using large quantities of agrochemicals to ensure that they realize high harvest to ensure they meet all their family and developmental needs. This study differs with what was reported by Nzonzo (2016) that farmers who had up to 2 acres were 47.9 % and those with 3- 4 acres were 41.7 %. However, it can be observed that since the current study was carried out about 6 years after Nzonzo's study, further land subdivisions of rice farms may have been done which may have led to increase of the farmers with up to 2 acres of rice farms from 47.9 % to 72 % and a decrease of farmers with 2-4 acres of rice farms from 41.7 % to 19.14 %. This study also differs slightly with Obwa (2016) who reported a little higher percentage (80.6 %) of farmers with rice farms of a size up to 2 acres at Ahero irrigation scheme.

About half of the farmers (50.57 %) had been growing rice in their pieces of land for less than 10 years while those who had grown rice in their farm between 10-19 years were 29.31 %, 20-29 years were 11.49 % and only 8.33 % of the farmers had grown rice in their farms for 30 to 39 years. It was observed that only 0.29 % had grown rice in their farms for 40 years and above. It was observed that 79.88 % of the farmers had been growing rice for up to 19 years in their pieces of land showing that majority had been farming for a relatively short time. This is in agreement with the observation that middle age farmers (up to 50 years) constituted to 75.71 % of all the farmers. This study does not agree fully with Nzonzo (2016) (although his range of years was different from the ranges of this study) who found that farmers who had farming experience of up to 15 years were 52 % (this study would give about 65.23 % which is slightly higher) and those with experience of 46-55 years were 6.3 % (which implies that farmers with experience of 40 years and above were more than that 6.3 %) which is much higher compared to 0.29 % from current study. This difference may be attributed to land subdivision as a result of population increase and more younger farmers getting into rice farming. This study also differs with what was reported by Omondi & Shikuku (2013) that farmers who had farming experience of 0-10 years were 25.79 % in Ahero irrigation scheme but this could be possible since that study was carried out about 10 years before the present study.

4.1.1.2 Food Crops Commonly Consumed by People of Mwea Irrigation Scheme

The foods that are commonly consumed by people living in Mwea irrigation scheme are given in Table 4.

Table 4: Food Commonly Consumed by People Living in Mwea Irrigation Scheme

Food crop	Respondents	Percentage (%)
Rice	314	18.86
Maize	312	18.74
Beans	286	17.18
Peas	78	4.68
Kales	77	4.62
Bananas	75	4.50
Green grams	70	4.20
Black beans	65	3.90
Spinach	60	3.60
Tomatoes	45	2.70
Others	283	17.00

The foods that are mainly consumed by people living in Mwea irrigation scheme are rice (18.86 %), maize (18.74 %) and beans (17.18 %). Peas, kales, bananas, green grams, black beans, spinach and tomatoes among several others are also consumed. These foods are mainly obtained from crops grown in and around Mwea irrigation scheme so are readily available, relatively affordable and culturally accepted. Rice is the most commonly consumed food in this area (18.86 %) because, in addition to being available, it can easily be fed to children, elderly and the sickly members of the society.

Rice and maize are the staple foods of the people living in Mwea irrigation scheme which agrees with FAO (2023) report that most people live on a diet based on one or more of foods such as rice, maize, wheat, sorghum, millet, tubers, roots and animal products. It can therefore be observed that it was necessary to know the status of heavy metal pollution in Mwea irrigation scheme since the rice is consumed in large quantities by people of this area and the rest of the country as alluded to by Watanabe *et al.* (2021) that eating rice custom has become widespread among middle and affluent classes in Nairobi which shows that they are moving from traditional staple foods (ugali, chapati and githeri) to rice. This study is also in line with Onyango *et al.* (2016) who reported reduction of maize and wheat in household shopping with addition of rice (among other food types) showing that Kenyans are embracing diversification of food.

4.1.1.3 Commercial fertilizers, manures and other substances used in rice farming

The fertilizers, sources of manures and other substances used in rice farming in Mwea irrigation scheme are given in Table 5.

Table 5: Fertilizers, Sources of Manures and other Substances Used in Rice Farming

Action	Type of fertilizer/substance/ source of manure	Number of Respondents	Percentage (%)
Planting	Triple super phosphate (TSP)	202	31.91
	Diammonium phosphate (DAP)	198	31.28
	Muriate of potash (MoP)	128	20.22
	Mavuno plant	31	4.90
	Baraka plant	24	3.79
	NPK 23:23:0	13	2.05
	Others	37	5.85
Top dressing	Sulphate of ammonia (SA)	303	65.58
	Urea	60	12.99
	Calcium ammonium nitrate (CAN)	26	5.63
	Amidas top	21	4.55
	Mavuno top	15	3.25
	Baraka top	13	2.81
	Others	24	5.19
Manure source	Cattle	147	35.59
	Goats	77	18.64
	Chicken	24	5.81
	Donkey	4	0.97
	None	161	38.98
Other substances	Ash	74	21.14
	Tobacco	34	9.71
	Black pepper	9	2.57
	Lime	4	1.14
	None	229	65.43

The farmers who use TSP, DAP and MoP during planting of rice were 31.91 %, 31.28 % and 20.22 % respectively which comprises 83.41 % of the rice farmers. Other fertilizers used during planting but by fewer farmers were Mavuno plant, Baraka plant and NPK 23:23:0 among others. This study concurs with Oyange *et al.* (2019) who reported use of TSP, DAP and MoP fertilizers in rice production at Mwea irrigation scheme. It also agrees with findings of Kuria in 2004 that DAP and TSP were the fertilizers that were mainly used during planting of rice in Mwea irrigation scheme. Muhunyu (2012) also reported that DAP and MoP fertilizers are used as basal fertilizers in Mwea irrigation scheme. The current study obtained slightly higher percentage of farmers using TSP fertilizer compared to previous studies that indicated DAP as the basal fertilizer being used by highest percentage of farmers. This may be attributed to better supply of TSP fertilizer through the rice farmers cooperative societies or realization that this fertilizer (TSP) causes little injuries to seedlings and inhibits root growth less compared to DAP (Kabir *et al.*, 2016) which results to higher production.

The farmers using SA for topdressing rice were 65.58 % and those using urea 12.99 % which consisted of 78.57 % of the farmers. Other fertilizers used for top dressing rice were CAN, Amidas, Mavuno top, Baraka top among others. In the current study, SA was mainly used for topdressing which in line with Kuria (2004) who reported that SA and urea were the main top-dressing fertilizers for rice in Mwea irrigation scheme. It also concurs with Oyange *et al.* (2019) and Muhunyu (2012) who reported SA was the main top dressing fertilizer in rice farming at Mwea irrigation scheme. This study is consistent with Sammy (2019) who reported that farmers who do rice farming at Mwea irrigation scheme use fertilizers such as DAP, MOP, TSP, SA and urea. It was observed that the relatively new fertilizers that have entered Kenyan markets such as Mavuno, Baraka and Amidas are also being used by some farmers in rice farming. This shows that if these fertilizers contain heavy metals, their application during rice farming may be increasing the heavy metals load in the soils and waters around Mwea irrigation scheme.

The farmers who used manures from cattle, goats and chicken in rice farming were 35.59 %, 18.64 % and 5.81 % respectively totalling to 60.04 %. Quite a good number of farmers were not using any manures (38.98 %) and a few were using manure from donkeys. The observation that many rice farmers were not using manures during rice farming shows that large portions of paddy soils in Mwea irrigation scheme may be lacking sufficient organic matter which may allow heavy metals in the soils be available for rice plants uptake and/or leach into ground water and may seep to water bodies. The current study found that majority of the farmers who applied manures during rice farming used cattle manure which concurs with Sammy (2019) who reported that cattle manure was the most commonly used manure in rice farming at Mwea irrigation scheme; Oyange *et al.* (2019) who reported that 23.7 % of farmers doing rice farming in Mwea irrigation scheme combine use of fertilizers with manures; and Kiarie (2003) who asserted that cattle provide manures for crop production at Mwea irrigation scheme.

Majority of farmers (65.43 %) indicated that they do not use any other substance during rice farming apart from fertilizers, pesticides and manures. However, some farmers use ash (21.14 %), tobacco (9.71 %), black pepper (2.57 %) and lime (1.14 %). Ash and lime were used in reducing soil acidity whereas tobacco and black pepper were used to control pests that do not respond to commercial pesticides. This study is in line with Khani *et al.* (2012) who reported that black pepper contains oils that have insecticidal effects and that tobacco leave extracts have excellent insecticidal activity due to the action of nicotine; Gupta *et al.* (2023) and Wiklund (2017) who indicated that applying ash on soil increased soil pH and provide other nutrients resulting to increase in grain yield; and Okalebo *et al.* (2009) who asserted that applying lime on agricultural soils raised soil pH leading to improved crop yield.

4.1.1.4 Pesticides Used During Rice Farming

Table 6 gives chemicals used in controlling pests, diseases and any other purpose during rice farming.

Table 6: Chemicals Used During Rice Farming

Target	Chemical	Respondents	Percentage (%)
Diseases	Goldazim	52	20.55
	Absolute	45	17.79
	Topsin	42	16.60
	Score	22	8.70
	Curfew	20	7.91
	Nativo	16	6.32
	Classic	12	4.74
	Rust kill	6	2.37
	Others	38	15.02
Pests	Ranger	265	51.46
	Alphatox	48	9.32
	Alpha	35	6.80
	Escort	32	6.21
	Kinetic	19	3.69
	Malathion	16	3.11
	Marshall	15	2.91
	Thunder	13	2.52
	Alfa kill	9	1.75
	Others	63	12.23
Other chemicals	Foliar sprays	188	31.92
	Herbicides	386	65.53
	Others	15	2.55

The chemicals that were mainly used to control diseases were goldazim (20.55 %), absolute 17.79 %) and topsin (16.60%) which comprised of 54.94 %. Score (8.70 %), curfew (7.91 %), nativo (6.32 % and classic (4.74 %) among others were also used in rice diseases control. Chemicals used for controlling pests, were ranger (51.46 %), alfatox (9.32 %), alpha (6.80 %) and escort (6.21 %) which comprised of 73.79 %. Other chemicals such as kinetic (3.69 %), malathion (3.11 %), marshall (2.91 %), thunder (2.52 %) and alfakill (1.75 %) among others were also used to control pests. The other chemicals used in rice farming were mainly herbicides (65.53 %) and foliar sprays (31.92 %). The herbicides that were given in the responses included glycel, dicopur, topshot, weedall, twigamethalin, panida, bailout and D-amine. The chemicals used by majority of the farmers to control pests and diseases were the most effective ones that were available in the market. Use of these pesticides may be contributing to addition of heavy metals in the soil and water at Mwea irrigation scheme since it has been reported that pesticides and herbicides contain heavy metals such as Cd, Co, Cu, Cr, Ni, Pb, Zn, Fe, As, Hg, Tl and Mn (Rashid *et al.*, 2023; Defarge *et al.*, 2018; Waheen & Selim, 2017; Gimeno-Garcia *et al.,* 1996).

This current study is consistent with various other studies done in this area which reported that farmers in Mwea irrigation scheme used pesticides during rice farming. Nyabonyi (2016) asserted that 98.8 % of the rice farmers in Mwea irrigation scheme used insecticides and fungicides. Sammy (2019) affirmed that all rice farmers used chemicals for management of pests and diseases in Mwea irrigation scheme. Kihoro, *et al.* (2013) reported some of the pesticides that farmers use during rice production as Topsin, Goldazim and Rodazim that were also found in the current study. Kuria (2004) reported that rice farmers used herbicides for weed control whereas Fenitrothion and Furadan were used to control pests.

However, in the current study, Furadan was not given by any respondent which may be attributed to the fact that Furadan (also known as Carbofuran) has been misused which has led to withdrawal pending banning in Kenya (Lalah *et al.*, 2022). It has been found that granular forms of Carbofuran which are fairly soluble in water can be taken by organisms like worms and grasshoppers and through food chain transfer, insect eating species and scavengers get poisoned (Lalah *et al.,* 2022). This study also concurs with

Oyange *et al.* (2019) who reported that herbicides that are used for weed control during rice farming are glyphosates for pre-plant herbicides and 2,4-dichlorophenoxyacetic acid (2,4-D) based post emergence selective herbicides.

4.1.1.5 Plants commonly found in rice farms of Mwea irrigation scheme

Nonedible plants that were commonly found in rice farms of Mwea irrigation scheme are given in Table 7.

Table 7: Nonedible Weeds Commonly Found in Rice Farms of Mwea Irrigation Scheme

Weed	Respondents	Percentage (%)
Tough grasses	286	27.53
Oxalis	282	27.14
Rice sedge	138	13.28
Cockspur grass	89	8.57
Nut grass	32	3.08
Wandering jew	15	1.44
Bitter lettuce	14	1.35
Elephant ear	12	1.15
Water primrose	11	1.06
Others	160	15.40

The weeds that were reported to be common in rice farms were tough grasses (27.53 %), oxalis (27.14 %), rice sedge (13.28 %), cockspur grass (8.57 %), nut grass (3.08 %) and wandering jew (1.44 %). Others were bitter lettuce (1.35 %), elephant ear (1.15 %) and water primrose (1.06 %) and others (15.40 %) (including bitter lettuce, datura, scirpus spp, Sodom apple, couch grass and black jack). Most of the weeds were managed and reduced considerably from rice farms before rice harvesting was done. However, five weed types were still commonly found in rice farms in reasonable numbers during rice harvesting. These weeds species were rice sedge (*Cyperus difformis*), cockspur grass (*Echinochloa crus-galli*), nut grass (*Cyperus rotundus*), wandering jew (*Tradescantia fluminensis*), and water primrose (*Ludwigia adscendens*). These were the plant species selected for determination of their phytoremediation potential since reasonable quantities were able to grow to maturity just like rice plants. The current study is coherent with Sammy (2019) and Koskei (2016) who affirmed that plant species such as *Echinochloa crus-galli*, *Cyperus rotundus*, *Cyperus difformis* and *Ludwigia adscendens* are common weeds found in rice farms of Mwea irrigation scheme. The present study also aligns with studies by Yao *et al.* (2019), Singh *et al.* (2017) and Smith (1981) that found *Cyperus difformis, Echinochloa crus-galli* and *Cyperus rotundus* as common weeds found in rice fields in most parts of the world.

4.1.2 Heavy Metals in Fertilizers commonly used in Rice farming at Mwea Irrigation Scheme

The amount of heavy metals in the fertilizers commonly used during rice farming at Mwea irrigation scheme are given in Table 8.

Table 8: Heavy Metals Amount (mg/kg) in Selected Fertilizers Commonly Used During Rice Farming in Mwea Irrigation Scheme

Fertilizer	Cd	Cr	Ni	Pb	Zn	As	Mn	Se
NPK(23:23:0)	0.0421±0.0095	11.4267±0.4721	436.4322±22.8894	1.1511±1.2122	BDL	11.1469±0.0023	109.7263±5.2517	34.4719±1.6323
TSP	0.5399±0.0498	67.3844±23.3673	539.9480±85.2018	0.1206±0.0286	2657.6785±1861.2074	0.2263±0.0582	88.3047±19.0495	0.7701±0.3268
DAP	8.1649±0.1633	(-)	955.5323±18.0143	1.2081±1.2038	577.1094±6.4260	7.5763±0.1321	21.4877±0.2561	0.1539±0.0001
MoP	0.0152±0.0023	2.5839±0.9902	BDL	0.9862±1.1792	BDL	0.1449±0.0046	8.7660±1.1527	BDL
Mavuno plant	0.2643±0.0714	7.9714±2.6301	253.8754±61.0159	1.8572±0.1641	1646.3112±541.7987	1.9492±0.4348	479.7057±85.4002	6.1555±2.7204
Baraka plant	3.3448±0.1250	38.5628±11.7847	501.8003±248.0318	1.4567±0.6065	3144.7381±496.0113	2.6784±0.1275	10.6591±3.5920	0.1539±0.0001
SA	0.0168±0.0001	5.5691±1.7860	108.5358±4.2440	0.7331±0.6981	BDL	0.0338±0.0160	3.6822±0.6850	0.2308±0.0001
Urea	BDL	6.3507±3.9821	20.6495±0.0001	0.1399±0.1010	BDL	0.1577±0.0001	7.4875±6.8770	BDL
CAN	0.0245±0.0155	4.2131±0.8352	BDL	0.5708±0.4263	BDL	0.3976±0.0432	12.7244±3.9740	BDL
Amidas top	0.0093±0.0012	5.3859±1.7230	12.2916±0.0000	1.2507±1.2915	BDL	0..161±0.0000	2.9614±1.2898	BDL
Mavuno top	0.1625±0.0917	15.9459±0.7061	105.1179±36.4883	0.8224±1.0477	52.9112±0.0001	0.2399±0.0892	39.8128±3.7268	BDL
KEBS limit	15.0	500.0	(-)	30.0	(-)	20.0	(-)	1.0

Key: BDL – below detection limit, (-) – not available

The results indicated that the amount of cadmium in the eleven fertilizers analysed ranged from BDL (for urea) to 8.1649±0.1633 mg/kg (for DAP). Two of the fertilizers, DAP and Baraka plant had relatively high amounts of cadmium (8.1649±0.1633 and 3.3448±0.1250 mg/kg, respectively) compared to the others which had amounts below 1 mg/kg. The amounts of chromium ranged from 2.5839±0.9902 (MoP) to 67.3844±23.3673 mg/kg (TSP). Fertilizers such as NPK 23:23:0, TSP, Baraka plant and Mavuno top had comparatively high amounts of chromium which was above 10 mg/kg. The amount of nickel in the ten fertilizers ranged from BDL (for MoP and CAN) to 955.5323±18.0143 mg/kg (for DAP). Amounts of nickel in MoP, urea, CAN and Amidas top were below 25 mg/kg whereas the rest had values above 100 mg/kg. The amount of lead found in the eleven fertilizers ranged from 0.1206±0.0286 (TSP) to 1.8572±0.1641 (Mavuno plant) mg/kg. The fertilizers that were found to have lead amounts above 1 mg/kg were NPK 23:23:0, DAP, Mavuno plant, Baraka plant and Amidas top.

The amount of zinc in the eleven fertilizers was found to range from BDL (for NPK 23:23:0, MoP, SA, urea, CAN and Amidas top) to 3144.7381±496.0113 mg/kg (Baraka plant). The zinc amounts for TSP, Mavuno plant and Baraka plant were relatively high and above 1000 mg/kg. For arsenic, the amounts ranged from 0.0338±0.0160 (SA) to 11.1469±0.0023 (NPK 23:23:0) mg/kg. The amounts of arsenic for most of the fertilizers was below 1 mg/kg except for NPK 23:23:0, DAP, Mavuno plant and Baraka plant. Manganese amounts in the eleven fertilizers was found to range from 2.9614±1.2898 (Amidas top) to 479.7057±85.4002 (Mavuno plant) mg/kg. Most of these fertilizers had manganese amounts below 100 mg/kg apart from NPK 23:23:0 and Mavuno plant which had amounts above 100 mg/kg. The amounts of selenium ranged from BDL (for MoP, urea, CAN, Amidas top and Mavuno top) to 34.4719±1.6323 (NPK 23:23:0) mg/kg. It was found that most of the fertilizers had selenium amounts below 1 mg/kg apart from NPK 23:23:0 and Mavuno plant. Table 9 shows (with a tick, √) the fertilizers with relatively high amounts of the analysed heavy metals.

Table 9: Fertilizers with Relatively High Amounts of Heavy Metals

Fertilizer	Cd	Cr	Ni	Pb	Zn	As	Mn	Se	No. of metals
TSP	√	√	√		√		√		5
DAP	√		√	√	√	√			5
MoP									0
Mavuno plant			√	√	√	√	√	√	6
Baraka plant	√	√	√	√	√	√			6
NPK 23:23:0		√	√	√		√	√	√	6
SA			√						1
Urea									0
CAN									0
Amidas top				√					1
Mavuno top		√	√						2

Key for tick (√): Cd above 0.5, Cr above 10, Ni above 100, Pb above 1, Zn above 500, As above 1, Mn above 50 and Se above 1 mg/kg

Table 9 shows that Mavuno plant, Baraka plant and NPK 23:23:0 had relatively high amounts of 6 heavy metals; DAP and TSP had relatively high amounts of 5 heavy metals; Mavuno top had 2 heavy metals in relatively high amount; SA and Amidas top had 1 heavy metal in relatively high amount; whereas MoP, urea and CAN had none of the heavy metals in relatively high amount. This showed that fertilizers used during planting rice had relatively high amounts of the analysed heavy metal compared to the fertilizers used for top dressing. This may be attributed to the source of planting (phosphatic) fertilizers whose source is naturally occurring phosphate rock which contains heavy metals (Faridullah *et al.*, 2017) or during the chemical processing of the fertilizers (Gambus & Weiczorek, 2012; Zhong & Zhao, 2016). This study therefore found that fertilizers such as TSP, DAP, Mavuno plant, Baraka plant and NPK 23:23:0, contained relatively high amounts of heavy metals.

A one-way between subjects' analysis of variance (ANOVA) was conducted with null hypothesis that there were statistically no significant differences in the amounts of Cd, Cr, Ni, Pb, Zn, As, Mn and Se in the fertilizers NPK, TSP, DAP, MoP, Mavuno plant, Baraka plant, SA, urea, CAN, Amidas and Mavuno top that are commonly used by rice farmers. The results of one-way ANOVA showing whether there was significant difference or not in the amount of Cd in the eleven fertilizers tested is given in Table 10.

Table 10: ANOVA for Cd Amount in Fertilizers Commonly Used by Rice Farmers

	Sum of Squares	Df	Mean Square	F	Sig.	F crit
Between Groups	127.732	10	12.773	2391.935	.000	2.85
Within Groups	.059	11	.005			
Total	127.790	21				

Table 10 shows that there was statistically significant difference in the amount of Cd in at least two of the fertilizers, $F(10,11) = 2391.935$, $p < 0.001$ at the confidence level of the study (α) = 0.05. Similarly, it was found that there were significant differences in the amount of Cr, Ni, Zn, As, Mn and Se in the fertilizers at $p<0.05$ level and $\alpha = 0.05$ (see Appendix IV). However, there was no significant difference in the amount of Pb in all the eleven fertilizers studied at the same level of significance.

A Tukey's honest significant difference (HSD) post hoc test was used to pinpoint which fertilizers had significant difference in the amount of Cd. Table 11 shows (an extract of Appendix IV) which fertilizers had significant difference in the amount of Cd from each other.

Table 11: Tukey's HSD Post Hoc Test Results (extract) for Differences in Amount of Cd in Various Fertilizers

I) Sample	(J) Sample	Mean Difference (I-J)	Std. Error	Sig.
NPK	DAP	-8.12275884169744*	.073075964017032	.000
	MOP	.026936318005998	.073075964017032	.719
	Mavuno Plant	-.222202530803111*	.073075964017032	.011
	Baraka Plant	-3.30267369143206*	.073075964017032	.000
	SA	.033669345471956	.073075964017032	.654
	Urea	.042086471432837	.073075964017032	.576
	CAN	.017678405240306	.073075964017032	.813
	Amidas	.032826875410278	.073075964017032	.662
	Mavuno Top	-.120356232467732	.073075964017032	.128
	TSP	-.497813528567163*	.073075964017032	.000
DAP	NPK	8.122758841697438*	.073075964017032	.000
	MOP	8.149695159703436*	.073075964017032	.000
	Mavuno Plant	7.900556310894327*	.073075964017032	.000
	Baraka Plant	4.820085150265375*	.073075964017032	.000
	SA	8.156428187169395*	.073075964017032	.000
	Urea	8.164845313130275*	.073075964017032	.000
	CAN	8.140437246937744*	.073075964017032	.000
	Amidas	8.155585717107716*	.073075964017032	.000
	Mavuno Top	8.002402609229707*	.073075964017032	.000
	TSP	7.624945313130275*	.073075964017032	.000
SA	NPK	-.033669345471956	.073075964017032	.654
	DAP	-8.156428187169395*	.073075964017032	.000
	MOP	-.006733027465958	.073075964017032	.928
	Mavuno Plant	-.255871876275067*	.073075964017032	.005
	Baraka Plant	-3.336343036904019*	.073075964017032	.000
	Urea	.008417125960881	.073075964017032	.910
	CAN	-.015990940231650	.073075964017032	.831
	Amidas	-.000842470061678	.073075964017032	.991
	Mavuno Top	-.154025577939688	.073075964017032	.059
	TSP	-.531482874039119*	.073075964017032	.000

**The mean difference is significant at the 0.05 level*

Tukey's HSD post hoc test revealed that there was statistically significant difference of the Cd amount in DAP and all the other fertilizers; Mavuno plant and all the other fertilizers (except Mavuno top); Baraka plant and all the other fertilizers; TSP and all the other fertilizers and; between urea and Mavuno top fertilizer. Similarly, the Tukey's HSD post hoc test established that there was significant difference between the amount of Cr in DAP and all the other fertilizers; Mavuno plant and all the other fertilizers (except Mavuno top); Baraka plant and all the other fertilizers; and TSP and all the other fertilizers. The test further indicated that there was significant difference in the amount of Ni between NPK and the other fertilizers (except Baraka plant and TSP); DAP and all the other fertilizers; Mavuno plant and the other fertilizers (except SA and TSP) and; TSP and the other fertilizers (except NPK 23:23:0).

The post hoc test also showed that there was statistically significant difference between the amount of Zn in Mavuno plant and the other fertilizers (except DAP and TSP); Baraka plant and the other fertilizers (except TSP) and; TSP and the other fertilizers (except Mavuno plant and Baraka plant). The test further revealed that there was significant difference in the amount of As between NPK and all the other fertilizers; DAP and all the other fertilizers; Mavuno plant and all the other fertilizers; Baraka plant and all the other fertilizers; SA and CAN; and also CAN and Amidas. Similarly, the test indicated that there was significant difference on the amount of Mn in NPK and the other fertilizers (except TSP); Mavuno plant and all the other fertilizers and; TSP and the other fertilizers (except NPK and Mavuno top). In addition, the test revealed that there was significant difference on the amount of Se between NPK and all the other fertilizers as well as Mavuno plant and all the other fertilizers. (See Appendix IV)

The current study obtained values close to those reported by Kananu (2015) that DAP contained 342.60 mg/kg of Zn, 30.53 mg/kg of Cr, 16.38 mg/kg of Pb and 1.67 mg/kg of Cd among other heavy metals. Nsikak *et al.* (2014) reported that phosphate fertilizer contained 0.0012 mg/kg of As, 2.59 mg/kg of Cd, 5.26 mg/kg of Ni, 6.65 mg/kg of Pb and 15.81 mg/kg of Zn and also reported that urea contained 0.0013 mg/kg of As, 2.67 mg/kg of Cd, 5.87 mg/kg Ni, 7.46 mg/kg of Pb and 3.90 mg/kg of Zn. Ghambus & Weiczorek (2012) showed that phosphorous fertilizers contained an average of 13 mg/kg Cd, 60 mg/kg Cr, 13 mg/kg Pb and 236 mg/kg Zn. Ukpabi *et al.* (2012) in Brazil reported similar amount of Cd but gave higher values of Pb in phosphatic fertilizers whereas Guilherme *et al.* (2019) in Nigeria reported fairly higher values of Cd, Pb and As. Some of the values reported by Kananu (2015), Nsikak *et al.* (2014) and Ghambus & Weiczorek (2012) were higher and others lower than those of current study but were generally close and shows that fertilizers contain small quantities of heavy metals. The differences in the amounts of the heavy metal content in fertilizers reported from different studies and different types of fertilizes may be attributed to the differences in concentration of these metals in the parent material and the other reagents used during the manufacture of the fertilizers (Jayasumana *et al.,* 2015).

The amounts of the heavy metals in fertilizers reported this study fall within the allowable limits in Texas state of United States of America, China, Canada and Japan except for Ni, Zn and Se in a few fertilizers (Ogabiela *et al.,* 2009; Westfall *et al.,* 2005). In Kenya, KEBS (2018) specifications of contaminants limits in fertilizers for Cd, Cr, Pb, As and Se are set at 15.0, 500.0, 30.0, 20.0 and 1.0 mg/kg respectively. This present study found that all the fertilizers analysed had heavy metal amounts less than the set limits for the specified metals except Se in NPK 23:23:0 and Mavuno plant. Notwithstanding this exception, this study showed that the eleven fertilizers studied were generally fit for use in Kenya as far as most of these heavy metal amounts are concerned.

Even if these fertilizers are allowed to be use in Kenya, they contain traces of many or all the determined heavy metals. This shows that continuous use of these fertilizers may lead/have led to accumulation of heavy metals in the soil of Mwea irrigation scheme and may have also contaminated river water, got into rice and entered food chain. It was therefore necessary to determine concentrations of these metals in soil, water, common weeds, and rice from Mwea irrigation scheme.

4.2 Heavy Metals in Sediment and Water Along Rivers Thiba and Nyamindi Upstream, Downstream and Within Mwea Irrigation Scheme

4.2.1 Heavy Metals in Sediment of River Thiba and Nyamindi

The amount of selected heavy metals determined from sediment samples collected upstream of river Thiba from Kiumbu (C2) to Ndiara (T8) and upstream of river Nyamindi from Kiumbu (C2) to Kiamatero (N6) are given in this section.

4.2.1.1 Heavy Metals in Sediment of River Thiba from Kiumbu to Ndiara During Wet Season

The amount of selected heavy metals in sediment sampled along river Thiba during wet season are presented in Table 12.

Table 12: Amount of Selected Heavy Metals (mg/kg) in Sediment Along River Thiba during Rainy Season

Point	Cd	Cr	Ni	Pb	Zn	As	Mn	Se
C2	0.0761±0.0006	33.5515±0.0041	69.1258±0.0330	10.5898±0.0077	44.0068±0.0072	2.1587±0.0064	1217.8688±0.7570	4.4417±0.0097
C1	0.0381±0.0006	42.8454±0.0092	90.1803±0.0660	10.1530±0.0092	41.0483±0.0064	3.1320±0.0071	1746.8943±2.2430	6.9934±0.0086
T1	0.1202±0.0033	34.2513±0.0028	70.8137±0.0650	11.4459±0.0083	37.6893±0.0049	2.1545±0.0035	1538.3773±2.7220	5.8593±0.0032
T2	0.0541±0.0009	44.5663±0.0055	88.9061±0.0710	7.4881±0.0059	47.1434±0.0044	2.2127±0.0045	1431.7761±0.4360	4.4417±0.0025
T3	0.1823±0.0046	35.8509±0.0071	78.1208±0.0760	10.9152±0.0035	40.0047±0.0062	2.2169±0.0052	2193.8618±6.5110	5.4813±0.0033
T4	0.0561±0.0007	43.2055±0.0033	67.8782±0.0550	7.5547±0.0062	40.5509±0.0085	1.9632±0.0076	1604.0594±3.1030	4.8198±0.0072
T5	0.0240±0.0004	33.1244±0.0053	73.9169±0.0870	11.9511±0.0055	40.9388±0.0075	2.3875±0.0045	1645.1722±1.8180	7.1824±0.0046
T6	0.0481±0.0008	50.3350±0.0140	128.1840±0.3980	8.9350±0.0066	45.0140±0.0077	2.2252±0.0065	2122.8698±7.2650	3.7801±0.0025
T7	0.2705±0.0076	43.0963±0.0092	93.9105±0.0760	12.9476±0.0055	50.5437±0.0340	2.5497±0.0094	1672.4769±2.8490	6.0483±0.0092
T8	0.0381±0.0005	38.1428±0.0038	90.0485±0.0650	11.9379±0.0046	38.6149±0.0025	2.6786±0.0081	1610.5140±1.8920	5.8593±0.0075
Mean	0.0908±0.0790	39.8969±5.7550	85.1085±18.0378	10.3918±1.8690	42.5555±4.0501	2.3679±0.3390	1678.3876±292.8288	5.4907±1.1195

The amount of cadmium in sediment from Kiumbu to Ndiara along river Thiba during wet season ranged from 0.0240±0.0004 (T5) to 0.2705±0.0076 (T7) mg/kg with an average of 0.0908±0.0790 mg/kg. Chromium values in the sediment ranged from 33.1244±0.0053 (T5) to 50.3350±0.0140 (T6) mg/kg and had a mean of 39.8969±5.7550 mg/kg. For nickel, values ranged from 67.8782±0.0550 (T4) to 128.1840±0.3980 (T6) mg/kg with a mean of 85.1085±18.0378 mg/kg. Lead values were ranging between 7.4881±0.0059 (T2) and 12.9476±0.0055 (T7) mg/kg with a mean of 10.3918±1.8690 mg/kg.

The amount of zinc in the sediment varied from 37.6893±0.0049 (T1) to 50.5437±0.0340 (T7) mg/kg and had an average of 42.5555±4.0501 mg/kg. Arsenic had values ranging from 1.9632±0.0076 (T4) to 3.1320±0.0071 (C1) mg/kg with a mean of 2.3679±0.3390 mg/kg. For manganese, the amount varied from 1217.8688±0.7570 (C2) to 2193.8618±6.5110 (T3) mg/kg with a mean of 1678.3876±292.8288 mg/kg. Whereas selenium values ranged from 3.7801±0.0025 (T6) to 7.1824±0.0046 (T5) mg/kg with an average of 5.4907±1.1195 mg/kg. The mean amounts of the heavy metals in sediment along river Thiba upstream from Kiumbu to Ndiara during wet season decreased in the order Mn>Ni>Zn>Cr>Pb>Se>As>Cd

These amounts of heavy metals did not show any uniform general trend (increase or decrease) upstream from Kiumbu to Ndiara. It was noted that at T7 (Kutus), the values were highest for cadmium, lead and zinc and at T6 (Karii) which was the next sampling point after Kutus downstream had highest values of chromium and nickel. This could be due to T6 and T7 sampling points close proximity to Kutus town which points to a possibility of the heavy metals from this town finding their way to the river sediment through surface run-offs, seepage or both.

4.2.1.2 Heavy Metals in Sediment of River Thiba from Kiumbu to Ndiara During Dry Season

The amount of selected heavy metals in sediment sampled along river Thiba during dry season are given in Table 13.

Table 13: Amount of Selected Heavy Metals (mg/kg) in Sediment Along River Thiba during Dry Season

Point	Cd	Cr	Ni	Pb	Zn	As	Mn	Se
C2	0.0292±0.0008	34.8881±0.0084	445.3931±0.4580	0.4845±0.0039	53.9087±0.0670	2.8721±0.0094	1856.6108±3.9050	4.8996±0.0018
C1	0.0475±0.0006	34.2762±0.0049	467.8451±0.6910	0.2615±0.0047	56.7001±0.0330	2.5988±0.0073	1682.6449±4.3420	6.6289±0.0083
T1	0.0701±0.0008	47.9639±0.0049	95.3359±0.0850	10.1497±0.0067	44.5538±0.0076	3.0697±0.0084	1844.6100±2.5180	4.7253±0.0077
T2	0.1242±0.0027	34.6627±0.0035	64.2392±0.0280	10.2168±0.0044	32.8121±0.0079	2.3750±0.0085	1597.5113±2.6710	5.3868±0.0039
T3	0.0541±0.0009	26.1350±0.0076	63.2156±0.0570	9.8610±0.0035	41.0933±0.0093	2.2627±0.0063	1851.5847±6.2820	4.0637±0.0066
T4	0.0821±0.0004	44.4167±0.0088	520.5808±0.7870	0.4760±0.0048	72.0498±0.0940	3.0223±0.0055	1791.4658±2.3060	8.0700±0.0066
T5	0.0456±0.0005	42.4511±0.0074	538.0829±0.1980	0.2753±0.0015	76.6965±0.0410	2.8875±0.0044	1862.6627±4.5260	6.1489±0.0054
T6	0.0785±0.0009	57.6709±0.0390	741.2449±0.6250	0.0523±0.0004	80.5621±0.0280	3.4536±0.0064	1758.8775±4.4860	8.4542±0.0085
T7	0.0602±0.0003	64.0501±0.0490	591.6598±0.4610	0.2682±0.0017	88.9347±0.0260	3.0955±0.0081	1745.5984±3.6280	7.0130±0.0055
T8	0.0365±0.0007	39.8045±0.0027	437.0949±0.5110	0.6233±0.0049	40.2741±0.0940	2.5025±0.0093	1672.4425±1.8070	5.6681±0.0037
Mean	0.0628±0.0276	42.6319±11.4988	396.4692±238.9054	3.2669±4.7021	58.7585±19.5531	2.8139±0.3721	1766.4009±92.0517	6.1059±1.4419

The amount of cadmium in sediment from Kiumbu to Ndiara along river Thiba during dry season varied from 0.0292±0.0008 (C2) to 0.1242±0.0027 (T2) mg/kg with an average of 0.0628±0.0276 mg/kg. For chromium, the values ranged from 26.1350±0.0076 (T3) to 64.0501±0.0490 (T7) mg/kg and had a mean of 42.6319±11.4988 mg/kg. The amount of nickel varied from 63.2156±0.0570 (T3) to 741.2449±0.6250 (T6) mg/kg with a mean of 396.4692±238.9054 mg/kg. The amount of lead varied from 0.0523±0.0004 (T6) to 10.2168±0.0044 (T2) mg/kg and had a mean of 3.2669±4.7021 mg/kg

The values of zinc were ranging from 32.8121±0.0079 (T2) to 88.9347±0.0260 (T7) and had an average of 58.7585±19.5531 mg/kg. For arsenic, the amount varied from 2.2627±0.0063 (T3) 3.4536±0.0064 (T6) mg/kg with an average of 2.8139±0.3721 mg/kg. Manganese had amounts that were varying from 1597.5113±2.6710 (T2) 1862.6627±4.5260 (T5) mg/kg with a mean of 1766.4009±92.0517 mg/kg. Whereas selenium had values ranging from 4.0637±0.0066 (T3) 8.4542±0.0085 (T6) mg/kg and with a mean of 6.1059±1.4419 mg/kg. The mean amounts of the heavy metals in sediment along river Thiba upstream from Kiumbu to Ndiara during dry season decreased in the order Mn>Ni>Zn>Cr>Se>Pb>As>Cd. It was noted that during dry season, at sampling point T7 (Kutus), the values were highest for chromium and zinc. It was also noted that at sampling point T6 (Karii) which is the next sampling point after Kutus downstream had highest values of nickel, arsenic and selenium. This suggests that activities at Kutus town and its surroundings could be contributing to higher amounts of heavy metals in river Thiba sediment.

The current study obtained mean amount of lead of 10.3918±1.8690 mg/kg during wet season and 3.2669±4.7021 mg/kg during dry season which is lower than 22.95±15.11 mg/kg that was reported by Gathumbi *et al.* (2013) on a study carried out in the same area. This may be an indication that lower quantities of lead may be finding their way in river Thiba as a result of use of unleaded petrol for several years now in powering water pumps that are usually placed next to the river during use. Moywaywa (2018) reported higher mean amounts of Mn, Zn and Pb and lower mean amount of Ni in sediment from Thika river implying that Thika river may have been generally more polluted with heavy metals than Thiba river. A study carried out by Omondi (2017) reported lower concentration of Mn, very close concentration of Ni and higher concentrations of Cr, Zn, Pb and As in sediment from river Nzoia which shows that river Thiba sediment may be slightly less polluted than river Nzoia. This study contrast Idiriah *et al.* (2012) who carried out a study along Abonnema shoreline in Nigeria and reported far much lower concentrations of Zn, Pb and Cr in sediment.

4.2.1.3 Heavy Metals in Sediment of River Nyamindi from Kiumbu to Kiamatero During Wet Season

The amount of selected heavy metals in sediment sampled along river Nyamindi during wet season are presented in Table 14.

Table 14: Selected Heavy Metals Amount (mg/kg) in Sediment Along River Nyamindi during Wet Season

Point	Cd	Cr	Ni	Pb	Zn	As	Mn	Se
C2	0.0761±0.0006	33.5515±0.0041	69.1258±0.0330	10.5898±0.0077	44.0068±0.0072	2.1587±0.0064	1217.8688±0.7570	4.4417±0.0097
C1	0.0381±0.0006	42.8454±0.0092	90.1803±0.0660	10.1530±0.0092	41.0483±0.0064	3.1320±0.0071	1746.8943±2.2430	6.9934±0.0086
N1	0.0621±0.0008	34.3949±0.0081	74.9157±0.0650	12.4343±0.0035	39.1437±0.0043	2.3084±0.0073	1466.3647±0.8170	6.6153±0.0045
N2	0.0721±0.0002	36.9219±0.0045	76.9449±0.0880	11.7891±0.0085	36.1477±0.0061	2.3708±0.0063	1529.8162±1.8480	6.8043±0.0066
N3	0.0382±0.0006	30.1670±0.0063	63.7684±0.0390	10.8809±0.0027	32.7516±0.0058	2.2918±0.0092	1385.3230±0.7770	5.2923±0.0057
N4	0.0481±0.0008	40.4863±0.0026	92.3219±0.0760	10.7975±0.0047	38.4861±0.0092	2.4706±0.0033	1184.3248±0.7970	4.6308±0.0028
N5	0.2084±0.0045	50.9584±0.0250	129.7994±0.2760	9.2169±0.0085	50.0610±0.0280	2.5455±0.0023	3130.7051±9.2440	4.4418±0.0043
N6	0.1002±0.0074	53.8026±0.0150	112.8805±0.0370	9.3480±0.0075	54.3880±0.0470	2.7494±0.0051	1823.1723±2.5860	6.8043±0.0044
Mean	0.0804±0.0558	40.3910±8.4251	88.7421±22.7473	10.6512±1.1056	42.0042±7.2078	2.5034±0.3112	1685.5587±626.0489	5.7530±1.1590

The amount of cadmium in sediment from Kiumbu to Kiamatero along river Nyamindi during wet season varied from 0.0381±0.0006 (CI) to 0.2084±0.0045 (N5) mg/kg and had an mean of 0.0804±0.0558 mg/kg. Chromium was found to have amounts ranging from 30.1670±0.0063 (N3) to 53.8026±0.0150 (N6) mg/kg with a mean of 40.3910±8.4251 mg/kg. Nickel amounts varied from 63.7684±0.0390 (N3) to 129.7994±0.2760 (N5) with a mean of 88.7421±22.7473 mg/kg. Lead values ranged from 9.2169±0.0085 (N5) to 12.4343±0.0035 (N1) mg/kg and had a mean of 10.6512±1.1056 mg/kg.

The values of zinc were varying from 32.7516±0.0058 (N3) to 54.3880±0.0470 (N6) mg/kg and had an average of 42.0042±7.2078 mg/kg. Arsenic had values ranging from 2.1587±0.0064 (C2) to 3.1320±0.0071 (C1) mg/kg with a mean of 2.5034±0.3112 mg/kg.

Manganese values varied between 1184.3248±0.7970 (N4) to 3130.7051±9.2440 (N5) mg/kg with an average of 1685.5587±626.0489 mg/kg. Whereas the values of selenium ranged from 4.4417±0.0097 (C2) to 6.8043±0.0044 (N6) mg/kg and had a mean of 5.7530±1.1590 mg/kg. The mean amounts of the heavy metals in sediment along river Nyamindi upstream from Kiumbu to Kiamatero during wet season decreased in the order Mn>Ni>Zn>Cr>Pb>Se>As>Cd.

It was observed that at N5 (Kathiriko), the values were highest for cadmium, nickel, lead and manganese. It was also noted that N6 (Kiamatero) which was the next sampling point after Kathiriko and the upper most sampling point upstream had highest values of chromium, zinc and selenium. Human activities around these two sampling points (N5 and N6) may be contributing to the higher amounts of these heavy metals in river Nyamindi sediment. It was found that sampling points N3 (Riandigiri) had lowest values of chromium, nickel and zinc.

4.2.1.4 Heavy Metals in Sediment of River Nyamindi from Kiumbu to Kiamatero During Dry Season

The amount of selected heavy metals in sediment sampled along river Nyamindi during dry season are presented in Table 15.

Table 15: Selected Heavy Metals Concentration (mg/kg) in Sediment Along River Nyamindi during Dry Season

Point	Cd	Cr	Ni	Pb	Zn	As	Mn	Se
C2	0.0292±0.0008	34.8881±0.0084	445.3931±0.4580	0.4845±0.0039	53.9087±0.0670	2.8721±0.0094	1856.6108±3.9050	4.8996±0.0018
C1	0.0475±0.0006	34.2762±0.0049	467.8451±0.6910	0.2615±0.0047	56.7001±0.0330	2.5988±0.0073	1682.6449±4.3420	6.6289±0.0083
N1	0.0694±0.0005	32.2162±0.0022	479.3399±0.6990	0.1765±0.0018	76.4621±0.0410	3.8040±0.0071	2208.4804±7.2440	5.6681±0.0071
N2	0.0602±0.0007	41.6762±0.0077	617.6797±0.4990	0.5943±0.0046	73.5968±0.0780	2.8914±0.0033	1586.2441±1.0960	7.8777±0.0034
N3	0.0986±0.0007	38.6655±0.0049	580.0957±0.2950	0.2351±0.0022	57.2619±0.0440	2.7489±0.0058	1609.8181±2.7210	7.5895±0.0051
N4	0.0310±0.0003	37.7108±0.0035	518.3989±0.6980	0.4103±0.0056	54.0231±0.0450	2.6180±0.0045	1556.9655±4.2840	6.0524±0.0092
N5	0.0438±0.0001	39.7309±0.0057	559.2734±0.1330	0.4811±0.0024	116.5999±0.3850	2.8336±0.0044	1603.2709±3.8040	6.3406±0.0056
N6	0.0511±0.0003	44.7058±0.0078	599.7628±0.6550	0.3712±0.0065	76.3715±0.019	3.1725±0.0068	1721.7379±5.7410	5.7642±0.0085
Mean	0.0539±0.0226	37.9837±4.1232	533.4736±64.9694	0.3768±0.1436	70.6155±21.1023	2.9424±0.3920	1728.2216±216.5871	6.3526±0.9963

The sediment sampled from Kiumbu to Kiamatero along river Nyamindi during the dry season had values of cadmium ranging from 0.0292±0.0008 (C2) to 0.0986±0.0007 (N3) mg/kg and had an average of 0.0539±0.0226 mg/kg. Chromium values ranged from 32.2162±0.0022 (N1) mg/kg to 44.7058±0.0078 (N6) mg/kg with a mean of 37.9837±4.1232 mg/kg. Nickel amount varied from 445.3931±0.4580 (C2) mg/kg to 617.6797±0.4990 (N2) mg/kg with an average of 533.4736±64.9694 mg/kg. Lead values ranged from 0.1765±0.0018 (N1) mg/kg to 0.5943±0.0046 (N2) mg/kg and had a mean of 0.3768±0.1436 mg/kg.

The amount of zinc in the sediment varied from 53.9087±0.0670 (C2) mg/kg to 116.5999±0.3850 (N5) mg/kg and had a mean of 70.6155±21.1023 mg/kg. Arsenic values ranged between 2.5988±0.0073 (C1) mg/kg and 3.8040±0.0071 (N1) mg/kg with a mean of 2.9424±0.3920 mg/kg. Manganese amounts ranged from 1556.9655±4.2840 (N4) mg/kg to 2208.4804±7.2440 (N1) mg/kg and had an average of 1728.2216±216.5871 mg/kg. Whereas selenium values were between 4.8996±0.0018 (C2) mg/kg and 7.8777±0.0034 (N2) mg/kg with a mean of 6.3526±0.9963 mg/kg. The mean amounts of the heavy metals in sediment along river Nyamindi upstream from Kiumbu to Kiamatero during dry season decreased in the order Mn>Ni>Zn>Cr>Se>As>Pb>Cd.It was observed that during dry season, sampling point N2 (Riangeci) had highest values of nickel, lead and selenium in the sediment. The next sampling point downstream (N1, Nyamindi village) had the highest values of arsenic and manganese during the same period.

The present study obtained mean amount of lead of 10.6512±1.1056 mg/kg during wet season and 0.3768±0.1436 mg/kg from river Nyamindi during dry season which is less than 16.10±7.69 mg/kg which was reported by Gathumbi *et al.* (2013) following a study done in the same area. This could be due to lower quantities of lead that may be finding their way in river Nyamindi as a result of stoppage of use of leaded petrol for several years now in powering water pumps that are usually placed next to the river course during use. Moywaywa (2018) reported higher mean concentrations of Mn, Zn and Pb and lower mean concentration of Ni in sediment from Thika river indicating that river Nyamindi may have been less polluted with heavy metals than Thika river. A study carried out by Omondi (2017) at river Nzoia reported lower concentration levels of Mn and Ni, same concentration of Zn and higher concentrations of Cr, Pb and As in sediment. This shows that during dry season, river Nyamindi may be equally polluted as river Nzoia. This study conflict Idiriah *et al.* (2012) who reported much lower concentrations of Zn, Pb and Cr in sediment during a study conducted along Abonnema shoreline in Nigeria. From this study, it was observed that sediment from both rivers Thiba and Nyamindi and during both seasons (wet and dry), the highest mean amount of heavy metal obtained was for manganese and the lowest was for cadmium.

4.2.2 Heavy Metals in Water of River Thiba and Nyamindi

The concentration of selected heavy metals determined from water samples collected upstream of river Thiba from Kiumbu (C2) to Ndiara (T8) and upstream of river Nyamindi from Kiumbu (C2) to Kiamatero (N6) are given in this section.

4.2.2.1 Heavy Metals in Water of River Thiba from Kiumbu to Ndiara During Wet Season

The concentration of selected heavy metals in water sampled along river Thiba during wet season are given in Table 16.

Table 16: Amount of Selected Heavy Metals (ppm) in Water Along River Thiba during Wet Season

Point	Cd	Cr	Ni	Pb	Zn	As	Mn	Se
C2	0.0003±0.00004	0.1536±0.00015	1.9008±0.00073	0.0038±0.00006	BDL	0.0074±0.00003	6.8320±0.00052	0.0092±0.00004
C1	0.0004±0.00003	0.1768±0.00071	0.8468±0.00031	0.0135±0.00004	BDL	0.0014±0.00008	1.3190±0.00028	BDL
T1	BDL	BDL	BDL	BDL	BDL	0.0001±0.00001	0.0177±0.00002	BDL
T2	0.0004±0.00002	0.1214±0.00033	3.2534±0.00062	0.0085±0.00002	BDL	0.0060±0.00003	3.2295±0.00043	0.0138±0.00003
T3	0.0003±0.00006	0.1927±0.00024	2.0554±0.00035	0.0141±0.00005	BDL	0.0048±0.00004	3.4972±0.00035	0.0092±0.00002
T4	0.0001±0.00005	0.0960±0.00004	1.1054±0.00039	0.0163±0.00007	BDL	0.0025±0.00005	1.5181±0.00022	BDL
T5	BDL	BDL	0.0701±0.00006	0.0024±0.00001	BDL	0.0003±0.00006	0.2879±0.00014	0.0004±0.00008
T6	0.0002±0.00001	0.0561±0.00007	0.4881±0.00053	0.0244±0.00002	BDL	0.0020±0.00005	1.4682±0.00044	0.0058±0.00007
T7	0.0001±0.00001	0.1196±0.00067	0.3455±0.00044	0.0999±0.00005	BDL	0.0004±0.00003	0.2959±0.00048	BDL
T8	BDL	BDL	BDL	0.1243±0.00007	BDL	0.0001±0.00008	0.0183±0.00003	BDL
Mean	0.0002±0.0002	0.0916±0.0741	1.0066±1.0849	0.0434±0.0554	BDL	0.0025±0.0027	1.8484±2.1484	0.0038±0.0052

The concentration of cadmium in river Thiba course from Kiumbu (C2) to Ndiara (T8) during rainy season varied between BDL and 0.0004±0.00003 (C1) ppm and had a mean of 0.0002±0.0002 ppm. Chromium concentration ranged from BDL to 0.1927±0.00024 (T3) ppm with a mean of 0.0916±0.0741 ppm. Nickel concentration varied from BDL to 3.2534±0.00062 (T2) ppm with an average of 1.0066±1.0849 ppm. Concentration of lead ranged between BDL and 0.1243±0.00007 (T8) ppm and had an average of 0.0434±0.0554 ppm. The concentration of zinc in all the sampling points along river Thiba course was BDL. Arsenic concentration was ranging from 0.0001±0.00008 (T8) ppm to 0.0074±0.00003 (C2) ppm and had a mean of 0.0025±0.0027 ppm. Manganese had concentration varying from 0.0177±0.00002 (T1) ppm to 6.8320±0.00052 (C2) ppm and a mean of 1.8484±2.1484 ppm. Whereas the concentration of selenium ranged between BDL and 0.0138±0.00003 (T2) ppm with a mean of 0.0038±0.0052 ppm. The mean concentrations of the heavy metals in water along river Thiba upstream from Kiumbu to Ndiara during wet season decreased in the order Mn>Ni>Cr>Pb>Se>As>Cd>Zn

It was observed that there was no trend in increase or decrease in concentrations of the heavy metals in water sampled from river Thiba water either downstream or upstream between Kiumbu and Ndiara during wet season. However, sampling point T2 (Ndindiruku) had the highest concentration of nickel and selenium whereas sampling point C2 (Kiumbu) had the highest concentrations of arsenic and manganese. It was noted that at sampling point T1 (Kakawa), the concentration of cadmium, chromium, nickel, lead, zinc and selenium was BDL. Similarly, it was noted that the concentration of zinc in water from all the sampling points along river Thiba was BDL. This study obtained lower concentrations levels of Pb and Cd than the ones reported by Wasike *et al.* (2019) on water of Kuywa river during wet season. Wasike *et al.* (2019) also reported lower level of Mn than what is reported in this study. Muiruri *et al.* (2013) reported very close concentration levels of Pb and Cd, lower levels of Ni, Cr and Mn and higher level of Zn in river water from Athi-Galana-Sabaki tributaries during wet season compared to what is reported in the current study.

4.2.2.2 Heavy Metals in Water of River Thiba from Kiumbu to Ndiara During Dry Season

The concentration of selected heavy metals in water sampled along river Thiba during dry season are given in Table 17.

Table 17: Amount of Selected Heavy Metals (ppm) in Water Along River Thiba during Dry Season

Point	Cd	Cr	Ni	Pb	Zn	As	Mn	Se
C2	BDL	BDL	BDL	0.0186±0.00005	BDL	0.0000	0.0067±0.00001	BDL
C1	BDL	BDL	BDL	0.0022±0.00003	BDL	BDL	0.0061±0.00003	BDL
T1	BDL	BDL	BDL	0.0011±0.00003	BDL	0.0001±0.00002	0.0096±0.00001	BDL
T2	BDL	BDL	BDL	0.0130±0.00005	BDL	BDL	0.0040±0.00003	BDL
T3	BDL	BDL	BDL	0.0038±0.00007	BDL	BDL	0.0093±0.00004	BDL
T4	BDL	BDL	BDL	0.0032±0.00008	BDL	0.0000	0.0037±0.00006	BDL
T5	BDL	BDL	BDL	0.0077±0.00006	BDL	0.0000	0.0066±0.00006	BDL
T7	BDL	BDL	BDL	0.0048±0.00004	BDL	0.0001±0.00008	0.0083±0.00005	0.0000
T8	0.0073±0.00005	BDL	BDL	0.0069±0.00008	BDL	0.0000	0.0085±0.00008	BDL
Mean	BDL	BDL	BDL	0.0068±0.0057	BDL	0.00002±0.00004	0.0070±0.0021	BDL

During the dry season, the concentration of cadmium in river Thiba water from Kiumbu to Ndiara was BDL for the all sampling points except T8 (Ndiara) where the concentration was 0.0073±0.00005 ppm. The concentrations of chromium, nickel, zinc and selenium was also BDL for all the sampling points except selenium at T7 whose concentration was 0.0000 ppm. The concentration of lead was ranging between 0.0011±0.00003 (T1) ppm and 0.0186±0.00005 (C2) ppm and had an average of 0.0068±0.0057 ppm. The concentration of arsenic was varying from BDL to 0.0001±0.00002 (T1) ppm with a mean of 0.0068±0.0057 ppm while the concentrations of manganese was ranging from 0.0037±0.00006 (T4) ppm to 0.0096±0.00001 (T1) ppm with a mean of 0.0070±0.0021 ppm. The mean concentrations of the heavy metals in water along river Thiba upstream from Kiumbu to Ndiara during dry season decreased in the order Mn>Pb>Cd>As>Cr/Ni/Zn/Se.

During dry season, it was observed that most sampling points in river Thiba had the heavy metal concentrations BDL apart from lead, manganese and arsenic (at some sampling points) which recorded low concentrations. The study obtained lower concentrations levels of Pb, Cd and Mn than those reported by Wasike *et al.* (2019) on water of Kuywa river during dry season. Muiruri *et al.*, (2013) reported higher concentration levels of Ni, Mn, Zn, Cd and Cr in water from Athi-Galana-Sabaki tributaries during dry season compared to findings of this study. The study by Muiruri *et al.* (2013) reported concentration of lead in the tributaries water that was close to what is reported in this study.

4.2.2.3 Heavy Metals in Water of River Nyamindi from Kiumbu to Kiamatero During Wet Season

The concentration of selected heavy metals in water sampled along river Nyamindi during wet season are presented in Table 18.

Table 18: Amount of Selected Heavy Metals (ppm) in Water Along River Nyamindi during Wet Season

Point	Cd	Cr	Ni	Pb	Zn	As	Mn	Se
C2	0.0003±0.00004	0.1536±0.00015	1.9008±0.00073	0.0038±0.00006	BDL	0.0074±0.00003	6.8320±0.00052	0.0092±0.00004
C1	0.0004±0.00003	0.1768±0.00071	0.8468±0.00031	0.0135±0.00004	BDL	0.0014±0.00008	1.3190±0.00028	BDL
N1	BDL	BDL	BDL	0.0097±0.00007	BDL	0.0000	0.0327±0.00005	BDL
N2	BDL	BDL	BDL	0.0090±0.00004	BDL	0.0001±0.00006	0.0286±0.00005	BDL
N3	BDL	BDL	BDL	0.0050±0.00004	BDL	0.0001±0.00007	0.0673±0.00002	BDL
N4	0.0002±0.00002	0.0630±0.00007	0.6792±0.00035	0.0339±0.00008	BDL	0.0009±0.00007	0.5268±0.00047	0.0000
N5	BDL	0.0373±0.00004	0.4863±0.00027	0.0539±0.00006	BDL	0.0000	0.1245±0.00003	BDL
N6	0.0001±0.00003	BDL	BDL	0.0225±0.00087	BDL	0.0001±0.00004	0.0473±0.00006	BDL
Mean	0.0001±0.0002	0.0538±0.0727	0.4891±0.6670	0.0184±0.0186	BDL	0.0013±0.0025	1.1223±2.3495	0.0012±0.0033

The concentration of cadmium in water sampled from Kiumbu (C2) to Kiamatero (N6) along river Nyamindi during rainy season varied from BDL to 0.0004±0.00003 (C1) ppm with a mean of 0.0001±0.0002 ppm. Chromium concentration ranged from BDL to 0.1768±0.00071 (C1) ppm and had an average of 0.0538±0.0727 ppm. Concentration of nickel was ranging between BDL and 1.9008±0.00073 (C2) ppm having a mean of 0.4891±0.6670 ppm. While that of lead varied between 0.0038±0.00006 (C2) ppm and 0.0539±0.00006 (N5) ppm with a mean of 0.0184±0.0186 ppm.

During the same season, the concentration of zinc was BDL in all the water sampled. Arsenic had concentration ranging from 0.0000 ppm to 0.0074±0.00003 (C2) ppm with an average of 0.0013±0.0025 ppm. The concentration of manganese was varying from 0.0286±0.00005 (N2) ppm to 6.8320±0.00052 (C2) ppm and had an average of 1.1223±2.3495 ppm. Whereas that of selenium ranged from BDL to 0.0092±0.00004 (C2) with an average of 0.0012±0.0033 ppm. The mean amounts of the heavy metals in water along river Nyamindi upstream from Kiumbu to Kiamatero during wet season decreased in the order Mn>Ni>Cr>Pb>As>Se>Cd>Zn.

It was observed that during wet season, the water samples from C2 (Kiumbu) had the highest concentrations of nickel, arsenic, manganese and selenium whereas the samples from C1 (Ngomano) had highest concentrations of cadmium and chromium. These two sampling points C2 and C1 are within the section where rivers Thiba and Nyamindi combined. It was also observed that these two points (C2 and C1) had the top two highest concentrations of cadmium, chromium, nickel, arsenic and manganese showing that the heavy metal concentrations were lower upstream although there was no regular trend. This study found lower concentrations levels of Pb and Cd in river Nyamindi compared to what is reported by Wasike *et al.* (2019) on water of Kuywa river during wet season. Wasike *et al.* (2019) however reported lower level of Mn compared to what is reported in the current study. A study by Muiruri *et al.* (2013) reported almost similar concentration values of Pb and Cd, lower concentrations of Ni, Cr and Mn and higher concentrations of Zn in river water from Athi-Galana-Sabaki tributaries during wet season compared to what is reported in this study.

4.2.2.4 Heavy Metals in Water of River Nyamindi from Kiumbu to Kiamatero During Dry Season

The concentration of selected heavy metals in water sampled along river Thiba during dry season are presented in Table 19.

Table 19: Amount of Selected Heavy Metals (ppm) in Water Along River Nyamindi during Dry Season

Point	Cd	Cr	Ni	Pb	Zn	As	Mn	Se
C2	BDL	BDL	BDL	0.0186±0.00005	BDL	0.0000	0.0067±0.00001	BDL
C1	BDL	BDL	BDL	0.0022±0.00003	BDL	BDL	0.0061±0.00003	BDL
N1	BDL	BDL	BDL	0.0724±0.00003	BDL	0.0000	0.0095±0.00007	BDL
N2	BDL	BDL	BDL	0.0044±0.00004	BDL	0.0001±0.00002	0.0074±0.00009	0.0002±0.00001
N3	BDL	BDL	BDL	0.0079±0.00007	BDL	0.0000	0.0074±0.00003	BDL
N4	BDL	0.0017±0.00006	BDL	0.0106±0.00003	BDL	0.0001±0.00001	0.0114±0.00002	BDL
N5	BDL	BDL	0.0890±0.00008	0.0112±0.00001	BDL	0.0000	0.0050±0.00008	BDL
N6	0.0055±0.00008	0.0010±0.00001	BDL	0.0037±0.00002	BDL	0.0000	0.0073±0.00002	BDL
Mean	BDL	0.0003±0.0007	BDL	0.0164±0.0232	BDL	0.00003±0.00005	0.0076±0.0020	BDL

The concentration of cadmium in the water sampled from Kiumbu (C2) to Kiamatero (N6) along river Nyamindi course during dry season was BDL for all samples apart from the sample from N6 which had a concentration of 0.0055±0.00008 ppm. Concentrations of chromium was BDL for all samples except N4 and N6 and that of nickel was BDL except N5. Whereas concentration of lead was varying from 0.0022±0.00003 (C1) ppm to 0.0724±0.00003 (N1) ppm with a mean of 0.0164±0.0232 ppm.

The concentration of zinc was BDL for all the samples during dry season whereas that of arsenic was ranging from BDL to 0.0001±0.00001 (N4) ppm and had a mean of 0.00003±0.00005 ppm. Manganese concentration was ranging from 0.0050±0.00008 (N5) ppm to 0.0114±0.00002 (N4) ppm with an average of 0.0076±0.0020 ppm. Whereas that of selenium was BDL for all samples except N2 which had a concentration of 0.0002±0.00001 ppm. The mean amounts of the heavy metals in water along river Nyamindi upstream from Kiumbu to Kiamatero during dry season decreased in the order Pb>Ni>Mn>Cd>Cr>As>Se>Zn.

It was observed that during the dry season, the concentrations of the heavy metals in water along river Nyamindi were generally low or were BDL. However, samples from N4 (Matandara) sampling point, had the highest concentrations of chromium, arsenic and manganese. Wasike *et al.* (2019) reported higher concentrations levels of Pb, Cd and Mn in water from Kuywa river during dry season compared to the concentrations reported in this study. Muiruri *et al.* (2013) reported higher concentration levels of Ni, Mn, Zn, Cd and Cr in river water from Athi-Galana-Sabaki tributaries during dry season compared to concentrations reported in this study. The study by Muiruri *et al.* (2013) reported similar concentration of lead in the water from these tributaries. It was found that the lowest sampling point (Kiumbu, C2) which is located downstream after rivers Thiba and Nyamindi combine and the next sampling point upstream (Ngomano, C1) which is located at the confluence of the two rivers did not show any unusual concentrations of the heavy metals in sediment or water during either wet or dry season.

4.2.3 Individual Heavy Metal Concentration in Sediment and Water During Wet and Dry Season

The amount of each selected heavy metal in sediment and water during wet and dry season along each of the river is presented separately in this section.

4.2.3.1 Cadmium in Rivers Thiba and Nyamindi

The amounts of cadmium in sediment and water during wet and dry season along river Thiba are presented in Table 20.

Table 20: Amount of Cadmium in Sediment and Water Along River Thiba

Sampling point	Rainy season Sediment	Water	Dry season Sediment	Water
T1	0.1202±0.0033	BDL	0.0701±0.0008	BDL
T2	0.0541±0.0009	0.0004±0.00002	0.1242±0.0027	BDL
T3	0.1823±0.0046	0.0003±0.00006	0.0541±0.0009	BDL
T4	0.0561±0.0007	0.0001±0.00005	0.0821±0.0004	BDL
T5	0.0240±0.0004	BDL	0.0456±0.0005	BDL
T6	0.0481±0.0008	0.0002±0.00001	0.0785±0.0009	(-)
T7	0.2705±0.0076	0.0001±0.00001	0.0602±0.0003	BDL
T8	0.0381±0.0005	BDL	0.0365±0.0007	0.0073±0.00005
Mean	0.0992±0.0867	0.0001±0.0002	0.0689±0.0273	0.0010±0.0028
WHO limit	0.6	0.005	0.6	0.005

The average amount of cadmium in sediment sampled from river Thiba from Kakawa (T1) to Ndiara (T8) was 0.0992±0.0867 mg/kg during wet season and 0.0689±0.0273 mg/kg during dry season. It was observed that on average, sediment had higher amount of cadmium in wet season compared to dry season although the difference was small. The average concentration of cadmium in water along the same river Thiba course was 0.0001±0.0002 ppm (which was quite low) during wet season and 0.0010±0.0028 during dry season. It was observed that in most sampling points, the river water had higher concentration of cadmium in wet season compared to dry season. The amount of cadmium in the sediment at each sampling point did not seem to affect the concentration of the same metal in water. For instance, sampling point T7 had the highest amount of cadmium in the sediment during wet season but did not have the highest concentration in the water. Similarly, sampling point T1 had third highest amount of cadmium in the sediment but had the least concentration (BDL) of the metal in the water during wet season. The sampling points that had higher or lower amount of cadmium in sediment during wet season did not necessarily have the same relative amount during dry season.

Independent-sample t-tests were conducted to establish whether there were differences in Cd amount in sediment and also in water from river Thiba during rainy and dry season. The results of the t-test determining whether there was a significant difference in the amount of Cd in sediment during rainy and dry season are given in Table 21.

Table 21: Results of t-test on Amount of Cd in Sediment from River Thiba During Rainy and Dry Season

		T	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Conf. Inter. of the Difference	
							Lower	Upper
Cd	Equal variances assumed	0.941	14	0.362	0.0302	0.0321	-.0386	0.0991
	Equal variances not assumed	0.941	8.375	0.373	0.0302	0.0321	-.0432	0.1037

t-critical = 2.145

The results in Table 21 established that there was no statistically reliable difference between mean Cd amount in river Thiba sediment during wet season (0.0992±0.0867 mg/kg) compared to during dry season (0.0689±0.0273 mg/kg) t (14) = 0.941 at significance of t-test p = 0.362 and confidence level of the study (α) = 0.05. A similar t-test showed that there was no reliable difference between the mean Cd concentration in water of river Thiba during rainy season (0.0001±0.0002 ppm) and dry season (0.0010±0.0028 ppm), t (13) = 0.368 at significance of t-test p = -0.932 and confidence level of the study (α) = 0.05 (see Appendix XVII and XVIII). These results showed that there was no difference in the amount of Cd in river Thiba sediment or water during both rainy and dry season at α = 0.05 confidence level.

Further independent t-test was conducted to determine whether there was a difference in the mean concentration of Cd in sediment and water from river Thiba. The results indicated that during rainy season, there was significant difference in the mean concentration of Cd in sediment (0.0992±0.0867 mg/kg) and water (0.0001±0.0002 mg/kg), t (14) = 3.232 at significance of t-test p = 0.006 and confidence level of the study (α) = 0.05. The t-test further revealed that during dry season, there was still significant difference in the mean concentration of Cd in sediment (0.0689±0.0273) and in water (BDL), t (13) = -6.521 at significance of t-test p = 0.001 and at the same confidence level of the study (α) = 0.05 (Appendix XIII and XIV). From these results, it was observed that there was considerable difference in the amount of Cd in sediment and water of river Thiba.

The amounts of cadmium in sediment and water during wet and dry season along river Nyamindi are presented in Table 22.

Table 22: Amount of Cadmium in Sediment and Water Along River Nyamindi

Sampling	Rainy season		Dry season	
point	Sediment	Water	Sediment	Water
N1	0.0621±0.0008	BDL	0.0694±0.0005	BDL
N2	0.0721±0.0002	BDL	0.0602±0.0007	BDL
N3	0.0382±0.0006	BDL	0.0986±0.0007	BDL
N4	0.0481±0.0008	0.0002±0.00002	0.0310±0.0003	BDL
N5	0.2084±0.0045	BDL	0.0438±0.0001	BDL
N6	0.1002±0.0074	0.0001±0.00003	0.0511±0.0003	0.0055±0.00008
Mean	0.0882±0.0627	0.00005±0.00002	0.0590±0.0235	0.0009±0.0022
WHO limit	0.6	0.005	0.6	0.005

The average amount of cadmium in sediment sampled from river Nyamindi from Nyamindi village (N1) to Kiamatero (N6) was 0.0882±0.0627 mg/kg during wet season and 0.0590±0.0235 mg/kg during dry season. The amount of cadmium was a little higher during wet season compared to dry season. The average concentration of cadmium in water along the same Nyamindi river course was 0.00005±0.00002 ppm during wet season and 0.0009±0.0022 during dry season. Just like for sediment, the concentration of cadmium in water was higher during rainy season compared to dry season although during both seasons, the concentration was very low. The amount of cadmium in sediment did not appear to affect its concentration in water. For instance, sampling point N5 had the highest amount of cadmium in sediment during wet season yet the concentration in water was BDL. It was also noted that the sampling points that had higher amount of cadmium in sediment during rainy season did not necessarily have higher amount during dry season.

Independent-sample t-tests were conducted to establish whether there were differences in Cd amount in sediment and also in water from river Nyamindi during rainy and dry season. The results of the t-test determining whether there was a significant difference in the amount of Cd in sediment during rainy and dry season are given in Table 23.

Table 23: T-test for Comparison of Amount of Cd in Sediment from River Nyamindi During Rainy and Dry Season

							95% Confidence Interval of Difference	
		T	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Cd	Equal variances assumed	1.066	10	.311	0.0291	0.0273	-.0317	0.0900
	Equal variances not assumed	1.066	6.4	.325	0.0291	0.0273	-.0367	0.0950

T-crit = 2.228

The results in Table 23 established that there was no statistically reliable difference between mean Cd amount in river Nyamindi sediment during rainy season (0.0882±0.0627 mg/kg) compared to during dry season (0.0590±0.0235 mg/kg) t (10) = 1.066 at significance of t-test p = 0.311 and confidence level of the study (α) = 0.05. A similar t-test showed that there was no reliable difference between the mean Cd concentration in water of river Nyamindi during rainy season (0.00005±0.00002 ppm) and dry season (0.0009±0.0022 ppm), t (10) = -0.954 at significance of t-test p = 0.362 and confidence level of the study (α) = 0.05 (see Appendix XVII and XVIII).

A t-test was run to determine whether there was a difference in the mean concentration of Cd in sediment and water from river Nyamindi. The results revealed that during rainy season, there was significant difference in the mean concentration of Cd in sediment (0.0882±0.0627 ppm) and water (0.00005±0.00002 ppm), t (10) = 3.443 at significance of t-test p = 0.006 and confidence level of the study (α) = 0.05. The t-test also indicated that during dry season, there was still significant difference in the mean concentration of Cd in sediment (0.0590±0.0235) and in water (BDL), t (10) = -6.042 at significance of t-test p = 0.001 and at the same confidence level of the study (α) = 0.05 (see Appendix XIII and XIV). These results revealed in river Nyamindi, that there was no effect of season on concentration of Cd in sediment or water; but there was discernible difference between the amount in sediment and water during each season at the confidence level α = 0.05.

Considering both rivers, the average amount of cadmium in the sediment from river Thiba was 0.0992±0.0867 mg/kg and from river Nyamindi was 0.0882±0.0627 mg/kg during wet season. During dry season, cadmium amount in sediment from river Thiba was 0.0689±0.0273 mg/kg while that from river Nyamindi was 0.0590±0.0235 mg/kg. In both cases, the sediment from river Thiba had slightly higher amount of cadmium than that from river Nyamindi. Similarly, the concentration of cadmium was higher in water from river Thiba (0.0001±0.0002 ppm) than in water from river Nyamindi (0.00005±0.00008 ppm) during wet season. However, both rivers had concentration BDL during dry season. It was observed that during both seasons, sediment from river Thiba had slightly higher amount of cadmium than that from river Nyamindi and the same was the case in water during wet season. This may be due to possible seepage and run-offs of Cd containing water from the larger rice farming area that is adjacent to River Thiba since four of the five main rice growing sections (Mwea, Thiba, Wamumu and Karaba) are adjacent to river Thiba and only one section (Tebere) is adjacent to river Nyamindi. The amount of Cd in sediment falls below WHO permissible limit of 0.6 mg/kg and the concentration in water also falls below WHO and KEBS/WASREB permissible limit of 0.005 ppm (Ameh *et al.*, 2016; Omondi, 2017; Mahmud *et al.*, 2016; WASREB, 2008) implying that rivers Thiba and Nyamindi are not polluted with Cd.

An independent-samples t-test was run to determine whether the mean concentrations of Cd in sediment and water from rivers Thiba and Nyamindi were statistically significantly different. The results indicated that there was no significant difference in the mean concentration of Cd in sediment from river Thiba (0.0992±0.0867 ppm) and sediment from river Nyamindi (0.0882±0.0627 ppm) during rainy season, t (12) = 0.263 at significance of t-test p = 0.797 and confidence level of the study (α) = 0.05. The t-test also showed that during dry season, there was still no significant difference in the mean concentration of Cd in sediment from river Thiba (0.0689±0.0273 mg/kg) and in sediment from river Nyamindi (0.0590±0.0235 mg/kg), t (12) = 0.712 at significance of t-test p = 0.490 and at the same confidence level of the study (α) = 0.05. Similarly, the t-test results revealed that there was no significant difference in the mean concentration of Cd in water from river Thiba (0.0001±0.0002 ppm) and water from river Nyamindi (0.00005±0.00002 ppm) during rainy season, t (12) = 1.376 at significance of t-test p = 0.194 and confidence level of the study (α) = 0.05. The t-test also indicated that during dry season, there was also no significant difference in the mean concentration of Cd in water from river Thiba (0.0010±0.0028 ppm) and in water from river Nyamindi (0.0009±0.0022 ppm), t (11) = 0.092 at significance of t-test p = 0.928 and at the same confidence level of the study (α) = 0.05 (see Appendix VI, VII, VIII and IX). These results showed that there was no effect of the river in the amount of Cd in sediment and also in water from the two rivers during each season at the confidence level of the study α = 0.05.

A two-way ANOVA was conducted to examine the effect of the two rivers (Thiba and Nyamindi) and seasons (rainy and dry) on concentration of Cd in sediment and water. The results on the effect of the rivers and seasons on the amount of Cd in sediment are given in Table 24.

Table 24: Two-way ANOVA on Effect of Rivers and Season on the Amount of Cd in Sediment

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	0.007[a]	3	.002	.694	.565
Intercept	0.170	1	.170	51.003	.000
Season	0.006	1	.006	1.809	.191
River	0.001	1	.001	.225	.640
Season * River	2.106E-6	1	2.106E-6	.001	.980
Error	.080	24	.003		
Total	.264	28			
Corrected Total	.087	27			

R Squared = .080 (Adjusted R Squared = -.035)

The results showed that there was statistically no significant interaction between the effect of river and season on the concentration of Cd in sediment, F (1,24) = 0.001, p = 0.980 (Fcrit = 4.26). Similarly, the two-way ANOVA test revealed no significant interaction between the effect of river and season on the Cd concentration in water, F (1,23) = 0.001, p = 0.980 (Fcrit = 4.28) (see Appendix XI and XII). These results revealed no considerable interaction between river and season on the amount of Cd for both sediment and water at the confidence level of the study α = 0.05.

The results of the various statistical tests conducted in this section revealed that there was no reliable difference in the amount of Cd in sediment during rainy and dry season; and no reliable difference between the concentration of Cd in water during rainy and wet season in river Thiba. Similarly, there was no reliable difference in the amount of Cd in sediment and also in water of river Nyamindi during both seasons. However, there was reliable difference in the concentration of Cd in sediment and water of each of the river during each season. It was also found that there was no considerable interaction between river and season on the amount of Cd in both sediment and water at the confidence level of the study (α) = 0.05.

This study obtained values similar to those reported by Idiriah *et al.* (2012), Tomno *et al.,* (2020), Muiruri *et al.* (2013) and Budambula & Mwachiro (2006) on amount of Cd in river sediment and water. However, Wasike *et al.* (2019), Javaid *et al.* (2022) reported higher values than those reported in the present study showing that the rivers involved in their studies were more polluted with Cd than rivers Thiba and Nyamindi.

4.2.3.2 Chromium in Rivers Thiba and Nyamindi

The amounts of chromium in sediment and water during wet and dry season along river Thiba are presented in Table 25.

Table 25: Amount of Chromium in Sediment and Water Along River Thiba

Sampling point	Rainy season Sediment	Water	Dry season Sediment	Water
T1	34.2513±0.0028	BDL	47.9639±0.0049	BDL
T2	44.5663±0.0055	0.1214±0.00033	34.6627±0.0035	BDL
T3	35.8509±0.0071	0.1927±0.00024	26.1350±0.0076	BDL
T4	43.2055±0.0033	0.0960±0.00004	44.4167±0.0088	BDL
T5	33.1244±0.0053	BDL	42.4511±0.0074	BDL
T6	50.3350±0.0140	0.0561±0.00007	57.6709±0.0390	(-)
T7	43.0963±0.0092	0.1196±0.00067	64.0501±0.0090	BDL
T8	38.1428±0.0038	BDL	39.8045±0.0027	BDL
Mean	40.3216±5.9484	0.0732±0.0714	44.6644±12.1173	BDL
WHO limit	25	0.05	25	0.05

The mean amount of chromium in sediment sampled from river Thiba from Kakawa (T1) to Ndiara (T8) was 40.3216±5.9484 mg/kg during wet season and 44.6644±12.1173 mg/kg during dry season. The mean amount during dry season was slightly higher than that of wet season. It was observed that the sampling points that had relatively higher amount of chromium during wet season did not necessarily have higher amount during dry season. The mean concentration of chromium in water along river Thiba course was 0.0732±0.0714 ppm during wet season which was higher than that during dry season which was BDL. It was also observed that the sampling points that had high amount of chromium in sediment did not necessarily have a corresponding high concentration of chromium in water. It was noted that the concentrations of chromium in water from all river Thiba sampling points were BDL during dry season.

Independent-sample t-tests were conducted to determine whether there were differences in Cr amount in sediment and also in water from river Thiba during rainy and dry season. The results of the t-test indicated that there was no statistically reliable difference between mean Cr amount in river Thiba sediment during rainy season (40.3216±5.9484 mg/kg) compared to during dry season (44.6644±12.1173 mg/kg) $t(14) = -0.906$ at significance of t-test $p = 0.380$ and confidence level of the study $(\alpha) = 0.05$. However, a similar t-test revealed that there was reliable difference between the mean Cr concentration in water of river Thiba during rainy season (0.0732±0.0714 ppm) and dry season (BDL ppm), t (13) = 2.702 at significance of t-test p = 0.018 and confidence level of the study (α) = 0.05 (see Appendix XVII and XVIII).

Further independent t-test was conducted to determine whether there was a difference in the mean concentration of Cr in sediment and water from river Thiba. The results revealed that during rainy season, there was significant difference in the mean concentration of Cr in sediment (40.3216±5.9484 ppm) and water (0.0732±0.0714 ppm), t (14) = 19.136 at significance of t-test p = 0.001 and confidence level of the study (α) = 0.05. The t-test further indicated that during dry season, there was still significant difference in the mean concentration of Cr in sediment (44.6644±12.1173 ppm) and in water (BDL), t (13) = -9.701 at significance of t-test p = 0.001 and at the same confidence level of the study (α) = 0.05 (Appendix XIII and XIV).

The amounts of chromium in sediment and water during wet and dry season along river Nyamindi are presented in Table 25.

Table 26: Amount of Chromium in Sediment and Water Along River Nyamindi

Sampling point	Rainy season		Dry season	
	Sediment	Water	Sediment	Water
N1	34.3949±0.0081	BDL	32.2162±0.0022	BDL
N2	36.9219±0.0045	BDL	41.6762±0.0077	BDL
N3	30.1670±0.0063	BDL	38.6655±0.0049	BDL
N4	40.4863±0.0026	0.0630±0.00007	37.7108±0.0035	0.0017±0.00006
N5	50.9584±0.0250	0.0373±0.00004	39.7309±0.0057	BDL
N6	53.8026±0.0150	BDL	44.7058±0.0078	0.0010±0.00001
Mean	41.1219±9.3900	0.0167±0.0271	39.1176±4.1944	0.0005±0.0007
WHO limit	25	0.05	25	0.05

The mean amount of chromium in sediment from river Nyamindi from Nyamindi village (N1) to Kiamatero (N6) was 41.1219±9.3900 mg/kg during wet season and 39.1176±4.1944 mg/kg during dry season. It was observed that the mean amount was slightly higher during wet season compared to dry season. It was also observed that the sampling points that had relatively high amount of chromium during wet season did not necessarily have high amount during dry season. On the same river Nyamindi course, the concentration of chromium in water was 0.0167±0.0271 ppm during wet season and 0.0005±0.0007 ppm during dry season. The concentration in water was found to be higher during wet season than during dry season. It was observed that on most sampling points, the concentration of chromium in water was BDL. It was also noted that the sampling points that had higher amount of chromium in sediment did not necessarily have high amount in water. For instance, N6 had the highest amount of chromium in sediment but had concentration in water being BDL.

Independent-sample t-tests were conducted to establish whether there were differences in Cr amount in sediment and also in water from river Nyamindi during rainy and dry season. The results of the t-test established that there was no statistically significant difference between mean Cr amount in river Nyamindi sediment during rainy season (41.1219±9.3900 mg/kg) compared to during dry season (39.1176±4.1944 mg/kg), t (10) = 0.477 at significance of t-test p = 0.311 and confidence level of the study (α) = 0.05. A similar t-test found that there was no significant difference between the mean Cr concentration in water of river Nyamindi during rainy season (0.0167±0.0271 ppm) and dry season (0.0005±0.0007 ppm), t (10) = 1.468 at significance of t-test p = 0.173 and confidence level of the study (α) = 0.05 (see Appendix XVII and XVIII).

A t-test was run to determine whether there was a difference in the mean concentration of Cr in sediment and water from river Nyamindi. The results indicated that during rainy season, there was significant difference in the mean concentration of Cr in sediment (41.1219±9.3900 ppm) and water (0.0167±0.0271 ppm), t (10) = 10.723 at significance of t-test p = 0.001 and confidence level of the study (α) = 0.05. The t-test also found that during dry season, there was still significant difference in the mean concentration of Cr in sediment (39.1176±4.1944) and in water (0.0005±0.0007 ppm), t (10) = -22.844 at significance of t-test p = 0.001 and at the same confidence level of the study (α) = 0.05 (see Appendix XIII and XIV).

Considering both rivers Thiba and Nyamindi, the mean amount of chromium in the sediment from river Thiba was 40.3216±5.9448 mg/kg which was almost equal to that from river Nyamindi which was 41.1219±9.3900 mg/kg during wet season. During dry season, mean chromium amount in sediment from river Thiba was 44.6644±12.1173 mg/kg which was a little higher than that from river Nyamindi that was 39.1176±4.1944 mg/kg. The mean concentration of chromium in river Thiba water was 0.0732±0.0714 ppm which was higher than that in water from river Nyamindi which had a mean of 0.0167±0.0271 ppm during wet season. During dry season, the mean concentration of chromium in river Thiba water was BDL which was less than that of river Nyamindi that had a mean of 0.0005±0.0007 ppm.

The mean values of chromium in sediment and water in rivers Thiba and Nyamindi were more or less the same. The mean amount of chromium in sediment exceeded WHO and US EPA permissible limit of 25 mg/kg (Omondi, 2017; Ameh *et al.,* 2016) implying that sediment in rivers Thiba and Nyamindi was chromium polluted according to WHO and US EPA standards. The mean concentration of chromium in river Thiba water during wet season was above WHO, US EPA and KEBS/WASREB permissible limit of 0.05 ppm (Wasike *et al.,* 2019; Mahmud *et al.,* 2016; WASREB, 2008) but during dry season and in river Nyamindi (both seasons), the chromium concentration in water was below the permissible limit. This shows that during wet season, river Thiba water may be classified as chromium polluted according to WHO, US EPA and WASREB therefore may not be recommended for drinking during such periods.

An independent-samples t-test was run to determine whether the mean concentrations of Cr in sediment and water from rivers Thiba and Nyamindi were statistically significantly different. The results showed that there was no significant difference in the mean concentration of Cr in sediment from river Thiba (40.3216±5.9484 ppm) and sediment from river Nyamindi (41.1219±9.3900 ppm) during rainy season, t (12) = 0.196 at significance of t-test p = 0.848 and confidence level of the study (α) = 0.05. The t-test also demonstrated that during dry season, there was still no significant difference in the mean concentration of Cr in sediment from river Thiba (44.6644±12.1173 ppm) and in sediment from river Nyamindi (39.1176±4.1944 ppm), t (12) = 1.061 at significance of t-test p = 0.309 and at the same confidence level of the study (α) = 0.05.

Similarly, the t-test results revealed that there was no significant difference in the mean concentration of Cr in water from river Thiba (0.0732±0.0714 ppm) and water from river Nyamindi (0.0167±0.0271 ppm) during rainy season, t (12) = 1.376 at significance of t-test p = 0.194 and confidence level of the study (α) = 0.05. The t-test also found that during dry season, there was also no significant difference in the mean concentration of Cr in water from river Thiba (BDL ppm) and in water from river Nyamindi (0.0005±0.0007 ppm), t (11) = -1.644 at significance of t-test p = 0.128 and at the same confidence level of the study (α) = 0.05 (see Appendix VI, VII, VIII and IX).

A two-way ANOVA was conducted to establish the effect of the two rivers (Thiba and Nyamindi) and seasons (rainy and dry) on concentration of Cr in sediment and water. The results showed that there was no statistically significant interaction between the effect of river and season on the concentration of Cr in sediment, F (1,24) = 0.913, p = 0.349 (F-crit = 4.26). Similarly, the two-way ANOVA test found that there was no significant interaction between the effect of river and season on the Cr concentration in water, F (1,23) = 3.154, p = 0.089 (F-crit = 4.28) (see Appendix XI and XII).

The results of the various statistical tests conducted in this section established that the amount of Cr in water was considerably higher in rainy season than dry season in river Thiba but there was no difference in Cr amount in water of river Nyamindi during both seasons; there was discernible effect between the amount of Cr in sediment and water during each season; no effect of river in the amount of Cr in sediment and also in water from the two rivers during each season; and no considerable interaction between river and season on the amount of Cr in sediment and also water at the confidence level of the study (α) = 0.05.

The present study aligns with findings of Tomno *et al.* (2020) who reported similar values of chromium in water of urban streams of Machakos municipality and Muiruri *et al.* (2013) who reported chromium values close to those of this study in water from Athi-Galana-Sabaki tributaries. However, Mustafa (2019) reported higher chromium values in water from river Yobe of Nigeria and Javaid *et al*. (2022) who reported much higher values of chromium in water from rice growing areas of Punjab in Pakistan. This may have been due to the longer period of rice farming in these areas coupled with excessive application of fertilizers and toxic agricultural chemicals which usually contain traces of heavy metals. However, the current study reported different values from those reported by Idriah *et al.* (2012) who reported lower values (0.076-0.3071 mg/kg) of chromium in sediment along Abonnema shoreline in Nigeria and Omondi (2017) who reported much higher values (122 mg/kg) of chromium in sediment from river Nzoia in Kenya.

4.2.3.3 Nickel in Rivers Thiba and Nyamindi

The amounts of nickel in sediment and water during wet and dry season along river Thiba are presented in Table 27.

Table 27: Amount of Nickel in Sediment and Water Along River Thiba

Sampling point	Rainy season Sediment	Water	Dry season Sediment	Water
T1	70.8137±0.0650	BDL	95.3359±0.0850	BDL
T2	88.9061±0.0710	3.2534±0.00062	64.2392±0.0280	BDL
T3	78.1208±0.0760	2.0554±0.00035	63.2156±0.0570	BDL
T4	67.8782±0.0550	1.1054±0.00039	520.5808±0.7870	BDL
T5	73.9169±0.0870	0.0701±0.00006	538.0829±0.1980	BDL
T6	128.1840±0.3980	0.4881±0.00053	741.2449±0.6250	(-)
T7	93.9105±0.0760	0.3455±0.00044	591.6598±0.4610	BDL
T8	90.0485±0.0650	BDL	437.0949±0.5110	BDL
Mean	86.4723±19.3915	0.9147±1.1771	381.4318±268.4307	BDL
WHO limit	20	0.1	20	0.1

The average amount of nickel in sediment from river Thiba from Kakawa (T1) to Ndiara (T8) was 86.4728±19.3915 mg/kg during wet season and 381.4318±268.4307 mg/kg during dry season. In this river, the average amount of nickel in the sediment during dry season was over four times higher than that of wet season. It was noted that all the sampling points had higher amount of nickel in sediment during dry season than during wet season except T2 and T3. The mean concentration of nickel in water along river Thiba course was 0.9147±1.1771 ppm during wet season which was higher than that during dry season that was BDL. It was also observed that the sampling points that had higher amount of nickel in sediment did not necessarily have a corresponding higher concentration of the same in water. It was observed that the concentration of nickel in water from all river Thiba sampling points during dry season was BDL.

Independent-sample t-tests were conducted to determine whether there were significant differences in amount of Ni in sediment and also in water from river Thiba during rainy and dry season. The results of the t-test indicated that there was statistically reliable difference between mean Ni amount in river Thiba sediment during rainy season (86.4723±19.3915 mg/kg) compared to during dry season (381.4318±268.4307 mg/kg) t (14) = -3.100 at significance of t-test p = 0.008 and confidence level of the study (α) = 0.05. However, t-test revealed that there was no reliable difference between the mean Ni concentration in water of river Thiba during rainy season (0.9147±1.1771 ppm) and dry season (BDL ppm), t (13) = 2.046 at significance of t-test p = 0.662 and confidence level of the study (α) = 0.05 (see Appendix XVII and XVIII). Further independent t-test was conducted to determine whether there was a difference in the mean concentration of Ni in sediment and water from river Thiba. The results revealed that during rainy season, there was significant difference in the mean concentration of Ni in sediment (86.4723±19.3915 ppm) and water (0.9147±1.1771 ppm), t (14) = 12.456 at significance of t-test p = 0.001 and confidence level of the study (α) = 0.05. The t-test further indicated that during dry season, there was still significant difference in the mean concentration of Ni in sediment (381.4318±268.4307 ppm) and in water (BDL), t (13) = -3.742 at significance of t-test p = 0.002 and at the same confidence level of the study (α) = 0.05 (Appendix XIII and XIV).

The amounts of nickel in sediment and water during wet and dry season along river Nyamindi are given in Table 28.

Table 28: Amount of Nickel in Sediment and Water Along River Nyamindi

Sampling point	Rainy season		Dry season	
	Sediment	Water	Sediment	Water
N1	74.9157±0.0650	BDL	479.3399±0.6990	BDL
N2	76.9449±0.0880	BDL	617.6797±0.4990	BDL
N3	63.7684±0.0390	BDL	580.0957±0.2950	BDL
N4	92.3219±0.0760	0.6792±0.00035	518.3989±0.6980	BDL
N5	129.7994±0.2760	0.4863±0.00027	559.2734±0.1330	0.0890±0.00008
N6	112.8805±0.0370	BDL	599.7628±0.6550	BDL
Mean	91.7718±25.2196	0.1943±0.3071	559.0917±52.0464	0.0148±0.0363
WHO limit	20	0.1	20	0.1

The average amount of nickel in sediment from river Nyamindi from Nyamindi village (N1) to Kiamatero (N6) was 91.7718±25.2196 mg/kg during wet season and 559.0917±52.0464 mg/kg during dry season. The average amount was about six times higher during dry season compared to wet season. On the same course of river Nyamindi, the average concentration of nickel in water was 0.1943±0.3071 ppm during wet season and 0.0148±0.0363 during dry season. The concentration of nickel in river water was found to be higher during wet season than during dry season. It was observed that on most sampling points, the concentration of nickel in water was BDL. It was also observed that the sampling points that had higher amount of nickel in sediment did not necessarily have higher concentration of the same metal in water. For instance, during wet season, N4 had the third highest amount of nickel in sediment but had the highest concentration of the same in water.

Independent-sample t-tests were carried out to determine whether there were differences in amount of Ni in sediment and also in water from river Nyamindi during rainy and dry season. The results of the t-test revealed that there was statistically reliable difference between mean Ni amount in river Nyamindi sediment during rainy season (91.7718±25.2196 mg/kg) compared to during dry season (559.0917±52.0464 mg/kg), $t(10) = -19.793$ at significance of t-test $p < 0.001$ and confidence level of the study (α) = 0.05. On the other hand, t-test found that there was no reliable difference between the mean Ni concentration in water of river Nyamindi during rainy season (0.1943±0.3071 ppm) and dry season (BDL ppm), $t(10) = 1.421$ at significance of t-test $p = 0.186$ and confidence level of the study (α) = 0.05 (see Appendix XVII and XVIII).

A t-test was conducted to examine whether there was any difference in the mean concentration of Ni in sediment and water from river Nyamindi. The results indicated that during rainy season, there was significant difference in the mean concentration of Ni in sediment (91.7718±25.2196 ppm) and water (0.1943±0.3071 ppm), $t(10) = 8.894$ at significance of t-test $p = 0.001$ and confidence level of the study (α) = 0.05. The t-test also indicated that during dry season, there was still significant difference in the mean concentration of Ni in sediment (559.0917±52.0464 ppm) and in water (BDL ppm), $t(10) = -26.312$ at significance of t-test $p = 0.001$ and at the same confidence level of the study (α) = 0.05 (see Appendix XIII and XIV).

Comparing rivers Thiba and Nyamindi, the average amount of nickel in the sediment from river Thiba was 86.4723±19.3915 mg/kg which was slightly less than that from river Nyamindi which was 91.7718±25.2196 mg/kg during wet season. During dry season, the average amount of nickel in sediment from river Thiba was

381.4318±268.4307 mg/kg which was lower than that from river Nyamindi that was 559.0917±52.0464 mg/kg. In both rivers and both seasons, the amount of nickel in sediment exceeded WHO and US EPA permissible limits which are set at 20 mg/kg and 16 mg/kg respectively (Ameh *et al.,* 2016; Omondi, 2017; Samlafo, 2006). It was noted that the average amount of nickel in sediment was higher in sediment from river Nyamindi compared to sediment from river Thiba. Since Tebere section that is adjacent to river Nyamindi was the first to be established, nickel (which is found in phosphatic fertilizers in relatively large quantities) has been getting into river Nyamindi for a longer period which may have led to its accumulation to higher amount in the sediment compared to river Thiba's sediment. In both rivers, the amount of nickel in sediment during dry season was higher than during wet season which concurs with Ebah *et al.* (2016) who reported higher amount of nickel during dry season compared to wet season. The present study is also in line with findings of Moywaywa (2018) who reported mean nickel amount of 119 mg/kg in sediment from Thika river and Omondi (2017) who reported mean nickel amount of 389 mg/kg in sediment from river Nzoia. This shows that repeated usage of phosphatic fertilizers (which contains nickel) in farming may be leading to accumulation of nickel in river sediment after surface runoffs carry fertilizers to the rivers.

The average concentration of nickel in river Thiba water was 0.9147±1.1771 ppm which was higher than that in water from river Nyamindi which had an average of 0.1943±0.3071 ppm during wet season which was higher than WHO permissible limit of 0.1 ppm (Mahmud *et al.,* 2016; WASREB, 2008). During dry season, the concentration of nickel in both rivers water was BDL from all sampling points except N5 that recorded a concentration of 0.0890±0.00008 ppm which was quite low. The concentration of nickel was therefore below WHO permissible limits and so water from both rivers was not nickel polluted during dry season. It was found that river Thiba water had higher concentration of nickel than river Nyamindi which may be due the larger rice farming section being adjacent to river Thiba compared to rice growing section adjacent river Nyamindi. It was also noted that during dry season, water from all sampling points had a concentration BDL (except N5) showing that when there are no surface runoffs, rivers Thiba and Nyamindi water is not nickel polluted.

An independent-samples t-test was run to determine whether the mean concentrations of Ni in sediment and water from rivers Thiba and Nyamindi were statistically significantly different. The results showed that there was no significant difference in the mean concentration of Ni in sediment from river Thiba (86.4723±19.3915 ppm) and sediment from river Nyamindi (91.7718±25.2196 ppm) during rainy season, t (12) = -0.446 at significance of t-test p = 0.664 and confidence level of the study (α) = 0.05. The t-test also indicated that during dry season, there was still no significant difference in the mean concentration of Ni in sediment from river Thiba (381.4318±268.4307 ppm) and in sediment from river Nyamindi (559.0917±52.0464 ppm), t (12) = -1.583 at significance of t-test p = 0.107 and at the same confidence level of the study (α) = 0.05.

Similarly, the t-test results established that there was no significant difference in the mean concentration of Ni in water from river Thiba (0.9147±1.1771 ppm) and water from river Nyamindi (0.1943±0.3071 ppm) during rainy season, t (12) = 1.449 at significance of t-test p = 0.173 and confidence level of the study (α) = 0.05. The t-test also indicated that during dry season, there was also no significant difference in the mean concentration of Ni in water from river Thiba (BDL ppm) and in water from river Nyamindi (0.0148±0.0363 ppm), t (11) = -1.068 at significance of t-test p = 0.300 and at the same confidence level of the study (α) = 0.05 (see Appendix VI, VII, VIII and IX).

A two-way ANOVA was run to show the effect of the two rivers (Thiba and Nyamindi) and seasons (rainy and dry) on concentration of Ni in sediment and water. The results revealed that there was no significant interaction between the effect of river and season on the concentration of Ni in sediment, F (1,24) = 2.334, p = 0.140. Similarly, the two-way ANOVA test revealed that there was no significant interaction between the effect of river and season on the Ni concentration in water, F (1,23) = 2.032, p = 0.167 (see Appendix XI and XII).

The results of the various statistical tests run in this section established that the amount of Ni in sediment during dry season was considerably higher than during rainy season in both rivers; there was no reasonable effect of season on the amount of Ni in water of each river; the amount of Ni was reliably higher in sediment than in water during each season; no effect of river in the amount of Ni in sediment and also in water from both rivers during each season; and no considerable interaction was found between river and season on the amount of Ni in sediment and also water at the confidence level of the study (α) = 0.05.

This study reported nickel values that closely agree with Omondi (2017) who reported a mean nickel value of 0.01574 ppm in water from lower river Nzoia and Muiruri *et al.* (2013) who reported nickel values ranging from below limit of detection to 0.062 ppm.

4.2.3.4 Lead in Rivers Thiba and Nyamindi

The amounts of lead in sediment and water during wet and dry season along river Thiba are presented in Table 29.

Table 29: Amount of Lead in Sediment and Water Along River Thiba

Sampling point	Rainy season Sediment	Water	Dry season Sediment	Water
T1	11.4459±0.0083	BDL	10.1497±0.0067	0.0011±0.00003
T2	7.4881±0.0059	0.0085±0.00002	10.2168±0.0044	0.0130±0.00005
T3	10.9152±0.0035	0.0141±0.00005	9.8610±0.0035	0.0038±0.00007
T4	7.5547±0.0062	0.0163±0,00007	0.4760±0.0048	0.0032±0.00008
T5	11.9511±0.0055	0.0024±0.00001	0.2753±0.0015	0.0077±0.00006
T6	8.9350±0.0066	0.0244±0.00002	0.0523±0.0004	(-)
T7	12.9476±0.0055	0.0999±0.00005	0.2682±0.0017	0.0048±0.00004
T8	11.9379±0.0046	0.1243±0.00007	0.6233±0.0049	0.0069±0.00008
Mean	10.3969±2.1160	0.0362±0.0479	3.9903±5.0430	0.0058±0.0039
US EPA Limit	40	0.015	40	0.015

The mean amount of lead in sediment from river Thiba from Kakawa (T1) to Ndiara (T8) was 10.3969±2.1160 mg/kg during rainy season and 3.9903±5.0430 mg/kg during dry season. It was noted that the amount of lead in the sediment in rainy season was about three times higher than that during dry season. It was also noted that all the sampling points had higher amount of lead in sediment during wet season than during dry season except T2. The mean concentration of lead in water along river Thiba course was 0.0362±0.0479 ppm during wet season and 0.0058±0.0039 ppm during dry season. The mean concentration of lead in water during rainy season was more than six times higher than during dry season. It was noted that the sampling points that had relatively higher amount of lead in sediment did not necessarily have a corresponding higher concentration of the same in water.

Independent-sample t-tests were carried out to examine if there were differences in amount of Pb in sediment and also in water from river Thiba during rainy and dry season. The results of the t-test revealed that there was statistically significant difference between mean amount of Pb in river Thiba sediment during rainy season (10.3969±2.1160 mg/kg) compared to during dry season (3.9903±5.0430 mg/kg) t (14) = 3.313 at significance of t-test p = 0.005 and confidence level of the study (α) = 0.05. On the contrary, a t-test indicated that there was no significant difference between the mean concentration of lead in water of river Thiba during rainy season (0.0362±0.0479 ppm) and dry season (0.0058±0.0039 ppm), t (13) = 1.669 at significance of t-test p = 0.119 and confidence level of the study (α) = 0.05 (see Appendix XVII and XVIII).

Further, independent t-test to determine whether there was a difference in the mean concentration of Pb in sediment and water from river Thiba was conducted. The results indicated that during rainy season, there was significant difference in the mean concentration of Pb in sediment (10.3969±2.1160 ppm) and water (0.0362±0.0479 ppm), t (14) = 13.846 at significance of t-test p = 0.001 and confidence level of the study (α) = 0.05. However, the t-test showed that during dry season, there was no significant difference in the mean concentration of Pb in sediment (3.9903±5.0430 ppm) and in water (0.0058±0.0039 ppm), t (13) = -2.080 at significance of t-test p = 0.058 and at the same confidence level of the study (α) = 0.05 (Appendix XIII and XIV).

The amounts of lead in sediment and water during wet and dry season along river Nyamindi are presented in Table 30.

Table 30: Amount of Lead in Sediment and Water Along River Nyamindi

Sampling point	Rainy season Sediment	Water	Dry season Sediment	Water
N1	12.4343±0.0035	0.0097±0.00007	0.1765±0.0018	0.0724±0.00003
N2	11.7891±0.0085	0.0090±0.00004	0.5943±0.0046	0.0044±0.00004
N3	10.8809±0.0027	0.0050±0.00004	0.2351±0.0022	0.0079±0.00007
N4	10.7975±0.0047	0.0339±0.00008	0.4103±0.0056	0.0106±0.00003
N5	9.2169±0.0085	0.0539±0.00006	0.4811±0.0024	0.0112±0.00001
N6	9.3480±0.0075	0.0225±0.00087	0.3712±0.0065	0.0037±0.00002
Mean	10.7445±1.2847	0.0223±0.0210	0.3781±0.1546	0.0184±0.0266
US EPA limit	40	0.015	40	0.015

The average amount of lead in sediment from river Nyamindi from Nyamindi village (N1) to Kiamatero (N6) was 10.7445±1.2847 mg/kg during rainy season and 0.3781±0.1546 mg/kg during dry season. The average amount of lead in sediment during rainy season was about twenty-eight times higher than during dry season. It was noted that all the sampling points had lower amount of lead during dry season than rainy season. On the same course of river Nyamindi, the average concentration of lead in water was 0.0223±0.0210 ppm during rainy season and 0.0184±0.0266 ppm during dry season. The average concentration of lead in river water was found to be slightly higher during rainy season than during dry season. It was also observed that the sampling points that had higher amount of lead in sediment did not necessarily have a corresponding higher concentration of the same metal in water.

Independent-sample t-tests were conducted to examine whether there were differences in amount of Pb in sediment and also in water from river Nyamindi during rainy and dry season. The results established that there was statistically significant difference between mean amount if Pb in river Nyamindi sediment during rainy season (10.7445±1.2847 mg/kg) compared to during dry season (0.3781±0.1546 mg/kg), $t(10) = 19.624$ at significance of t-test $p < 0.001$ and confidence level of the study (α) = 0.05. Unlike in sediment, t-test found that there was no significant difference between the mean concentration of Pb in water of river Nyamindi during rainy season (0.0223±0.0210 ppm) and dry season (0.0184±0.0266 ppm), $t(10) = 1.004$ at significance of t-test $p = 0.339$ and confidence level of the study (α) = 0.05 (see Appendix XVII and XVIII).

A t-test was also carried out to determine whether there was any difference in the mean concentration of Pb in sediment and water from river Nyamindi. The results found that during rainy season, there was significant difference in the mean concentration of Pb in sediment (10.7445±1.2847 ppm) and water (0.0223±0.0210 ppm), t (10) = 8.239 at significance of t-test p = 0.001 and confidence level of the study (α) = 0.05. The t-test also showed that during dry season, there was still significant difference in the mean concentration of Pb in sediment (0.3781±0.1546 ppm) and in water (0.0184±0.0266 ppm), t (10) = -5.616 at significance of t-test p = 0.001 and at the same confidence level of the study (α) = 0.05 (see Appendix XIII and XIV).

Comparing amount of lead in rivers Thiba and Nyamindi, the average amount of lead in the sediment from river Thiba during rainy season was 10.3969±2.1160 mg/kg which was very close to that from river Nyamindi that was 10.7445±1.2847 mg/kg. But during dry season, the average amount of lead in sediment from river Thiba was 3.9903±5.0430 mg/kg which was higher than that from river Nyamindi that was 0.3781±0.1546 mg/kg. The sediments of rivers Thiba and Nyamindi are not polluted with lead metal since the mean amounts of lead were below US EPA permissible limit of 40 mg/kg (Omondi, 2017; Ameh *et al.* 2016). It was observed that the amount of lead in sediment from river Thiba was higher than that from river Nyamindi (during dry season) which concurs with Gathumbi *et al.* (2013) who reported higher amount of lead in sediment from river Thiba compared to that from river Nyamindi. This may be due to the fact that four sections (Mwea, Thiba, Wamumu and Karaba) out of the five main sections of Mwea irrigation scheme lie next to river Thiba so more lead metal may be finding its way from rice farms to the river. However, Gathumbi *et al.* (2013) found higher levels of lead in sediments compared to this study which could be attributed to presence of petrol-powered pumps next to water courses which were initially using leaded petrol (which was being used before that time) that may have been leaking into rivers. The amount of lead reported by Moywaywa (2018) in sediment from Thika river was much higher than what was found in sediments of rivers Thiba and Nyamindi showing that human activities in the current study area have not resulted to much lead pollution in the sediment. This study closely agrees Omondi (2017) who reported a mean of 13 mg/kg of lead in sediment from lower river Nzoia and Jepkoech *et al.* (2013) who reported a range of 0.63-1.27 mg/kg of lead during dry season and 0.75-1.31 mg/kg lead during wet season in sediment from Sosiani river showing that agricultural activities in Kenya so far may not have contributed to lead pollution of river sediment.

During rainy season, average concentration of lead in river Thiba water was 0.0362±0.0479 ppm whereas that from river Nyamindi had lower concentration of 0.0223±0.0210 ppm. During dry season, the mean concentration of lead in river Thiba water was 0.0058±0.0039 ppm and from river Nyamindi was 0.0184±0.0266 ppm. In both rivers, the mean concentration of lead in water was above permissible limit by WHO (0.01 ppm) and US EPA (0.015 ppm) except in river Thiba during dry season but was below WASREB permissible limit of 0.05 ppm (Wasike *et al.,* 2019; Mahmud *et al.,* 2016; WASREB, 2008). This implies that using Kenyan standards, the water of river Thiba and Nyamindi was not polluted by lead.

An independent-samples t-test was run to determine whether the mean concentrations of Pb in sediment and water from rivers Thiba and Nyamindi were statistically significantly different. The results revealed that there was no significant difference in the mean concentration of Pb in sediment from river Thiba (10.3969±2.1160 ppm) and sediment from river Nyamindi (10.7445±1.2847 ppm) during rainy season, t (12) = 0.354 at significance of t-test p = 0.729 and confidence level of the study (α) = 0.05. The t-test also showed that during dry season, there was still no significant difference in the mean concentration of Pb in sediment from river Thiba (3.9903±5.0430 ppm) and in sediment from river Nyamindi (0.3781±0.1546 ppm), t (12) = 1.736 at significance of t-test p = 0.108 and at the same confidence level of the study (α) = 0.05.

Similarly, the t-test results indicated that there was no significant difference in the mean concentration of Pb in water from river Thiba (0.0362±0.0479 ppm) and water from river Nyamindi (0.0223±0.0210 ppm) during rainy season, t (12) = -1.153 at significance of t-test p = 0.271 and confidence level of the study (α) = 0.05. The t-test also established that during dry season, there was also no significant difference in the mean concentration of Pb in water from river Thiba (0.0058±0.0039 ppm) and in water from river Nyamindi (0.0184±0.0266 ppm), t (11) = -1.243 at significance of t-test p = 0.240 and at the same confidence level of the study (α) = 0.05 (see Appendix VI, VII, VIII and IX).

A two-way ANOVA was conducted to show the effect of the two rivers (Thiba and Nyamindi) and seasons (rainy and dry) on concentration of Pb in sediment and water. The results found that there was statistically no significant interaction between the effect of river and season on the concentration of Pb in sediment, $F (1,24) = 2.963$, $p = 0.098$. Similarly, a two-way ANOVA test showed that there was no significant interaction between the effect of river and season on the Pb concentration in water, $F (1,23) = 1.211$, $p = 0.283$ (see Appendix XI and XII).

The results of the various statistical tests determined in this section revealed that there was significantly higher amount of Pb in sediment during rainy season compared to dry season in each of the two rivers; the amount of Pb in water was not affected by the season so there was no difference in the amount during both seasons; there was reliably higher amounts of Pb in sediment than water during rainy season but the amounts were not different during dry season; no effect of river in the amount of Pb in sediment and also in water from the two rivers during each season; and no considerable interaction between river and season on the amount of Pb in sediment and also water at the confidence level of the study (α) = 0.05.

The results in this study are in line with Omondi (2017) who reported a mean value of 0.01494 ppm of Pb in water from lower Nzoia river and Muiruri *et al.* (2013) who reported concentration of up to 0.047 ppm of Pb in water from Athi-Galana-Sabaki tributaries. Tomno (2020) reported lower values of Pb in water from streams of Machakos municipality whereas Jepkoech *et al.* (2013) reported higher values of Pb in water from Sosiani river. However, Wasike *et al.* (2019) reported higher values (1.36-3.36 ppm during wet season and 1.38-1.96 ppm during dry season) of lead concentration in water from river Kuywa and the adjacent wells but reported higher range of values during wet season compared to dry season just as the current study has reported.

4.2.3.5 Zinc in Rivers Thiba and Nyamindi

The amounts of zinc in sediment and water during wet and dry season along river Thiba are given in Table 31.

Table 31: Amount of Zinc in Sediment and Water Along River Thiba

Sampling point	Rainy season		Dry season	
	Sediment	Water	Sediment	Water
T1	37.6893±0.0049	BDL	44.5538±0.0076	BDL
T2	47.1434±0.0044	BDL	32.8121±0.0079	BDL
T3	40.0047±0.0062	BDL	41.0933±0.0093	BDL
T4	40.5509±0.0085	BDL	72.0498±0.0940	BDL
T5	40.9388±0.0075	BDL	76.6965±0.0410	BDL
T6	45.0140±0.0077	BDL	80.5621±0.0280	(-)
T7	50.5437±0.034	BDL	88.9347±0.0260	BDL
T8	38.6149±0.0025	BDL	40.2741±0.0940	BDL
Mean	42.5625±4.5238	BDL	59.6221±22.0622	BDL
WHO limit	123	5.0	123	5.0

The average amount of zinc in sediment from river Thiba from Kakawa (T1) to Ndiara (T8) was 42.5625±4.5238 mg/kg during wet season and 58.6221±22.0622 mg/kg during dry season. In this river, the average amount of zinc in the sediment during dry season was higher than that during wet season. It was noted that all the sampling points had higher amount of zinc in sediment during dry season than during wet season except T2. The mean concentration of zinc in water along rivers Thiba during wet and dry season in the area of study was BDL.

Independent-sample t-tests were carried out to examine whether there were differences in amount of Zn in sediment and also in water from river Thiba during rainy and dry season. The results of the t-test revealed that there was no significant difference between mean amount of Zn in river Thiba sediment during rainy season (42.5625±4.5238 mg/kg) compared to during dry season (59.6221±22.0622 mg/kg) t (14) = 2.143 at significance of t-test p = 0.050 and confidence level of the study (α) = 0.05 (t-crit = 2.145). There was also no difference in concentration of Zn in water of river Thiba during both seasons (all sampling points had concentration of Zn as BDL (see Appendix XVII and XVIII)).

Further, independent t-test to determine whether there was a difference in the mean concentration of Zn in sediment and water from river Thiba was conducted. The results indicated that during rainy season, there was significant difference in the mean concentration of Zn in sediment (42.5625±4.5238 ppm) and water (BDL ppm), t (14) = 26.612 at significance of t-test p = 0.001 and confidence level of the study (α) = 0.05.

The t-test further showed that during dry season, there was still significant difference in the mean concentration of Zn in sediment (59.6221±22.0622 ppm) and in water (BDL ppm), t (13) = -7.116 at significance of t-test p = 0.001 and at the same confidence level of the study (α) = 0.05 (Appendix XIII and XIV).

The amounts of zinc in sediment and water during wet and dry season along river Nyamindi are presented in Table 32.

Table 32: Amount of Zinc in Sediment and Water Along River Nyamindi

Sampling point	Rainy season Sediment	Water	Dry season Sediment	Water
N1	39.1437±0.0043	BDL	76.4621±0.0410	BDL
N2	36.1477±0.0061	BDL	73.5968±0.0780	BDL
N3	32.7516±0.0058	BDL	57.2619±0.0440	BDL
N4	38.4861±0.0092	BDL	54.0231±0.0450	BDL
N5	50.0610±0.0280	BDL	116.5999±0.3850	BDL
N6	54.3880±0.0470	BDL	76.3715±0.0190	BDL
Mean	41.8297±8.4683	BDL	75.7192±20.3638	BDL
WHO limit	123	5.0	123	5.0

The average amount of zinc in sediment from river Nyamindi from Nyamindi village (N1) to Kiamatero (N6) was 41.8297±8.4683 mg/kg during wet season and 75.7192±20.3638 mg/kg during dry season. This average amount was about one and a half times higher during dry season than during wet season. It was observed that the sampling points that had relatively higher amount of zinc during wet season did not necessarily have relatively higher amount during dry season. On the same Nyamindi river course, the concentration of zinc in water was BDL for all sampling points during both wet and dry season.

Independent-sample t-tests were conducted out to examine whether there were differences in amount of Zn in sediment and also in water from river Nyamindi during rainy and dry season. The results established that there was significant difference between mean amount of Zn in river Nyamindi sediment during rainy season (41.8297±8.4683 mg/kg) compared to during dry season (75.7192±20.3638 mg/kg), t (10) = -3.479 at significance of t-test p = 0.006 and confidence level of the study (α) = 0.05. There was no difference in concentration of Zn in water of river Nyamindi since all sampling points had concentration BDL (see Appendix XVII and XVIII).

A t-test was also carried out to determine whether there was any difference in the mean concentration of Zn in sediment and water from river Nyamindi. The results found that during rainy season, there was significant difference in the mean concentration of Zn in sediment (41.8297±8.4683 ppm) and water (BDL ppm), t (10) = 12.099 at significance of t-test p = 0.001 and confidence level of the study (α) = 0.05. The t-test also showed that during dry season, there was still significant difference in the mean concentration of Zn in sediment (75.7192±20.3638 ppm) and in water (BDL ppm), t (10) = -8.314 at significance of t-test p = 0.001 and at the same confidence level of the study (α) = 0.05 (see Appendix XIII and XIV).

Comparing the amounts of zinc in rivers the two rivers, the average amount of zinc in the sediment from river Thiba was 42.5625±4.5238 mg/kg which was almost equal to that from river Nyamindi which was 41.8297±8.4683 mg/kg during wet season. But during dry season, the average amount of zinc in sediment from river Thiba was 59.6221±22.0622 mg/kg and that from river Nyamindi which was 75.7192±20.3638 mg/kg. It was noted that the amount of zinc in sediment from both rivers was higher during dry season than during wet season. It was noted that the amount of zinc in sediment from both river Thiba and Nyamindi and during both wet and dry seasons was below the permissible limit by WHO and US EPA which is set at 123 mg/kg and 110 mg/kg, respectively (Ameh *et al.*, 2016; Samlafo, 2006). This current study therefore found that sediment from rivers Thiba and Nyamindi is not polluted with zinc. This study obtained values similar to those obtained by Omondi (2017) who reported zinc values ranging from 40-100 mg/kg in sediment from lower river Nzoia. However, Moywaywa (2018) reported higher mean amount of zinc (198 mg/kg) in sediment from Thika river implying that Thika river may be more polluted than rivers Thiba and Nyamindi and Jepkoech *et al.* (2013) reported much lower values of zinc in sediment (between 2.79-6.73 mg/kg) but obtained higher values in dry season compared to wet season which agrees with the current study. This study is coherent with Ebah *et al.* 2016 who reported higher amounts of zinc in sediment during dry season than during wet season.

It was conspicuously noted that the concentration of zinc in river water from all sampling points of both rivers Thiba and Nyamindi during wet and dry season was

BDL. This shows that sediment in these rivers may have been acting as sink for zinc ions that may have been getting into the rivers. This study therefore found that river Thiba and Nyamindi are not polluted with zinc.

Independent-samples t-tests were conducted to determine whether the mean concentrations of Zn in sediment and water from rivers Thiba and Nyamindi were statistically significantly different. The results revealed that there was no significant difference in the mean concentration of Zn in sediment from river Thiba (42.5625±4.5238 ppm) and sediment from river Nyamindi (41.8297±8.4683 ppm) during rainy season, t (12) = 0.210 at significance of t-test p = 0.837 and confidence level of the study (α) = 0.05. The t-test also showed that during dry season, there was still no significant difference in the mean concentration of Zn in sediment from river Thiba (59.6221±22.0622 ppm) and in sediment from river Nyamindi (75.7192±20.3638 ppm), t (12) = -1.345 at significance of t-test p = 0.204 and at the same confidence level of the study (α) = 0.05. There were no differences in mean concentrations of Zn in water from rivers Thiba and Nyamindi during rainy and dry seasons since the values obtained from all sampling points were BDL (see Appendix VI, VII, VIII and IX).

Two-way ANOVA was conducted to show the effect of the two rivers (Thiba and Nyamindi) and seasons (rainy and dry) on concentration of Zn in sediment. The results found that there was no significant interaction between the effect of river and season on the concentration of Zn in sediment, F (1,24) = 1.822, p = 0.190 (see Appendix XI and XII).

The results of the various statistical tests run in this section indicated that there was no effect of season in the amount of Zn in sediment of river Thiba but the Zn amount in river Nyamindi was reasonably higher during dry season compared to rainy season; there was no seasonal effect in the amount of Zn in water of both rivers; there was reasonably higher amounts of Zn in sediment compared to water during each season in both rivers; no effect of river in the amount of Zn in sediment and also in water from the two rivers during each season; and no considerable interaction existed between the river and the season on the amount of Zn in sediment and also water at the confidence level of the study (α) = 0.05. However, this study does not concur with Idiriah *et al.*

(2012), Omondi (2017), Mustafa (2019) and Tomno *et al.* (2020) who reported higher values in river water from their study areas. Possibly, their study areas were more zinc polluted or the sediments were not very efficient in acting as zinc ions sink.

4.2.3.6 Arsenic in Rivers Thiba and Nyamindi

The amounts of arsenic in sediment and water during wet and dry season along river Thiba are given in Table 33.

Table 33: Amount of Arsenic in Sediment and Water Along River Thiba

Sampling point	Rainy season Sediment	Water	Dry season Sediment	Water
T1	2.1545±0.0035	0.0001±0.00001	3.0697±0.0084	0.0001±0.00002
T2	2.2127±0.0045	0.0060±0.00003	2.3750±0.0085	BDL
T3	2.2169±0.0052	0.0048±0.00004	2.2627±0.0063	BDL
T4	1.9632±0.0076	0.0025±0.00005	3.0223±0.0055	0.0000
T5	2.3875±0.0045	0.0003±0.00006	2.8875±0.0044	0.0000
T6	2.2252±0.0065	0.0020±0.00005	3.4536±0.0064	(-)
T7	2.5497±0.0094	0.0004±0.00003	3.0955±0.0081	0.0001±0.00008
T8	2.6786±0.0081	0.0001±0.00008	2.5025±0.0093	0.0000
Mean	2.2985±0.2293	0.0020±0.0023	2.8336±0.4128	0.00003±0.00005
US EPA limit	3	0.01	3	0.01

The mean amount of arsenic in sediment from river Thiba from Kakawa (T1) to Ndiara (T8) was 2.2985±0.2293 mg/kg during wet season and 2.8336±0.4128 mg/kg during dry season. The average amount of arsenic in the sediment during dry season was a little higher than during wet season. The mean concentration of arsenic in water along river Thiba course was 0.0020±0.0023 ppm during wet season which was far much higher than that during dry season that was 0.00003±0.00005 ppm. In fact, during wet season, arsenic concentration in river Thiba water was over 60 times more than during dry season although in both cases the concentration was very low. It was also observed that the sampling points that had higher amount of arsenic in sediment did not necessarily have a corresponding higher concentration of the same in water.

Independent-sample t-tests were run to determine if there were significant differences in amount of As in sediment and also in water from river Thiba during rainy and dry season. The results of the t-test established that there was statistically reliable difference between mean amount of As in river Thiba sediment during rainy season

(2.2985±0.2293 mg/kg) compared to during dry season (2.8336±0.4128 mg/kg) t (14) = -3.205 at significance of t-test p = 0.006 and confidence level of the study (α) = 0.05. Similarly, the t-test revealed that there was still a reliable difference between the mean As concentration in water of river Thiba during rainy season (0.0020±0.0023 ppm) and dry season (0.00003±0.00005 ppm), t (13) = 2.278 at significance of t-test p = 0.040 and confidence level of the study (α) = 0.05 (see Appendix XVII and XVIII).

Further, independent t-test to determine whether there was a difference in the mean concentration of As in sediment and water from river Thiba was conducted. The results found that during rainy season, there was significant difference in the mean concentration of As in sediment (2.2985±0.2293 ppm) and water (0.0020±0.0023 ppm), t (14) = 28.326 at significance of t-test p = 0.001 and confidence level of the study (α) = 0.05. The t-test further revealed that during dry season, there was still significant difference in the mean concentration of As in sediment (2.8336±0.4128 ppm) and in water (0.00003±0.00005 ppm), t (13) = -18.072 at significance of t-test p = 0.001 and at the same confidence level of the study (α) = 0.05 (Appendix XIII and XIV).
The amounts of arsenic in sediment and water during wet and dry season along river Nyamindi are given in Table 34.

Table 34: Amount of Arsenic in Sediment and Water Along River Nyamindi

Sampling point	Rainy season Sediment	Water	Dry season Sediment	Water
N1	2.3084±0.0073	0.0000	3.8040±0.0071	0.0000
N2	2.3708±0.0063	0.0001±0.00006	2.8914±0.0033	0.0001±0.00002
N3	2.2918±0.0092	0.0001±0.00007	2.7489±0.0058	0.0000
N4	2.4706±0.0033	0.0009±0.00007	2.6180±0.0045	0.0001±0.00001
N5	2.5455±0.0023	0.0000	2.8336±0.0044	0.0000
N6	2.7494±0.0051	0.0001±0.00004	3.1725±0.0068	0.0000
Mean	2.4561±0.1734	0.0002±0.0003	3.0114±0.4298	0.00003±0.00005
US EPA limit	3	0.01	3	0.01

The mean amount of arsenic in sediment from river Nyamindi from Nyamindi village (N1) to Kiamatero (N6) was 2.4561±0.1734 mg/kg during wet season and 3.0114±0.4298 mg/kg during dry season. The mean amount of arsenic was slightly higher during dry season compared to wet season. The sampling points that had relatively higher amount of arsenic in sediment during wet season did not necessarily have higher amount during dry season. On the same course of river Nyamindi, the average concentration of arsenic in water was 0.0002±0.0003 ppm during wet season and 0.00003±0.00005 ppm during dry season. The concentration of arsenic in river Nyamindi water was found to be over six times higher during wet season than during dry season. It was also observed that the sampling points that had higher amount of arsenic in sediment did not necessarily have higher concentration of the same in water.

Independent-sample t-tests were carried out to determine whether there were differences in amount of As in sediment and also in water from river Nyamindi during rainy and dry season. The results of the t-test indicated that there was statistically significant difference between mean As amount in river Nyamindi sediment during rainy season (2.4561±0.1734 mg/kg) compared to during dry season (3.0114±0.4298 mg/kg), t (10) = -2.935 at significance of t-test p = 0.015 and confidence level of the study (α) = 0.05. However, results of a similar t-test established that there was no statistically significant difference between the mean As concentration in water of river Nyamindi during rainy season (0.0002±0.0003 ppm) and dry season (0.00003±0.00005), t (10) = 1.129 at significance of t-test p = 0.285 and confidence level of the study (α) = 0.05 (see Appendix XVII and XVIII).

An independent sample t-test was also conducted to examine whether there was any difference in the mean concentration of As in sediment and water from river Nyamindi. The results found that during rainy season, there was significant difference in the mean concentration of As in sediment (2.4561±0.1734 ppm) and water (0.0002±0.0003 ppm), t (10) = 34.698 at significance of t-test p = 0.001 and confidence level of the study (α) = 0.05. The t-test also indicated that during dry season, there was still significant difference in the mean concentration of As in sediment (3.0114±0.4298 ppm) and in water (0.00003±0.00005 ppm), t (10) = -17.161 at significance of t-test p = 0.001 and at the same confidence level of the study (α) = 0.05 (see Appendix XIII and XIV).

Comparing the amount of arsenic in rivers Thiba and Nyamindi, the average amount in the sediment from river Thiba was 2.2985±0.2293 mg/kg which was almost equal to that from river Nyamindi that was 2.4561±0.1734 mg/kg during wet season. During dry season, the average amount of arsenic in sediment from river Thiba was 2.8336±0.4128 mg/kg which was close to that from river Nyamindi which was 3.0114±0.4298 mg/kg. The mean amount of arsenic in sediment from river Thiba during wet and dry season and in sediment from river Nyamindi during wet season was below US EPA permissible limit that is set at 3 mg/kg (Ameh *et al.,* 2016). However, the mean amount of arsenic in sediment from river Nyamindi during dry season was slightly above the US EPA limit implying that river Nyamindi sediment may be slightly polluted with arsenic during dry season. This study does not align with Omondi (2017) who reported a mean of 10 mg/kg in sediment from lower river Nzoia which implies that rivers Thiba and Nyamindi may be less polluted with arsenic compared to lower river Nzoia.

During wet season, the average concentration of arsenic in river Thiba water was 0.0020±0.0023 ppm which was higher than that in water from river Nyamindi which had an average of 0.0002±0.0003 ppm during wet season. Interestingly, the mean concentration of arsenic in river Thiba and river Nyamindi water was exactly equal (0.00003±0.00005 ppm) during dry season. It was noted that the concentration of arsenic in both rivers water quite low in the study area and was below the US EPA and WHO/WASREB permissible limit of 0.01 and 0.05 ppm respectively. This shows that the water of river Thiba and Nyamindi is not polluted with arsenic.

An independent-samples t-test was conducted to examine whether the mean concentrations of As in sediment and water from rivers Thiba and Nyamindi were statistically significantly different. The results revealed that there was no significant difference in the mean concentration of As in sediment from river Thiba (2.2985±0.2293 ppm) and sediment from river Nyamindi (2.4561±0.1734 ppm) during rainy season, t (12) = -1.404 at significance of t-test p = 0.186 and confidence level of the study (α) = 0.05. The t-test also showed that during dry season, there was still no significant difference in the mean concentration of As in sediment from river Thiba (2.8336±0.4128 ppm) and in sediment from river Nyamindi (3.0114±0.4298 ppm), t (12) = -0.184 at significance of t-test p = 0.448 and at the same confidence level of the study (α) = 0.05.

Similarly, the t-test results revealed that there was no significant difference in the mean concentration of As in water from river Thiba (0.0020±0.0023 ppm) and water from river Nyamindi (0.0002±0.0003 ppm) during rainy season, t (12) = 1.922 at significance of t-test p = 0.079 and confidence level of the study (α) = 0.05. The t-test also showed that during dry season, there was also no significant difference in the mean concentration of As in water from river Thiba (0.00003±0.00005 ppm) and in water from river Nyamindi (0.00003±0.00005 ppm), t (11) = -0.145 at significance of t-test p = 0.887 and at the same confidence level of the study (α) = 0.05 (see Appendix VI, VII, VIII and IX).

A two-way ANOVA was conducted to show the effect of the two rivers (Thiba and Nyamindi) and seasons (rainy and dry) on concentration of As in sediment and water. The results showed that there was statistically no significant interaction between the effect of river and season on the concentration of As in sediment, F (1,24) = 0.006, p = 0.937. Similarly, a two-way ANOVA test showed that there was no significant interaction between the effect of river and season on the As concentration in water, F (1,23) = 3.424, p = 0.077 (see Appendix XI and XII).

The results of the various statistical tests conducted in this section indicated that there was considerable difference in the amount of As in sediment of river Thiba and also of river Nyamindi during rainy and dry season; there was seasonal effect in the amount of As in water of river Thiba but no such difference in water of river Nyamindi; there was discernible higher amounts of As in sediment compared to water during each season in each of the rivers; and no considerable interaction was found between the river and the season on the amount of As in sediment and also water at the confidence level of the study (α) = 0.05. This study does not align with findings of Mustafa (2019) who reported mean values of 1.88 and 3.96 ppm in irrigation water in Lahore and Gujranwala rice growing areas respectively in Punjab, Pakistan. This shows that water from these areas of Pakistan may be highly polluted with arsenic unlike Mwea irrigation scheme.

4.2.3.7 Manganese in Rivers Thiba and Nyamindi

The amounts of manganese in sediment and water during wet and dry season along river Thiba are presented in Table 35.

Table 35: Amount of Manganese in Sediment and Water Along River Thiba

Sampling point	Rainy season Sediment	Water	Dry season Sediment	Water
T1	1538.3773±2.7220	0.0177±0.00002	1844.6100±2.5180	0.0096±0.00001
T2	1431.7761±0.4360	3.2295±0.00043	1597.5113±2.6710	0.0040±0.00003
T3	2193.8618±6.5110	3.4972±0.00035	1851.5847±6.2820	0.0093±0.00004
T4	1604.0594±3.1030	1.5181±0.00022	1791.4658±2.3060	0.0037±0.00006
T5	1645.1722±1.8180	0.2879±0.00014	1862.6627±4.5260	0.0066±0.00006
T6	2122.8698±7.2650	1.4682±0.00044	1758.8775±4.4860	(-)
T7	1672.4769±2.8490	0.2959±0.00048	1745.5984±3.6280	0.0083±0.00005
T8	1610.5140±1.8920	0.0183±0.00003	1672.4425±1.8070	0.0085±0.00008
Mean	1727.3884±276.6533	1.2916±1.4115	1665.5941±93.4295	0.0071±0.0024
Limit	300	0.1	300	0.1

The average amount of manganese in sediment from river Thiba from Kakawa (TI) to Ndiara (T8) was 1727.3884±276.6533 mg/kg during wet season and 1665.5941±93.4295 mg/kg during dry season. In this river, the average amounts of manganese in the sediment during wet and dry season were almost equal. The mean concentration of manganese in water along river Thiba course was 1.2916±1.4115 ppm during wet season and 0.0071±0.0024 ppm during dry season. The amount of manganese in sediment did not appear to influence the relative concentration of the same metal in the river water at the same sampling point.

Independent-sample t-tests were run to determine if there were significant differences in amount of Mn in sediment and also in water from river Thiba during rainy and dry season. The results of the t-test established that there was no statistically reliable difference between mean amount of Mn in river Thiba sediment during rainy season (1727.3884±276.6533 mg/kg) compared to during dry season (1665.5941±93.4295 mg/kg) $t(14) = -0.370$ at significance of t-test $p = 0.717$ and confidence level of the study (α) = 0.05. On the other hand, t-test revealed that there was statistically reliable difference between the mean Mn concentration in water of river Thiba during rainy season (1.2916±1.4115 ppm) and dry season (0.0071±0.0024 ppm), $t(13) = 2.396$ at significance of t-test $p = 0.032$ and confidence level of the study (α) = 0.05 (see Appendix XVII and XVIII). Further, independent t-test to determine whether there was a difference in the mean concentration of Mn in sediment and water from river Thiba was conducted. The results found that during rainy season, there was significant difference in the mean concentration of Mn in sediment (1727.3884±276.6533 ppm) and water (1.2916±1.4115 ppm), $t(14) = 17.646$ at significance of t-test $p = 0.001$ and confidence level of the study (α) = 0.05. The t-test further revealed that during dry season, there was still significant difference in the mean concentration of Mn in sediment (1665.5941±93.4295 ppm) and in water (0.0071±0.0024 ppm), t (13) = -49.759 at significance of t-test p = 0.001 and at the same confidence level of the study (α) = 0.05 (Appendix XIII and XIV).

The amounts of manganese in sediment and water during wet and dry season along river Nyamindi are presented in Table 36.

Table 36: Amount of Manganese in Sediment and Water Along River Nyamindi

Sampling point	Rainy season Sediment	Water	Dry season Sediment	Water
N1	1466.3647±0.8170	0.0327±0.00005	2208.4804±7.2440	0.0095±0.00007
N2	1529.8162±1.8480	0.0286±0.00005	1586.2441±1.0960	0.0074±0.00009
N3	1385.3230±0.7770	0.0673±0.00002	1609.8181±2.7210	0.0074±0.00003
N4	1184.3248±0.7970	0.5268±0.00047	1556.9655±4.2840	0.0114±0.00002
N5	3130.7051±9.2440	0.1245±0.00003	1603.2709±3.8040	0.0050±0.00008
N6	1823.1723±2.5860	0.0473±0.00006	1721.7379±5.7410	0.0073±0.00002
Mean	1753.5587±706.1931	0.1379±0.1937	1714.4195±248.4616	0.0080±0.0022
Limit	300	0.1	300	0.1

The average amount of manganese in sediment from river Nyamindi from Nyamindi village (N1) to Kiamatero (N6) was 1753.5587±706.1931 mg/kg during wet season and 1714.4195±248.4116 mg/kg during dry season. The average amount of manganese in sediment was almost equal during both seasons. On the same river Nyamindi course, the average concentration of manganese in water was 0.1379±0.1937 ppm during wet season which was much higher than the concentration during dry season which was 0.0080±0.0022 ppm. It was noted that the sampling points that had higher amount of manganese in sediment did not necessarily have higher concentration of the same metal in water.

Independent-sample t-tests were carried out to determine whether there were differences in amount of Mn in sediment and also in water from river Nyamindi during rainy and dry season. The results of the t-test indicated that there was no reliable difference between mean Mn amount in river Nyamindi sediment during rainy season (1753.5587±706.1931 mg/kg) compared to during dry season (1714.4195±248.4616 mg/kg), t (10) = 0.127 at significance of t-test p = 0.901 and confidence level of the study (α) = 0.05. Similarly, results of t-test established that there was no reliable difference between the mean Mn concentration in water of river Nyamindi during rainy season (0.1379±0.1937 ppm) and dry season (0.0080±0.0022 ppm), t (10) = 1.642 at significance of t-test p = 0.162 and confidence level of the study (α) = 0.05 (see Appendix XVII and XVIII).

An independent sample t-test was also conducted to examine whether there was any difference in the mean concentration of Mn in sediment and water from river Nyamindi. The results found that during rainy season, there was significant difference in the mean concentration of Mn in sediment (1753.5587±706.1931 ppm) and water (0.1379±0.1937 ppm), t (10) = 6.081 at significance of t-test p = 0.001 and confidence level of the study (α) = 0.05. The t-test also indicated that during dry season, there was still significant difference in the mean concentration of Mn in sediment (1714.4195±248.4616 ppm) and in water (0.0080±0.0022 ppm), t (10) = -16.902 at significance of t-test p = 0.001 and at the same confidence level of the study (α) = 0.05 (see Appendix XIII and XIV).

Comparing the levels of manganese in rivers Thiba and Nyamindi, the average amount of manganese in the sediment from river Thiba was 1727.3884±276.6533 mg/kg which was very close to that from river Nyamindi which was 1753.2844±706.1931 mg/kg during wet season. Similarly, during dry season, the average amount of manganese in sediment from river Thiba was 1665.5941±93.4295 mg/kg which was close though slightly lower than in sediment from river Nyamindi that was 1714.4195±248.4616 mg/kg. It was therefore noted that the mean amounts of manganese in sediment from rivers Thiba and Nyamindi in the study area was almost equal during both seasons and highly exceeded US EPA permissible limit that is set at 300 mg/kg (Ameh *et al.,* 2016) implying that sediment from these two rivers have high amount of manganese which could be due to high amount that is naturally found in the surrounding soils. This study closely agrees with Omondi (2017) who reported a slightly lower manganese mean of 1163 mg/kg in sediment from lower river Nzoia and Moywaywa (2018) who reported a higher mean of 4817 mg/kg.

During wet season, the average concentration of manganese in river Thiba water was 1.2916±1.4115 ppm which was higher than that in water from river Nyamindi which had an average of 0.1379±0.1937 ppm. During dry season, the mean concentration of manganese in river Thiba water was 0.0071±0.0024 ppm which was almost equal to the concentration in water from river Nyamindi that was 0.0080±0.0022 ppm. It was noted that the concentration of manganese in water in both rivers was higher during wet season than during dry season which may have been as a result of surface runoffs and seepage of water containing manganese from agricultural farms to the rivers. The higher concentration of manganese in water from river Thiba during wet season may be due to the larger rice growing area adjacent to river Thiba compared to river Nyamindi which may have been leading to more runoffs and seepage water containing manganese getting into the river. During rainy season, the mean concentration of manganese in water from both rivers was above WASREB permissible limit of 0.1 ppm (Ameh *et al.,* 2016). However, during dry season, the mean manganese concentration in the water from both rivers was below WASREB permissible limit implying that the water was not polluted with manganese.

An independent-samples t-test was conducted to examine whether the mean concentrations of Mn in sediment and water from rivers Thiba and Nyamindi were statistically significantly different. The results revealed that there was no significant difference in the mean concentration of Mn in sediment from river Thiba (1727.3884±276.6533 ppm) and that from river Nyamindi (1753.5587±706.1931 ppm) during rainy season, $t(12) = -0.095$ at significance of t-test $p = 0.926$ and confidence level of the study (α) = 0.05. The t-test also indicated that during dry season, there was still no significant difference in the mean concentration of Mn in sediment from river Thiba (1665.5941±93.4295 ppm) and in sediment from river Nyamindi (1714.4195±248.4616 ppm), $t(12) = -0.540$ at significance of t-test $p = 0.599$ and at the same confidence level of the study (α) = 0.05.

Similarly, the t-test results showed that there was no significant difference in the mean concentration of Mn in water from river Thiba (1.2916±1.4115 ppm) and water from river Nyamindi (0.1379±0.1937 ppm) during rainy season, $t(12) = 1.977$ at significance of t-test $p = 0.071$ and confidence level of the study (α) = 0.05. The t-test also found that during dry season, there was also no significant difference in the mean concentration of Mn in water from river Thiba (0.0071±0.0024 ppm) and in water from river Nyamindi (0.0080±0.0022 ppm), $t(11) = -0.650$ at significance of t-test $p = 0.529$

and at the same confidence level of the study (α) = 0.05 (see Appendix VI, VII, VIII and IX).

A two-way ANOVA was conducted to show the effect of the two rivers (Thiba and Nyamindi) and seasons (rainy and dry) on concentration of Mn in sediment and water. The results showed that there was statistically no significant interaction between the effect of river and season on the concentration of Mn in sediment, $F (1,24) = 0.072$, $p = 0.791$. Similarly, a two-way ANOVA test found that there was no significant interaction between the effect of river and season on the Mn concentration in water, $F (1,23) = 3.608$, $p = 0.070$ (see Appendix XI and XII).

The results of the various statistical tests run in this section indicated that there was no effect of season in the amount of Mn in sediment of river Thiba or river Nyamindi during rainy season and dry; there was seasonal difference in the amount of Mn in water of river Thiba but no difference in water of river Nyamindi; there was significantly higher amounts of Mn in sediment relative to the water during each season and in both rivers; no effect of river in the amount of Mn in sediment and also in water between the two rivers during each season; and no reliable interaction was found between the river and the season on the amount of Mn in sediment and also water at the confidence level of the study (α) = 0.05.

The results of the current study aligns with Moywaywa (2018) who reported manganese mean concentration of 0.179 ppm in water from Thika river and Omondi (2017) who reported a mean concentration of 0.078 ppm in water from lower river Nzoia. The present study is also in line with Wasike *et al.* (2019) who reported manganese concentration of 0.13-0.20 ppm in water during wet season and 0.12-0.14 ppm during dry season which showed that the concentration was lower during dry season just as in the current study. In the current study and those of Moywaywa (2018) and Omondi (2017), the amount of manganese in sediment was very high yet the concentration of the same in water was comparatively very low which shows that sediment is an effective sink for manganese.

4.2.3.8 Selenium in Rivers Thiba and Nyamindi

The amounts of selenium in sediment and water during wet and dry season along river Thiba are presented in Table 37.

Table 37: Amount of Selenium in Sediment and Water Along River Thiba

Sampling point	Rainy season Sediment	Water	Dry season Sediment	Water
T1	5.8593±0.0032	BDL	4.7253±0.0077	BDL
T2	4.4417±0.0025	0.0138±0.00003	5.3868±0.0039	BDL
T3	5.4813±0.0033	0.0092±0.00002	4.0637±0.0066	BDL
T4	4.8198±0.0072	BDL	8.0700±0.0066	BDL
T5	7.1824±0.0046	0.0004±0.00008	6.1489±0.0054	BDL
T6	3.7801±0.0025	0.0058±0.00007	8.4542±0.0085	(-)
T7	6.0483±0.0092	BDL	7.0130±0.0055	0.0000
T8	5.8593±0.0075	BDL	5.6681±0.0037	BDL
Mean	5.4340±1.0620	0.0037±0.0054	6.1913±1.5549	BDL
Limit	2.5	0.01	2.5	0.01

The mean amount of selenium in sediment from river Thiba from Kakawa (T1) to Ndiara (T8) was 5.4340±1.0620 mg/kg during wet season and 6.1913±1.5549 mg/kg during dry season. In this river, the average amount of selenium in the sediment during dry season was slightly higher than during wet season. The mean concentration of selenium in water along river Thiba course was 0.0037±0.0054 ppm during wet season which was higher than that during dry season which was BDL. It was observed that the sampling points that had higher amount of selenium in sediment did not necessarily have a corresponding higher concentration of the same in water.

Independent-sample t-tests were conducted to examine if there were significant differences in amount of Se in sediment and also in water from river Thiba during rainy and dry season. The results of the t-test established that there was no significant difference between mean amount of Se in river Thiba sediment during rainy season (5.4340±1.0620 mg/kg) compared to during dry season (6.1913±1.5549 mg/kg) $t(14) = -1.137$ at significance of t-test $p = 0.274$ and confidence level of the study (α) = 0.05. Similarly, a t-test revealed that there was no significant difference between the mean Se concentration in water of river Thiba during rainy season (0.0037±0.0054 ppm) and dry season (0.0000 ppm), $t(13) = 1.784$ at significance of t-test $p = 0.098$ and confidence level of the study (α) = 0.05 (see Appendix XVII and XVIII).

Further, independent t-test to examined whether there was a difference in the mean concentration of Se in sediment and water from river Thiba was conducted. The results found that during rainy season, there was significant difference in the mean concentration of Se in sediment (5.4340±1.0620 ppm) and water (0.0037±0.0054 ppm), t (14) = 14.462 at significance of t-test p = 0.001 and confidence level of the study (α) = 0.05. The t-test further showed that during dry season, there was still significant difference in the mean concentration of Se in sediment (6.1913±1.5549 ppm) and in water (0.0000 ppm), t (13) = -10.485 at significance of t-test p = 0.001 and at the same confidence level of the study (α) = 0.05 (Appendix XIII and XIV).

The amounts of selenium in sediment and water during wet and dry season along river Nyamindi are given Table 38.

Table 38: Amount of Selenium in Sediment and Water Along River Nyamindi

Sampling point	Rainy season Sediment	Water	Dry season Sediment	Water
N1	6.6153±0.0045	BDL	5.6681±0.0071	BDL
N2	6.8043±0.0066	BDL	7.8777±0.0034	0.0002±0.00001
N3	5.2923±0.0057	BDL	7.5895±0.0051	BDL
N4	4.6308±0.0028	0.0000	6.0524±0.0092	BDL
N5	4.4418±0.0043	BDL	6.3406±0.0056	BDL
N6	6.8043±0.0044	BDL	5.7642±0.0085	BDL
Mean	5.7648±1.1085	BDL	6.5488±0.9518	0.00003±0.00008
Limit	2.5	0.01	2.5	0.01

The average amount of selenium in sediment from river Nyamindi from Nyamindi village (NI) to Kiamatero (N6) was 5.7648±1.1085 mg/kg during wet season and 6.5488±0.9518 mg/kg during dry season. The average amount of selenium in sediment was slightly higher during dry season compared to wet season. It was noted that the sampling points that had relatively higher amount of selenium during wet season did not necessarily have higher amount during dry season. On the same course of river Nyamindi, the concentration of selenium in river water from all sampling points was BDL during both wet and dry season except point N2 during dry season which had a very low concentration of 0.0002±0.00001 ppm. The concentration of selenium in river Nyamindi water may be said to be generally very low.

Independent-sample t-tests were carried out to examine whether there were differences in amount of Se in sediment and also in water from river Nyamindi during rainy and dry season. The results of the t-test indicated that there was no statistically significant difference between mean amount of Se in river Nyamindi sediment during rainy season (5.7648±1.1085 mg/kg) compared to during dry season (6.5488±0.9518 mg/kg), t (10) = -1.314 at significance of t-test p = 0.218 and confidence level of the study (α) = 0.05. A similar t-test established that there was still no statistically significant difference between the mean concentration of Se in water of river Nyamindi during rainy season (0.0000 ppm) and dry season (0.00003±0.00008 ppm), t (10) = -1.000 at significance of t-test p = 0.363 and confidence level of the study (α) = 0.05 (see Appendix XVII and XVIII).

Independent sample t-test was also run to examine whether there was any difference in the mean concentration of Se in sediment and water from river Nyamindi. The results found that during rainy season, there was significant difference in the mean concentration of Se in sediment (5.7648±1.1085 ppm) and water (0.0000 ppm), t (10) = 12.738 at significance of t-test p = 0.001 and confidence level of the study (α) = 0.05. The t-test also found that during dry season, there was still significant difference in the mean concentration of Se in sediment (6.5488±0.9518 ppm) and in water (0.00003±0.00008 ppm), t (10) = -16.852 at significance of t-test p = 0.001 and at the same confidence level of the study (α) = 0.05 (see Appendix XIII and XIV).

Comparing amounts from both rivers Thiba and Nyamindi, the average amount of selenium in the sediment from river Thiba was 5.4340±1.0620 mg/kg which was almost equal to that from river Nyamindi which was 5.7648±1.1085 mg/kg during wet season. During dry season, the average amount of selenium in sediment from river Thiba was 6.1913±1.5549 mg/kg which was very close to that from river Nyamindi which was 6.5488±0.9518 mg/kg. It was observed that the mean amount of selenium in sediment from rivers Thiba and Nyamindi was almost equal during each season, was a little higher during dry season compared to wet season and was slightly higher in river Nyamindi compared to river Thiba. In both rivers and during both seasons, the amount of selenium in sediment was above 2.5 mg/kg threshold limit proposed by Van Derveer & Canton (2009).

The average concentration of selenium in river Thiba water was 0.0037±0.0054 ppm which was higher than that in water from river Nyamindi which had concentration BDL. During dry season, the mean concentration of selenium in both rivers water was BDL except N2 which very low concentration. In the two rivers and during both seasons, the concentration of selenium in water was below WASREB, WHO and US EPA permissible limits of 0.01, 0.04 and 0.05 ppm respectively (Wasike *et al.,* 2019; Mahmud *et al.,* 2016; WASREB, 2008) implying that the two rivers water was not selenium polluted.

An independent-samples t-test was conducted to determine whether the mean concentrations of Se in sediment and water from rivers Thiba and Nyamindi were statistically significantly different. The results revealed that there was no significant difference in the mean concentration of Se in sediment from river Thiba (5.4340±1.0620 ppm) and sediment from river Nyamindi (5.7648±1.1085 ppm) during rainy season, t (12) = -0.566 at significance of t-test p = 0.582 and confidence level of the study (α) = 0.05. The t-test also showed that during dry season, there was still no significant difference in the mean concentration of Se in sediment from river Thiba (6.1913±1.5549 ppm) and in sediment from river Nyamindi (6.5488±0.9518 ppm), t (12) = -0.495 at significance of t-test p = 0.629 and at the same confidence level of the study (α) = 0.05.

Similarly, the t-test results indicated that there was no significant difference in the mean concentration of Se in water from river Thiba (0.0037±0.0054 ppm) and water from river Nyamindi (5.7648±1.1085 ppm) during rainy season, t (12) = -0.345 at significance of t-test p = 0.734 and confidence level of the study (α) = 0.05. The t-test also found that during dry season, there was also no significant difference in the mean concentration of Se in water from river Thiba (0.0000 ppm) and in water from river Nyamindi (0.00003±0.00008 ppm), t (11) = -1.088 at significance of t-test p = 0.300 and at the same confidence level of the study (α) = 0.05 (see Appendix VI, VII, VIII and IX).

A two-way ANOVA was run to show the effect of the two rivers (Thiba and Nyamindi) and seasons (rainy and dry) on concentration of Se in sediment and water. The results revealed that there was statistically no significant interaction between the effect of river and season on the concentration of Se in sediment, F (1,24) = 0.001, p = 0.977. Similarly, a two-way ANOVA test established that there was no significant interaction between the effect of river and season on the Se concentration in water, F (1,23) =2.553, p = 0.124 (see Appendix XI and XII).

The results of the various statistical tests conducted in this section revealed that there was no influence of season in the amount of Se in sediment or in water of river Thiba or river Nyamindi during each of the season; there was considerable higher amounts of Se in sediment compared to the water during each season and in both rivers; there was no influence of the river in the amount of Se present in sediment or in water between the two rivers during each season; and no discernible interaction was detected between the river and the season on the amount of Se in sediment or in water at the confidence level of the study (α) = 0.05.

The present study is in line with Njuguna *et al.* (2021) who reported selenium concentration BDL from all sampled sites on Ewaso Nyiro river surface water. The present study also aligns with Minuye *et al.* (2020) who reported selenium values ranging from 0.0031- 0.007 ppm in selected waters of Ethiopian rivers.

4.2.3.9 Summary of the Amounts of the Selected Heavy Metals in Sediment and Water from Rivers Thiba and Nyamindi

Section 4.2.3 has tabulated and discussed the amounts of Cd, Cr, Ni, Pb, Zn, As, Mn and Se in sediment and water from rivers Thiba and Nyamindi during wet and dry season. The sampling points were from Kakawa (T1) to Ndiara (T8) along river Thiba and from Nyamindi village (N1) to Kiamatero (N6) along river Nyamindi. The mean values are summarized in Table 39.

Table 39: Summary of the Mean Amount of Heavy Metals in Sediment and Water from Rivers Thiba and Nyamindi

HM	River	Sediment		Water	
		Wet season	Dry season	Wet season	Dry season
Cd	T	0.0992±0.0273	0.0689±0.0273	0.0001±0.0002	BDL
	N	0.0882±0.0627	0.0590±0.0235	0.00005±0.00008	BDL
Cr	T	40.3216±5.9484	44.6644±12.1173	0.0732±0.0714	BDL
	N	40.1219±9.3900	39.1176±4.1944	0.0167±0.0271	0.0005±0.0007
Ni	T	86.4723±19.3915	381.4318±268.4397	0.9147±1.1771	BDL
	N	91.7718±25.2196	599.0917±52.0464	0.1943±0.3071	BDL
Pb	T	10.3969±2.1160	3.9903±5.0430	0.0362±0.0479	0.0058±0.0039
	N	10.7445±1.2847	0.3781±0.1546	0.0223±0.0210	0.0184±0.0266
Zn	T	42.5625±4.5238	59.6221±22.0622	BDL	BDL
	N	41.8297±8.4683	75.7192±20.3638	BDL	BDL
As	T	2.2985±0.2293	2.8336±0.4128	0.0020±0.0023	0.00003±0.00005
	N	2.4561±0.1734	3.0114±0.4298	0.0002±0.0003	0.00003±0.00005
Mn	T	1727.3884±276.6533	1665.5941±93.4295	1.2916±1.4115	0.0071±0.0024
	N	1753.2844±706.1931	1714.4195±248.4616	0.1379±0.1937	0.0080±0.0022
Se	T	5.4340±1.0620	6.1913±1.5549	0.0037±0.0054	BDL
	N	5.7648±1.1085	6.5488±0.9518	BDL	0.00003±0.00008

Key: HM- Heavy metal; T- Thiba; N- Nyamindi; BDL- below detection limit

The present study found that the highest heavy metal concentration in sediment from both rivers was of Mn and the lowest was of Cd. There was generally no pattern in the concentration trends upstream for all the metals during both seasons and along both rivers Thiba and Nyamindi. It was interestingly observed that out of the eight heavy metals studied, only Zn had concentrations BDL in water in both rivers and during both seasons. The mean amounts of all the studied heavy metals were almost equal (in magnitude) in sediment from both rivers Thiba and Nyamindi during wet season. During dry season, both rivers had sediments which were almost equal in the amounts of the studied heavy metals except Ni which was higher in river Nyamindi, Pb was higher in river Thiba and Zn was slightly higher in river Nyamindi. It was also found that the amount of Cd, Pb and Mn in sediment were higher during wet season compared to dry season; Cr amount was almost equal during both seasons and; Ni, Zn, As and Se amount were higher during dry season compared to wet season.

The current study found that for rivers Thiba and Nyamindi during wet and dry seasons, the concentrations of Cd, Pb, Zn and As (except for As in river Nyamindi during dry season) were below the upper limits set by World Health Organization (WHO) and United States Environmental Protection Agency (US EPA) for sediments that are not polluted. However, Cr, Ni and Mn concentrations in rivers Thiba and Nyamindi were above WHO and US EPA limits of the heavy metals in sediment which are set as 0.6, 25, 16, 40, 110, 3, and 300 mg/kg for Cd, Cr, Ni, Pb, Zn, As and Mn respectively (Omondi, 2017; Ameh *et al.,* 2016; Samlafo, 2006). It was found that the concentration of the studied heavy metals in river water was higher during wet season compared to dry season which may be due to discharge from surrounding and upstream farms, urban centres, human settlements and other human activities. It was noted that water from both rivers had almost equal mean concentrations of all the studied heavy metals during dry season but during wet season, river Thiba water was found to have higher mean concentration of Cr, Ni and Mn and slightly higher concentration of Pb and As than river Nyamindi water. Generally, river Thiba water was found to have slightly elevated mean concentrations of heavy metals compared to river Nyamindi during wet season. This may be attributed to larger rice growing area that is adjacent to river Thiba compared to that adjacent to river Nyamindi (four out of five main rice growing areas which are Mwea, Thiba, Wamumu and Karaba are adjacent to river Thiba leaving only

Tebere section adjacent to river Nyamindi) and so more water through surface runoffs and seepage may be getting into river Thiba which carry with it heavy metals from rice farms to the river. During wet season, the mean concentration of Cd, Pb, Zn, As and Se in rivers Thiba and Nyamindi obtained in this study were lower than the upper limit set by WHO and KEBS/WASREB for drinking water which are set as 0.005, 0.05, 5.0, 0.05 and 0.01 ppm for Cd, Pb, Zn, As and Se respectively. At the same time, the mean concentration of Cr and Mn in water from river Thiba during wet season was found to be above the WHO, US EPA and KEBS/WASREB limit that has been set as 0.05 and 0.50 ppm for Ni and Mn respectively. The mean concentration of Ni was higher than WHO upper limit that is set at 0.1 ppm in both rivers Thiba and Nyamindi during rainy season. This suggests that during rainy season, water from rivers Thiba and Nyamindi may not be fit for direct drinking from the rivers since the concentrations of Cr, Ni and Mn are above the recommended upper limits (Wasike *et al.,* 2019; Mahmud *et al.,* 2016; WASREB, 2008).

During dry season, the mean concentrations of all the heavy metals studied, which were Cd, Cr, Ni, Pb, Zn, As, Mn and Se in water from river Thiba were found to be lower than the upper limit set by WHO, US EPA and KEBS/WASREB for drinking water. The same was the case in water from river Nyamindi except for Pb which was found to be above the WHO and US EPA limit but was below WASREB limit. This suggests that during dry season and considering the eight heavy metals involved in this study, water from rivers Thiba and Nyamindi may be fit for direct human drinking from the rivers since the concentrations of these heavy metals are lower than the set upper limit. However, further studies need to be carried out to cover other potable water parameters to ascertain if this water is actually fit for direct drinking by humans. It is also worth noting that concentrations the heavy metals in water from these rivers should continuously be monitored to ensure that health of consumers of the water from these rivers is not jeopardized.

4.3 Heavy Metals in Paddy Water, Soil, Rice Straw, Rice Husks and Rice Grains from Mwea Irrigation Scheme

4.3.1 Heavy Metals in Paddy Water from Mwea Irrigation Scheme

The concentrations of selected heavy metals in paddy water are given in Table 40.

Table 40: Concentration of Heavy Metals (ppm) in Paddy Water

Section	Cd	Cr	Ni	Pb	Zn	As	Mn	Se
H6	BDL	0.4481±0.00078	4.3818±0.00045	0.0020±0.00002	BDL	0.0060±0.00005	1.7109±0.00073	0.0081±0.00006
K8	0.0002±0.00002	0.5274±0.00036	7.1676±0.00066	0.0059±0.00004	0.3860±0.00031	0.0122±0.00009	2.3246±0.00055	0.0369±0.00008
M17	0.0110±0.00009	0.3399±0.00083	4.1286±0.00052	0.0028±0.00004	0.0906±0.00005	0.0057±0.00008	1.4324±0.00063	0.0242±0.00005
Mean	0.0037±0.0063	0.4385±0.0941	5.2260±1.6862	0.0036±0.0021	0.1589±0.2019	0.0080±0.0037	1.8226±0.4565	0.0231±0.0144

The concentration of cadmium in paddy water was ranging from BDL to 0.0110±0.00009 ppm with a mean of 0.0037±0.0063 ppm, chromium was ranging from 0.3399±0.00083 ppm to 0.5274±0.00036 ppm with a mean of 0.4385±0.0941 ppm, nickel was ranging from 4.1286±0.00052 ppm to 7.1676±0.00066 ppm with a mean of 5.2260±1.6862 ppm and lead was ranging from 0.0020±0.00002 ppm to 0.0059±0.00004 ppm with a mean of 0.0036±0.0021 ppm. At the same time, zinc concentration ranged from BDL to 0.3860±0.00031 ppm with a mean of 0.1589±0.2019 ppm, arsenic ranged from 0.0057±0.00008 ppm to 0.0122±0.00009 ppm with a mean of 0.0080±0.0037 ppm, manganese ranged from 1.4324±0.00063 ppm to 2.3246±0.00055 ppm with a mean of 1.8226±0.4565 ppm and selenium ranged from 0.0081±0.00006 ppm to 0.0369±0.00008 ppm with a mean of 0.0231±0.0144 ppm

The average heavy metal concentrations in paddy water and the average heavy metal concentrations in river water adjacent to these paddies (water sampled from T2 and T4) are given in Table 41.

Table 41: Average Heavy Metal Concentration in Paddy Water and Adjacent River Water

Heavy Metal	Cd	Cr	Ni	Pb	Zn	As	Mn	Se
Paddy Water	0.0037±0.0063	0.4385±0.0941	5.2260±1.6862	0.0036±0.0021	0.1589±0.2019	0.0080±0.0037	1.8226±0.4565	0.0231±0.0144
R W (DS)	BDL	BDL	BDL	0.0081±0.0069	BDL	0.0000±0.0000	0.0039±0.0002	BDL
R W (RS)	0.0003±0.0002	0.1087±0.0180	2.1794±1.5189	0.0124±0.0055	BDL	0.0043±0.0025	2.3758±1.2108	0.0069±0.0098

Key: R W – River water; DS – Dry season; RS – Rainy season

Table 41 shows that the mean concentration of the heavy metals in paddy water was higher than the mean concentration of the river water adjacent to the paddies during dry season for all the heavy metals except for lead. Similarly, the mean concentration of heavy metals was in paddy water was still higher than the concentration in river water during rainy season except for lead and manganese.

It was observed that the mean concentration of zinc in river water was BDL during both dry and wet season but was 0.2383±0.2089 ppm in paddy water.

Independent t-test were run on this data to determine whether there were differences in selected heavy metal concentration in paddy water and river water during dry season and; paddy water and river water during rainy season with 95 % confidence interval., The results revealed that there were significant differences in mean concentrations of Cr, Ni and Mn between paddy water and river water during dry season. The results also indicated that there was significant difference in mean concentration of Cr between paddy water and river water during rainy season (see Appendix XV). It can be noted that the concentration of chromium was reasonably higher in paddy water than river water during both seasons.

The results of the present study showed that farming activities in Mwea irrigation scheme may be contributing to addition of Cd, Cr, Ni, Zn, As and Se to the soil in Mwea irrigation scheme. This study obtained mean arsenic concentration in paddy water close to what was reported by Rudzi *et al.* (2018) of 0.01 ppm but obtained higher values of cadmium, chromium, nickel, lead and zinc. This shows that the agrochemical used in rice farming in Mwea irrigation scheme may be containing higher heavy metal content than the ones used in the Rudzi *et al.* (2018) area of study.

4.3.2 Heavy Metals in Soil from Mwea Irrigation Scheme

Heavy metal content in soil from the five main rice growing sections of Mwea irrigation scheme (Tebere- T, Mwea- M, Thiba- H, Wamumu- W and Karaba- K), control (C) and WHO/US EPA limits are presented in Table 42.

Table 42: Amount of Heavy Metals (mg/kg) in Soils of Mwea Irrigation Scheme

Section	Cd	Cr	Ni	Pb	Zn	As	Mn	Se
T	0.0781±0.0201	36.8741±8.7283	70.5979±11.2400	9.0631±0.9180	39.0030±8.4175	1.7455±0.1109	612.1488±319.4578	5.0403±0.7697
M	0.0615±0.0232	27.5925±2.7781	62.9930±7.1475	12.6316±0.5564	38.6054±1.2287	2.4138±0.2147	834.1097±376.6257	7.6235±1.0623
H	0.0701±0.0236	26.7482±1.3080	77.0324±1.8663	14.7824±0.9365	41.3311±2.1276	3.0142±0.1816	1373.9669±237.0039	8.5055±0.8662
W	0.0608±0.0046	36.0202±5.4766	86.1371±13.7299	11.1549±0.5762	38.5528±5.1195	1.7954±0.1400	557.3625±174.7254	5.0088±0.5001
K	0.0655±0.0364	34.9408±3.8391	83.2633±7.3026	11.1918±0.4425	42.8927±5.9183	1.5750±0.1418	563.6139±261.7135	5.0402±1.2866
Mean	0.0672±0.0071	32.4352±4.8638	76.0047±9.4200	11.7648±2.1129	40.0770±1.9457	2.1088±0.5975	788.2404±346.3919	6.2437±1.9457
C	0.0511±0.0010	30.6883±1.7653	64.6501±5.0430	12.8997±3.0790	45.4869±6.4869	2.2669±0.7722	562.6157±295.5068	6.5839±1.6158
Limit	0.8	100	35	85	50	20	2000	2

The amount of cadmium in soil from the five main rice growing sections of Mwea irrigation scheme was varying between 0.0608±0.0046 mg/kg and 0.0781±0.0201 mg/kg with a mean of 0.0672±0.0071 mg/kg and control sample value of 0.0511±0.0010 mg/kg. The amount of chromium ranged from 26.7482±1.3080 mg/kg to 36.8741±8.7283 mg/kg, had a mean of 32.4352±4.8638 mg/kg and soil control sample value of 30.6883±1.7653 mg/kg. Nickel amount varied from 62.9930±7.1475 mg/kg to 86.1371±13.7299 mg/kg and had a mean of 76.0047±9.4200 mg/kg and the amount in the control soil sample had 64.6501±5.0430 mg/kg. Lead amount ranged between 11.1549±0.5762 mg/kg and 14.7824±0.9365 mg/kg with a mean of 11.7648±2.1129 mg/kg and soil control sample having 12.8997±3.0790 mg/kg.

Further, the paddy soils contained zinc amount ranging from 38.5528±5.1195 mg/kg to 42.8927±5.9183 mg/kg, had a mean of 40.0770±1.9457 mg/kg and 45.4869±6.4869 mg/kg in soil control samples. Arsenic amount was ranging between 1.5750±0.1418 mg/kg and 3.0142±0.1816 mg/kg, had a mean of 2.1088±0.5975 mg/kg and control soil sample amount of 2.2669±0.7722 mg/kg. For manganese, the amount in the soil was varying from 557.3625±174.7254 mg/kg to 1373.9669±237.0039 mg/kg with a mean of 788.2404±346.3919 mg/kg and control soil sample with 562.6157±295.5068 mg/kg. Whereas the amount of selenium in rice farm soil ranged from 5.0088±0.5001 mg/kg to 8.5055±0.8662 mg/kg, had a mean of 6.2437±1.9457 mg/kg and with soil control sample having 6.5839±1.6158 mg/kg. From Table 42, it was noted that there was no trend in the order of decrease or increase in the amount of the heavy metals from Tebere section to Karaba section even though rice farming has been carried out in Tebere section for the longest time and in Karaba section least time. The mean amounts of the studied heavy metals in the soil decreased in the sequence of Mn>Ni>Zn>Cr>Pb>Se>As>Cd.

One-way between subjects ANOVA was conducted to compare the amounts of the heavy metals in soil from the five rice growing sections of Mwea irrigation scheme. The results for one-way ANOVA comparing the amount of Cd in the five main rice growing sections are given in Table 43.

Table 43: One-way ANOVA for the Amount of Cd in the Five Rice Growing Sections of Mwea Irrigation Scheme

	Sum of Squares	df	Mean Square	F	Sig.	F-crit
Between Groups	.001	4	.000	.272	.890	3.478
Within Groups	.006	10	.001			
Total	.006	14				

The results showed that that there was no significant difference in the amount of Cd [F (4,10) = 0.272], Cr [F (4,10) = 2.723], Ni [F (4,10) = 3.149] and Zn [F (4,10) = 0.272] in the soil from the five main rice growing sections (Fcrit = 3.478). However, in the soils from the five main rice growing sections of Mwea irrigation scheme, there was significant differences in the amount of Pb [F (4,10) = 26.186], As [F (4,10) = 40.853], Mn [F (4,10) = 4.510] and Se [F (4,10) = 9.803] (see Appendix X). A Tukey's HSD post hoc test revealed that the amount of Pb in soils was statistically different in all the sections except Karaba (K) and Wamumu (W). The post hoc test also showed significant differences in amount of As in soil from Mwea (M) and all the other sections, Thiba (H) and all the other sections but there was no statistically significant difference in amount of As between soils of Tebere (T), Karaba (K) and Wamumu (W). The post hoc test further indicated that there was significant difference in the amount of Mn in the Thiba (H) and all the other sections. Furthermore, the post hoc test established significant differences in the amount of Se in the soils Mwea (M) and the other sections (except Thiba, H), Thiba and other sections (except Mwea, M) but there was no statistically significant difference in the amount of Se between soils from Tebere (T) and Karaba (K); Tebere (T) and Mwea (M); Mwea (M) and Karaba (K); and between Mwea (M) and Thiba (H) (see Appendix X).

It was observed that the mean amounts of cadmium, chromium, nickel and manganese in soil from the main rice growing sections were slightly higher than the mean amount of the same metals in the soil control samples. It was also observed that the mean amount of lead, zinc, arsenic and selenium in soil from rice growing sections was slightly less than the mean amounts in the control soil samples. This implies that rice farming may not have contributed to addition of lead, zinc, arsenic and selenium in the soils of Mwea irrigation scheme. In the soils of the five main rice growing sections, the amount of cadmium decreased in the order T>H>K>M>W, chromium decreased in the order T>W>K>M>H, nickel W>K>H>T>M, lead H>M>K>W>T, zinc

K>H>T>M>W, arsenic H>M>W>T>K, manganese H>M>T>W>K and selenium H>M>T>K>W. If rice farming has contributed to increase of the heavy metals amount in the soils of Mwea irrigation scheme, it would be expected that the order of decrease to be T>M>H>W>K since that is the order in which rice farming was established in this scheme. This order is not followed by any of the eight metals determined implying that so far, rice farming may not have contributed to accumulation of these metals in the soils of Mwea irrigation scheme. The amount of these heavy metals may therefore be due to geological factors and not farming.

Independent t-tests were carried out to determine whether there were differences in the amount of each of the heavy metal in each section and control samples. The results of t-test on comparison of the amount of the heavy metals in Tebere section and control samples is presented in Table 44.

Table 44: The t-test Results of Comparison of the Amount of the Heavy Metals in the Soil from Tebere Section and Control Soil Sample

		t	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of Difference	
							Lower	Upper
Cd	Equal variances assumed	2.335	4	.080	.0270	.0115	-.0051	.05919
Cr	Equal variances assumed	1.203	4	.295	6.1862	5.1413	-8.0882	20.4608
Ni	Equal variances assumed	.836	4	.450	5.9478	7.1126	-13.8001	25.6957
Pb	Equal variances assumed	-2.068	4	.107	-3.8364	1.8549	-8.9866	1.3137
Zn	Equal variances assumed	-1.068	4	.346	-6.4838	6.0699	-23.3366	10.3689
As	Equal variances assumed	-1.158	4	.311	-.5213	.4503	-1.7717	.7291
Mn	Equal variances assumed	.197	4	.853	49.5330	251.2486	-648.0449	747.1111
Se	Equal variances assumed	-1.494	4	.210	-1.5435	1.0333	-4.4124	1.3253

The t-critical value: 2.776 at 0.05 level

The results of the t-test presented in Table 44 established that there were no statistically significant differences in the amount of the eight studied heavy metals in soil from Tebere section and control soil. Similarly, independent t-test revealed that there were no significant differences in the amount of the heavy metals in soil from Mwea section and the control soil. The t-tests further revealed that there were no significant differences in the amount of the heavy metals between the soil from Karaba section and control soil except nickel; soil from Wamumu section and control soil except cadmium; and soil from Thiba section and control soil except chromium, nickel and manganese (see Appendix XVI). This confirms that rice farming has not significantly contributed to accumulation of the heavy metals in soils of Mwea irrigation scheme.

The mean amount of Cd, Cr, Pb, Zn and Mn in the paddy soil from Mwea irrigation scheme were found to be below WHO permissible limit that is set at 0.8, 100, 85, 50 and 2000 mg/kg respectively (Osobamiro *et al.,* 2019). The mean amount of As in the paddy soil was also found to be below US EPA permissible limit that is set at 20 mg/kg (Rahaman *et al.,* 2013). This implies that paddy soils in Mwea irrigation scheme are not polluted with Cd, Cr, Pb, Zn, As and Mn following WHO and US EPA standards and that rice farming has not contributed to soil pollution with these metals. However, the mean amount of Ni and Se in Mwea irrigation scheme paddy soil was found to be above WHO permissible limit which is set at 35 and 2 mg/kg for Ni and Se respectively (Osobamiro *et al.,* 2019; Bawwab *et al.,* 2022). This shows that Mwea irrigation Scheme paddy soils naturally has fairy high amounts of Ni and Se which may be attributed to natural sources like base rocks from which the soil originated/weathered from since even the soil control samples from areas where rice farming has never been carried out had Ni and Se levels above WHO permissible limit.

The present study agrees with Kundu *et al.* (2017) that there were wide variations of manganese concentration in the soil from the five sections of Mwea irrigation scheme although the current study obtained much higher amounts of zinc and manganese in the paddy soils. The current study found amount of cadmium in paddy soil that was close to the mean value of cadmium in surface soil from central Kenya which was reported as 0.1 mg/kg by Ndungu *et al.* (2019). Tomno *et al.* (2020) also reported cadmium and lead values in soils of Machakos municipality which were close to those of this study.

However, Ndungu *et al.* (2019) and Tomno *et al.* (2020) reported much lower values of chromium, nickel, zinc and arsenic in soils which may be attributed to differences in geological factors. Studies carried out on paddy soils from other countries have reported higher amounts of cadmium (Budianta *et al.,* 2022; Lu *et al.,* 2018; Satpathy *et al.,* 2014; Machiwa, 2010); lead (Budianta *et al.,* 2022; Lu *et al.,* 2018; Machiwa, 2010) and arsenic (Lu *et al.,* 2018; Rudzi *et al.,* 2018). These studies reported similar amounts of cadmium (Rudzi *et al.*, 2018), lead (Satpathy *et al.*, 2014), zinc (Satpathy *et al.*, 2014; Machiwa, 2010) and chromium (Machiwa, 2010). The studies also reported lower amounts of chromium (Satpathy *et al.,* 2014; Rudzi *et al.,* 2018), nickel, lead and zinc (Rudzi *et al.,* 2018), manganese (Satpathy *et al.,* 2014) and selenium (Ma *et al.,* 2023; Wang *et al.,* 2021). All these studies reported amounts with wide variations which may be as a result of varying geological factors. Budianta *et al.* (2022) reported amounts of cadmium and lead from Indonesian paddy soils that increased with length of time that rice farming that had taken place which differs from the findings of the current study that showed no trend of the same elements in paddy soils of Mwea irrigation scheme. This could be due to the agrochemicals used in Indonesia that may be containing higher amounts of cadmium and lead and so continuous use of these agrochemicals leads to accumulation of the same metals in the paddy soils.

4.3.3 Heavy metals in Different Parts of Rice from Mwea Irrigation Scheme

The content of the eight selected heavy metals was determined in rice straw, rice husks and rice grains sampled from the five main rice growing sections of Mwea irrigation scheme. The coding was similar to that of soil (showing the section samples were collected from). The results are presented in this section.

4.3.3.1 Heavy Metals in Rice Straws from Mwea Irrigation Scheme

The amount of the selected heavy metals in rice straw are presented in Table 45.

Table 45: Amount of Heavy Metals (mg/kg) in Rice Straw

Section	Cd	Cr	Ni	Pb	Zn	As	Mn	Se
T	0.0117±0.0118	24.0575±4.9490	46.8296±4.7831	0.4741±0.0779	23.3952±4.5114	0.0925±0.0913	597.7431±186.9460	0.3507±0.0950
M	0.0060±0.0001	21.8312±8.1000	32.9175±8.2094	0.6032±0994	20.0863±3.0965	0.0845±0.0213	518.6430±128.8083	0.1890±0.1637
H	0.0401±0.0001	18.0190±0.0332	53.9982±35.3653	0.6415±0.0260	30.4898±8.0087	0.2218±0.2223	1039.0945±270.4115	0.3150±0.0546
W	0.0040±0.0001	23.8076±1.9420	51.4607±9.7911	0.5469±0.0626	27.5257±3.1349	0.2163±0.0646	549.5035±114.9194	0.2205±0.1444
K	0.0100±0.0001	22.1596±5.5870	44.3542±5.5245	0.5981±0.1005	26.5013±1.2818	0.2676±0.0577	573.2069±146.2001	0.2205±0.1444
Mean	0.0144±0.0147	21.9750±2.4187	45.9120±8.1899	0.5728±0.0646	25.5997±3.9904	0.1765±0.0828	559.7741±33.7606	0.2591±0.0697

The heavy metal content in the straw from these five sections were diverse with no predictable trend across various sections. The amount of cadmium in rice straw varied from 0.0040±0.0001 to 0.0401±0.0001 mg/kg and had a mean of 0.0144±0.0147 mg/kg, chromium amount varied from 18.0190±0.0332 to 24.0575±4.9490 mg/kg with a mean of 21.9750±2.4187 mg/kg, nickel amount varied from 32.9175±8.2094 to 53.9982±35.3653 mg/kg with a mean of 45.9120±8.1899 mg/kg and lead amount varied from 0.6032±0994 to 0.6415±0.0260 mg/kg with a mean of 0.5728±0.0646 mg/kg. In the same rice straws, the amount of zinc ranged from 20.0863±3.0965 to 30.4898±8.0087 mg/kg with a mean of 25.5997±3.9904 mg/kg, arsenic amount ranged from 0.0845±0.0213 to 0.2676±0.0577 with a mean of 0.1765±0.0828 mg/kg, manganese content ranged from 518.6430±128.8083 to 1039.0945±270.4115 mg/kg with a mean of 559.7741±33.7606 mg/kg and selenium content ranged from 0.1890±0.1637 to 0.3507±0.0950 with a mean of 0.2591±0.0697 mg/kg. The mean heavy metal content in the rice straw increased in the sequence of Cd<As<Se<Pb<Cr<Zn<Ni<Mn.

The current study obtained values close to those reported by Alrawiq *et al.* (2014) for cadmium (0.032 mg/kg) and lead (0.171 mg/kg) and also that reported by Singh *et al.* (2011) for arsenic (0.87 mg/kg) in rice straw. However, the present study obtained much higher values of chromium, nickel, zinc and manganese in rice straw compared to what was obtained by Alrawiq *et al.* (2014) and Zhao *et al.* (2023) which may be due to differences the amounts of these metals in the soils. On the other hand, studies carried out by Zhao *et al.* (2023) and Singh *et al.* (2011) reported much higher values of cadmium, lead and zinc in rice straw which may be attributed to use of irrigation water and soils polluted with these metals. Rahman *et al.* (2010) reported much higher amounts of zinc and selenium in rice leaves and stem (which are the components of rice straw) which could be due to the fact that the soil on which rice was growing was receiving industrial effluent.

4.3.3.2 Heavy Metals in Rice husks from Mwea Irrigation Scheme

The amounts of heavy metals in rice husks from the five main sections of Mwea irrigation scheme are given in Table 46.

Table 46: Amount of Heavy Metals (mg/kg) in Rice Husks

Section	Cd	Cr	Ni	Pb	As	Se
T	0.0106±0.0019	1.6071±1.3866	331.1990±28.8296	5.9250±5.6189	0.0037±0.0001	0.0836±0.0001
M	0.0100±0.0061	BDL	45.7277±29.2500	19.8455±10.5423	BDL	0.1950±0.0965
H	0.0385±0.0001	0.9106±0.8433	79.0503±29.7196	1.6360±0.0001	BDL	BDL
W	0.0095±0.0025	0.7787±0.6274	45.6466±23.5247	17.3168±6.5572	0.0075±0.0001	0.0836±0.0836
K	0.0340±0.0260	0.3658±0.3079	59.0239±49.0744	1.2058±0.0694	0.0162±0.0185	0.2090±0.1773
Mean	0.0205±0.0145	0.7324±0.6062	57.3621±15.7665	9.1859±8.8181	0.0055±0.0067	0.1142±0.0872

The content of heavy metals in the husks from Mwea irrigation scheme showed inequality in the different sections with no predictable sequence. The cadmium content in rice husks spanned from 0.0095±0.0025 to 0.0385±0.0001 mg/kg with a mean of 0.0205±0.0145 mg/kg, chromium content spanned from BDL to 1.6071±1.3866 mg/kg with a mean of 0.7324±0.6062 mg/kg and nickel content spanned from 45.6466±23.5247 to 331.1990±28.8296 mg/kg with a mean of 57.3621±15.7665 mg/kg

(331.1990±40.7711 treated as outlier). In addition, the lead content in rice husks stretched from 1.2058±0.0694 to 19.8455±10.5423 with a mean of was 9.1859±8.8181 mg/kg, arsenic content stretched from BDL to 0.0162±0.0185 mg/kg with a mean of 0.0055±0.0067 mg/kg and selenium content stretched from BDL to 0.2090±0.1773 mg/kg with a mean of 0.1142±0.0872 mg/kg. The mean heavy metal content in the rice husks increased in the order of As<Cd<Se<Cr<Pb<Ni.

This study concurs with Rahman *et al.* (2010) who reported chromium content in rice husks ranging from 0-2.59 mg/kg and Daulta *et al.* (2020) who reported 0.62 and 0.71 mg/kg of chromium in rice husks during year 2014 and 2015 respectively. However, this study obtained higher values of nickel and lead compared to values reported by Daulta *et al.* (2020) and Zhao *et al.* (2023). On the other hand, this study also obtained lower values of cadmium, arsenic and selenium compared to the values reported by Daulta *et al.* (2020), Hema & Sangeeta (2019) and Rahman *et al.* (2010).

4.3.3.3 Heavy Metals in Rice grains from Mwea Irrigation Scheme

The amounts of heavy metals in rice grains obtained from the five main rice growing sections are presented in Table 47.

Table 47: Amount of Heavy Metals in Rice Grains

Section	Cd	Cr	Ni	Pb	Zn	As	Mn	Se
T	0.0269±0.0215	1.3422±0.9688	BDL	0.1826±0.0217	BDL	0.0322±0.0290	25.8455±11.4790	0.1539±0.0001
M	0.0438±0.0001	0.3661±0.0475	BDL	0.0516±0.0185	4.9397±0.0001	0.0472±0.0049	16.7811±2.5729	0.0000±0.0000
H	0.0842±0.0337	1.6140±0.4448	11.4308±7.8919	0.1827±0.0507	2.1662±0.0001	0.0097±0.0091	22.9568±1.7085	BDL
W	0.0112±0.0122	2.0429±1.3673	BDL	0.1679±0.0494	0.9669±0.0001	0.0322±0.0148	18.5322±0.9981	BDL
K	0.0270±0.0047	0.7070±0.3812	BDL	0.2845±0.2007	BDL	0.0365±0.0493	15.8653±0.7542	0.0000±0.0000
Mean	0.0386±0.0280	1.2144±0.6781	BDL	0.1739±0.0827	1.6146±2.0612	0.0316±0.0137	19.9962±4.2581	0.0308±0.0000
Limit	0.3	5	0.1	5	60	0.5	0.5	(-)

The heavy metal quantity in the rice grains from the five main sections of Mwea irrigation scheme were diverse with no specific trend. The quantity of cadmium in rice grains from Mwea irrigation scheme spanned between 0.0112±0.0122 and 0.0842±0.0337 mg/kg with a mean of 0.0386±0.0280 mg/kg, quantity of chromium spanned between 0.3661±0.0475 and 2.0429±1.3673 mg/kg with a mean of 1.2144±0.6781 mg/kg, quantity of nickel was BDL mg/kg for all sections except Thiba section (H) and lead quantity spanned between 0.0516±0.0185 and 0.2845±0.2007 mg/kg with a mean of 0.1739±0.0827 mg/kg. At the same time, the quantity of zinc in rice grains stretched from BDL to 4.9397±0.0001 mg/kg with a mean of 1.6146±2.0612 mg/kg, arsenic quantity stretched from 0.0097±0.0091 to 0.0472±0.0049 mg/kg with a mean of 0.0316±0.0137 mg/kg, quantity of manganese stretched from 15.8653±0.7542 to 25.8455±11.4790 mg/kg with a mean of 19.9962±4.2581 mg/kg and selenium quantity stretched from BDL to 0.1539±0.0001 mg/kg with a mean of 0.0308±0.0000 mg/kg.

The mean heavy metal content in the rice grains increased in the sequence of Ni<Se<As<Cd<Pb<Cr<Zn<Mn. The amount of cadmium, chromium, nickel, lead, zinc and arsenic in rice grains from Mwea irrigation scheme were below WHO/FAO permissible limits which are set at 0.3, 5, 0.1, 5, 60 and 0.5 mg/kg respectively (Machiwa, 2010; Hasan *et al.,* 2022; Hema & Sangeeta, 2019). However, the amount of Mn in the rice grains was above Australian and New Zealand Environmental and Conservation Council (ANZECC) permissible limit that has been set at 5 mg/kg of Mn (Budaraga & Salihat, 2021).

This current study concurs with several other studies because it obtained values of cadmium in unpolished rice grains similar to those reported by Satpathy *et al.* (2014), Machiwa (2010), Singh *et al.* (2011) and Alrawiq *et al.* (2014); mean value of chromium similar to that reported by Alrawiq *et al.* (2014); values of lead similar to those reported by Machiwa (2010), Alrawiq *et al.* (2014) and Zhao *et al.* (2023); values of arsenic similar to those reported by Hasan *et al.* (2022), Njue *et al*. (2019) and Singh *et al.* (2011) and; values of manganese similar to that reported by Alrawiq *et al.* (2014). On the other hand, the current study obtained higher values of chromium than those reported by Satpathy *et al.* (2014), Machiwa (2010), Singh *et al.* (2011) and Daulta *et al.* (2020) and; higher lead and manganese values than those reported by Satpathy *et al.* (2014).

However, the present study obtained lower values of cadmium than those reported by Budianta *et al.* (2022), Hasan *et al.* (2022), Daulta *et al.* (2020) and Zhao *et al.* (2023); lower value of chromium than that reported by Hasan *et al.* (2022); lower values of nickel than those reported by Hasan *et al.,* (2022), Daulta *et al.* (2020) and Zhao *et al.* (2023); lower values of lead than those reported by Budianta *et al.* (2022), Singh *et al.* (2011) and Daulta *et al.* (2020); lower values of zinc than those reported by Satpathy *et al.* (2014), Machiwa (2010), Hasan *et al.* (2022), Rahman *et al.* (2010), Daulta *et al.* (2020), Zhao *et al.* (2023) and Alrawiq *et al.* (2014) and; lower value of selenium than that reported by

Rahman *et al.* (2010). The differences in values of the heavy metals content in rice obtained by different studies may be attributed to differences in soils heavy metals content arising from geological factors, heavy metal concentrations in irrigation water and heavy metal contents in agrochemicals used during rice farming.

4.3.3.4 Comparison of the Amount of Heavy Metals in Soil, Rice Straw, Rice Husks and Rice Grains from Mwea Irrigation Scheme

The mean amounts of selected heavy metals determined in soil, rice straw, rice husks and rice grains are presented in Table 48.

Table 48: Mean Amount of Heavy Metals in Soil, Rice Straw, Rice Husks and Rice Grains.

Source	Cd	Cr	Ni	Pb	Zn	As	Mn	Se
Soil	0.0672±0.0071	32.4352±4.8638	76.0047±9.4200	11.7648±2.1129	40.0770±1.9457	2.1088±0.5975	788.2404±346.3919	6.2437±1.9457
Straw	0.0144±0.0147	21.9750±2.4187	45.9120±8.1899	0.5728±0.0646	25.5997±3.9904	0.1765±0.0828	559.7741±33.7606	0.2591±0.0697
Husks	0.0205±0.0145	0.7324±0.6062	57.3621±15.7665	9.1859±8.8181	(-)	0.0055±0.0067	(-)	0.1142±0.0872
Grains	0.0386±0.0280	1.2144±0.6781	BDL	0.1739±0.0827	1.6146±2.0612	0.0316±0.0137	19.9962±4.2581	0.0308±0.0000

The mean amount of cadmium in soil was 0.0672±0.0071 mg/kg, amount in straw was 0.0144±0.0147 mg/kg, amount in husks was 0.0205±0.0145 mg/kg and the amount in grain was 0.0386±0.0280 mg/kg. It was found that soil had the highest amount of cadmium while straw had the least. The cadmium amount decreased in the order soil>grains>husks>straw. The mean amount of chromium in soil was 32.4352±4.8638 mg/kg, amount in rice straw was 21.9750±2.4187 mg/kg, amount in rice husks was 0.7324±0.6062 mg/kg and the amount in rice grains was 1.2144±0.6781 mg/kg. It was found that soil had the highest amount of chromium while rice husks had the lowest amount. The amount of chromium in various rice plant parts decreased in the order soil>straw>grains>husks. The mean amount of nickel in soil was 76.0047±9.4200 mg/kg, amount in rice straw was 45.9120±8.1899 mg/kg, amount in rice husks was 57.3621±15.7665 mg/kg and the amount in rice grains was BDL. It was found that soil had the highest amount of nickel while rice grains had the lowest amount. The amount of nickel decreased in the order soil>husks>straw>grains.

The mean amount of lead in soil was 11.7648±2.1129 mg/kg, amount in rice straw was 0.5728±0.0646 mg/kg, amount in rice husks was 9.1858±8.8184 mg/kg and the amount in rice grains was 0.1739±0.0827 mg/kg. It was found that soil had the highest amount of nickel while rice grains had the least amount. The amount of lead decreased in the order soil>husks>straw>grains. The mean amount of zinc in soil was 40.0770±1.9457 mg/kg, amount in rice straw was 25.5997±3.9904 mg/kg and the amount in rice grains was 1.6146±2.0612 mg/kg. It was found that soil had the highest amount of zinc while rice grains had the least amount. The amount of zinc decreased in the order soil>straw>grains. The mean amount of arsenic in soil was 2.1088±0.5975 mg/kg, amount in rice straw was 0.1765±0.0828 mg/kg, amount in rice husks was 0.0055±0.0067 mg/kg and the amount in rice grains was 0.0316±0.0137 mg/kg. The soil was found to have the highest amount of arsenic while rice grains had the least amount. The amount of arsenic decreased in the order soil>straw>grains>husks.

The mean amount of manganese in soil was 788.2404±346.3919 mg/kg, amount in rice straw was 559.7741±33.7606 mg/kg and the amount in rice grains was 19.9962±4.2581 mg/kg. It was found that soil had the highest amount of manganese while rice grains had the least amount. The amount of manganese decreased in the order soil>straw>grains. The mean amount of selenium in soil was 6.2437±1.6912 mg/kg, amount in rice straw was 0.2591±0.0697 mg/kg, amount in rice husks was 0.1142±0.0872 mg/kg and the amount in rice grains was 0.0308±0.00002 mg/kg. It was found that soil had the highest amount of selenium while rice grains had the least amount. The amount of selenium decreased in the order soil>straw>husks>grains.

A one-way ANOVA was run to determine if there were significant differences in amount of heavy metals between soil, rice straw, husks and grains. The results are given in Table 49.

Table 49: ANOVA for the Amount of Cadmium in Soil, Straw, Husks and Rice Grains

	Sum of Squares	df	Mean Square	F	Sig.	F-crit
Between Groups	.033	3	.011	21.892	.000	2.77
Within Groups	.028	56	.001			
Total	.061	59				

The results of one-way ANOVA presented in Table 49 showed that there was significant difference in the amount of cadmium in at least two means from soil, rice straw, rice husks and rice grains [F (3,56) = 21.892, p = 0.05]. A Tukey's post hoc test was run to pinpoint the exact points of difference and the results are presented in Table 50.

Table 50: Post Hoc Test results on Differences in the Amount of Cd Between Soil, Rice Straw, Rice Husks and Rice Grains from Mwea Irrigation Scheme

(I) Sample	(J) Sample	Mean Difference (I-J)	Std. Error	Sig.
Rice Husks	Rice Straw	.009825815571907	.008173797559529	.234
	Soil	-.05179432023499*	.008173797559529	.000
	Rice Grain	-.015582249238616	.008173797559529	.062
Rice Straw	Rice Husks	-.009825815571907	.008173797559529	.234
	Soil	-.06162013580690*	.008173797559529	.000
	Rice Grain	-.02540806481052*	.008173797559529	.003
Soil	Rice Husks	.051794320234993*	.008173797559529	.000
	Rice Straw	.061620135806900*	.008173797559529	.000
	Rice Grain	.036212070996377*	.008173797559529	.000
Rice Grain	Rice Husks	.015582249238616	.008173797559529	.062
	Rice Straw	.025408064810523*	.008173797559529	.003
	Soil	-.03621207099638*	.008173797559529	.000

**The mean difference is significant at the 0.05 level*

The results in Table 50 revealed that there was significant difference between the means of soil and straw; soil and husks; soil and grains; and straw and grains but there was no significant difference between husks and straw; and also husks and grains. Similarly, there was statistically significant difference in chromium amount in the four groups (soil, rice straw, rice husks and rice grains) as was determined using one-way ANOVA [$F(3,56) = 242.311$, $p = 0.000$, $\alpha = 0.05$). Tukey's post hoc test revealed that there was significant difference in the amount of chromium between all group pairs except rice grains and rice husks. In the same way, there was statistically significant difference in nickel amount in the four groups as examined using one-way ANOVA [$F(3,56) = 9.673$, $p = 0.000$, $\alpha = 0.05$). A Tukey's post hoc test showed that there was significant difference in the amount of nickel between all group pairs except husks and soil; and also between soil and straw.

There was significant difference in lead amount in the four groups as was revealed by one-way ANOVA [$F(3,56) = 23.189$, $p = 0.000$, $\alpha = 0.05$). A Tukey's post hoc test established that the significant differences in the amount of lead was between all groups pairs except rice straw and rice grains. Similarly, it was found that there was statistically significant difference in the amount zinc in the four groups as was established by use one-way ANOVA [$F(2,42) = 346.760$, $p = 0.000$, $\alpha = 0.05$). Tukey's post hoc test found that there was significant difference in the amount of zinc between all group pairs (except rice husks whose amount of zinc was not determined). In addition, it was found that there was significant difference in arsenic amount in the four groups as examined using one-way ANOVA [$F(3,56) = 183.885$, $p = 0.000$, $\alpha = 0.05$). Tukey's post hoc test indicated that there was significant difference in the arsenic amount between all group pairs except husk and straw; husks and grains; and also between grains and straw.

Statistically significant difference was found in manganese amount in the four groups as examined using one-way ANOVA [$F(2,42) = 34.698$, $p = 0.000$, $\alpha = 0.05$). A Tukey's post hoc test showed that the significant difference in the amount of manganese was between all group pairs except soil and straw (amount of manganese in husks was not determined). Furthermore, it was found that there was statistically significant difference in the amount of selenium in the four groups as determined by use of one-way ANOVA [$F(3,56) = 181.698$, $p = 0.000$, $\alpha = 0.05$). Tukey's post hoc test revealed that the significant difference in the amount of selenium was between all group pairs except husks and straw; grains and husks; and also grains and straw (see Appendix III).

It was observed that between the soil, rice straw, rice husks and rice grains from Mwea irrigation scheme, there were discernible differences in the amounts of the heavy metals in all possible pairs except between soil and rice husks for Ni; soil and rice straw for Ni and Mn; rice straw and rice grains for Pb, As and Se; rice husks and rice straw for Cd, As and Se; and between rice husks and rice grains for Cd, Cr, As and Se. A key revelation from the statistical analysis of this study was that there were considerable differences in the amounts of the heavy metals between the soil and rice grains which established that statistically, no reasonable amount of Cd, Cr, Ni, Pb, Zn, As, Mn and Se was translocated from soil to the rice grains from Mwea irrigation scheme.

4.3.3.5 Bioaccumulation Factors (BAFs) of Selected Heavy Metals in Different Parts of Rice Grown in Mwea Irrigation Scheme

The mean amount of selected heavy metals found in soil, rice straw, rice husks and rice grains from Mwea irrigation scheme was organized and used to determine the heavy metal bioaccumulation factor (BAF) in rice straw, rice husks and rice grains. The mean amounts of the heavy metals and the calculated values of BAFs are presented in Table 51.

Table 51: Mean Amount (mg/kg) of Selected Heavy Metals in Soil, Different Parts of Rice Plants and their Corresponding Bioaccumulation Factors (BAF)

Heavy metal	Mean amount of the heavy metal obtained				Bioaccumulation factor (BAF)		
	Soil	Straw	Husks	Grains	Straw	Husks	Grains
Cd	0.0672	0.0144	0.0205	0.0386	0.2143	0.3051	0.5744
Cr	32.4352	21.9750	0.7324	1.2144	0.6775	0.0226	0.0374
Ni	76.0047	45.9120	57.3621	BDL	0.6041	0.7547	BDL
Pb	11.7648	0.5728	9.1858	0.1739	0.0487	0.7808	0.0148
Zn	40.0770	25.5997	(-)	1.6146	0.6388	(-)	0.0403
As	2.1088	0.1765	0.0055	0.0316	0.0837	0.0026	0.0150
Mn	788.2404	559.7741	(-)	19.9962	0.7102	(-)	0.0254
Se	6.2437	0.2591	0.1142	0.0308	0.0415	0.0183	0.0049

Key: BDL - Below limit of quantification; (-) - Not available

Table 51 shows that cadmium BAF was 0.2143, 0.3051 and 0.5744 for rice straw, rice husks and rice grains respectively. Straw had the smallest cadmium BAF and grains had the highest. It was observed that all the three rice parts that were studied had a cadmium BAF of less than 1 showing that rice had low cadmium uptake. However, it was observed that rice grains had a relatively high cadmium BAF implying that about half of the cadmium in the soil was absorbed, transferred and concentrated in rice grains in Mwea irrigation scheme. This present study closely agrees with Chang *et al.* (2019), Xie *et al.* (2016), Li *et al.* (2022) and Chen *et al.* (2021) who reported rice grains BAF of 0.34, 0.459, 0.730 and 0.915 respectively. Studies by Chen *et al.* (2023), Kong *et al.* (2018), Satpathy *et al.* (2014) and Kunhikrishna *et al.* (2015) reported rice grains cadmium BAF value much lower than 0.5 which does not deviate much from the results of this study since all the mean values are below 1 which implies that rice grains do not uptake and concentrate much cadmium from the soil. The current study obtained values of rice husks BAF falling within the same range as the values reported by Chen *et al.* (2023).

Chromium BAF was 0.6775, 0.0226 and 0.0374 for rice straw, rice husks and rice grains respectively. Rice straw had the highest chromium BAF and rice husks had the lowest. It was observed that each of the rice part that was studied had a chromium BAF of less than 1. It was noted that even though rice straw had accumulated relatively high amount of chromium, only little amount of the metal was transferred and concentrated into rice husks and rice grains. This shows that rice straw accumulates and confines chromium which prevents much of it from reaching rice husks and grains. This study concurs with Satpathy *et al.* (2014) who reported chromium BAF of 0.04-0.07 and Xie *et al.* (2016) who reported chromium BAF value of 0.015 and so from these studies and the current study, very little chromium is transferred from soil to the rice grains.

Nickel BAF for rice straw was 0.6041, that of rice husks was 0.7547 whereas that of rice grains negligible (BDL). It was observed that rice husks had a higher BAF than rice straw and each of the studied rice part had BAF less than 1. The higher rice husks nickel BAF shows that the husks may be accumulating and confining nickel in them which could be preventing significant amount of nickel from getting to the rice grains. This shows that rice husks are very useful in trapping and preventing nickel from getting into rice grains. This study agrees with Kunhikrishna *et al.* (2015) who reported a very low nickel BAF for rice grains which was of 0.033. Rahimi *et al.* (2017) obtain nickel BAF less than 0.5 which shows that little nickel reaches the rice grains.

Lead BAF for rice straw was 0.0487, that of rice husks was 0.7808 and that of rice grains was 0.0148. It was observed that the rice husks had the highest lead BAF which was of over three quarters (3/4) and was higher than that of rice straw and rice grains. The relatively high rice husks lead BAF and the very low rice grain lead BAF shows that rice husks accumulate and confines most of the lead in them allowing only very little lead to get to the rice grains. It was observed that rice straw and grains had very low BAF showing that very little lead is accumulated in them. This study agrees with Xie *et al.* (2016) who reported rice grains lead BAF of 0.012, Chen *et al.* (2023) who reported rice grains lead BAF ranging from 0.01 to 0.05 and Satpathy *et al.* (2014) who reported rice grains lead BAF ranging from 0.001 to 0.06. However, Kong *et al.* (2018) reported a slightly higher rice lead BAF of 0.1259 and Kunhikrishna *et al.* (2015) who reported a lower rice grains BAF of 0.005. However, all these studies and the current study shows very little lead is translocated from soil to rice grains.

Zinc BAF for rice straw was 0.6388 and that of rice grains was 0.0403. It was observed that the zinc BAF for grains was very little implying that very little zinc is transferred from soil to rice grains. It was also observed that the studied parts of rice had zinc BAF of less than 1 showing that rice is not a zinc hyperaccumulator. However, it was noted that even though substantial amount of zinc is absorbed and transferred to the rice straw, only little amount of it is transferred and stored in the rice grains which shows that much of zinc taken up is confined in other parts of rice plant making the rice grains accumulate very little. This study obtained rice grains zinc BAF of 0.0403 which lies in the same range of 0.01-0.05 as reported by Chen *et al.* (2023). Studies by Chang *et al.* (2019), Kong *et al.* (2018) and Kunhikrishna *et al.* (2015) reported rice grains zinc BAF values greater than 0.1 but less than 0.5 which agrees with the current study that little zinc is transferred from soil to rice grains.

Arsenic BAF for rice straw was 0.0837, that of rice husks was 0.0026 and that of rice grains was 0.0150. The arsenic BAF in rice straw, rice husks and rice grains was quite low showing that rice does not absorb and/or accumulate arsenic in significant amount in the above ground parts. This study closely agrees with Kong *et al.* (2018) who reported a rice grains arsenic BAF of 0.0231 and Xie *et al.* (2016) who reported a value of 0.056 for rice grains arsenic BAF. Kunhikrishna *et al.* (2015) reported a slightly higher value of 0.101 for rice grains arsenic BAF. However, all the three studies and the current study obtained low values of rice grains arsenic BAF showing that the four studies concur that little arsenic is transferred and concentrated in rice grains.

Manganese BAF for rice straw was 0.7102 and that of rice grains was 0.0254. It was observed that the manganese BAF for rice straw was high but that of rice grains was very low. This shows that rice plants uptakes and accumulates manganese in the rice straw but very little of it is transferred and concentrated into the rice grains. Satpathy *et al.* (2014) reported a little higher rice grains manganese BAF (0.1-0.2) compared to this study but both studies showed that little manganese from the soil is concentrated in rice grains.

Selenium BAF for rice straw was 0.0415, that of rice husks was 0.0183 and that of rice grains was 0.0049. It was observed that the selenium BAF for the studied parts was very low showing that rice plant uptakes little amount of selenium from the soil and transfer it to rice straw and rice husks and very little of it reaches and is concentrated into the rice grains. This study closely agrees with Chen *et al.* (2023) who reported rice grains selenium BAF of 0.02-0.04. However, Shao *et al.* (2020) and Zhao (2017) reported slightly higher rice grains selenium BAFs and; Chen *et al.* (2023) and Shao *et al.* (2020) reported slightly higher straw arsenic BAF but in all these studies and the current study, rice straw and rice grain arsenic BAFs are low showing that rice plant uptake and concentrates only little amount of selenium in above ground parts.

In general, different rice parts had low heavy metal BAFs (of less than 0.5) for most of the studied heavy metals. It was found that rice straw had relatively high heavy metal BAF (above 0.5) for chromium, nickel, zinc and manganese. This shows that over half of the concentration of Cr, Ni, Zn and Mn is transferred to the rice straw. It was also found that rice husks had high heavy metal BAF (above 0.75) for nickel and lead. The high nickel and lead BAF for rice husks may be a good trait because husks seem to absorb much of Ni and Pb which prevents reasonable amount from reaching rice grains. All the heavy metal BAFs for rice grains were very low for the heavy metal studied except for cadmium metal which was high (above 0.5). The heavy metal BAFs in rice grains for Cr, Ni, Pb, Zn, As, Mn and Se were indeed too low (below 0.05) which shows that very little of these heavy metals are transferred to the rice grains. In fact, Ni and Se BAFs were very low (below 0.005) implying that negligible amount of these metals reaches the rice grains. However, cadmium BAF for rice grains was shockingly high (0.5744) which shows that over 50 % of the Cd is transferred concentrated to the rice grains. However, more studies on this needs to be carried out especially in areas that heavy metal pollution is higher before concluding this observation so that proper precautions can be taken.

4.4. Heavy Metal Phytoremediation Potential of Selected Non-Edible Plants Commonly Found in Mwea Irrigation Scheme

4.4.1 Heavy metals in Shoots of Plants Commonly found in Rice Farms of Mwea Irrigation Scheme

The selected heavy metals were determined in plant shoots of five commonly found plants from each of the five main rice growing sections of Mwea irrigation scheme. The plants were *Cyperus difformis* (rice sedge), *Tradescantia fluminensis* (wandering jew), *Echinochloa crus-galli* (cockspur grass), *Cyperus rotundus* (nut grass), *Ludwigia adscendens* (water primrose).

4.4.1.1 Selected Heavy Metals in Plant Shoots of Cyperus difformis (rice sedge)

The amount of heavy metals in shoots of rice sedge found in rice farms of Mwea irrigation are given in Table 52.

Table 52: Amount (mg/kg) of Selected Heavy Metals in Rice Sedge Shoots

Section	Cd	Cr	Ni	Pb	Zn	As	Mn	Se
T	0.0184±0.0003	25.2988±0.0075	2710.4040±1.7740	0.4806±0.0092	27.9754±0.0062	0.0150±0.0004	200.1374±0.4370	0.2507±0.0097
M	0.0903±0.0004	9.0140±0.0073	679.2995±0.4840	0.1155±0.0041	32.0677±0.0082	0.0187±0.0005	309.1805±0.5230	0.2507±0.0018
H	0.0134±0.0008	7.1130±0.0094	714.5847±0.6870	5.8937±0.0064	43.1776±0.0055	BDL	348.2274±0.5130	0.0836±0.0005
W	0.0184±0.0002	6.0546±0.0036	959.2262±0.6440	0.7973±0.0024	28.3775±0.0094	BDL	113.4388±0.2410	0.2507±0.0001
K	0.0502±0.0004	3.1414±0.0084	759.8670±0.6950	5.5195±0.0044	29.9131±0.0048	BDL	165.9378±0.4920	0.0836±0.0005
Mean	0.0381±0.0326	10.1244±8.7448	778.2444±125.0797	2.5613±2.8844	32.3023±6.2881	0.0067±0.0093	227.3844±98.4826	0.1839±0.0915

The mean cadmium content in the shoots of rice sedge was 0.0381±0.0326 mg/kg with a range from 0.0134±0.0008 mg/kg to 0.0903±0.0004 mg/kg; the mean chromium content was 10.1244±8.7448 mg/kg with a range from 3.1414±0.0084 mg/kg to 25.2988±0.0075 mg/kg; the mean nickel content was 778.2444 ±125.0797 mg/kg with a range from 679.2995±0.4840 mg/kg to 2710.4040±1.7740 mg/kg and; the mean lead content was 2.5613±2.8844 mg/kg and had a range from 0.1155±0.0041 mg/kg to 5.8937±0.0064 mg/kg.

In the same rice sedge shoots, the mean content of zinc was 32.3023±6.2881 mg/kg with a range from 27.9754±0.0062 mg/kg to 43.1776±0.0055 mg/kg; the mean arsenic content was 0.0067±0.0093 mg/kg with a range from BDL to 0.0187±0.0005 mg/kg; the manganese mean content was 227.3844±98.4826 mg/kg with a range from 113.4388±0.2410 mg/kg to 348.2274±0.5130 mg/kg whereas the mean selenium content was 0.1839±0.0915 mg/kg with values ranging from 0.0836±0.0005 mg/kg to 0.2507±0.0018 mg/kg.

The content of the heavy metals in the shoots of the rice sedge did not depict any trend in the various rice growing section. However, it was noted that the rice sedge shoots from Thiba section (H) had highest amount of three heavy metal which were lead, zinc and manganese. It was also noted that Mwea section (M) rice sedge shoots had highest content of cadmium and arsenic whereas Tebere section (T) rice sedge shoots were found to have highest content of chromium and nickel. The mean amount of heavy metals in rice sedge decreased in the order Ni>Mn>Zn>Cr>Pb>Se>Cd>As. Little has been published on the heavy metal content found in *Cyperus difformis* (rice sedge). However, Ramos & Manangiki (2021) reported that cadmium was absent in rice sedge shoots which contradicts the results from the present study.

4.4.1.2 Selected Heavy Metals in Plant Shoots of Tradescantia fluminensis (wandering jew)

The content of heavy metals in shoots of wandering jew found in rice farms of Mwea irrigation are given in Table 53.

Table 53: Amount (mg/kg) of Selected Heavy Metals in Wandering Jew Shoots

Section	Cd	Cr	Ni	Pb	Zn	As	Mn	Se
T	0.0134±0.0008	3.8419±0.0017	748.6601±0.7670	2.1030±0.0066	42.1330±0.0075	0.0562±0.0003	388.9144±0.5040	0.2507±0.0046
M	0.0151±0.0005	10.1407±0.0062	1145.9690±0.7850	0.4907±0.0042	48.3358±0.0074	BDL	486.2256±0.4070	0.3343±0.0082
H	BDL	13.1511±0.0092	794.4221±0.3930	3.9836±0.0074	34.9357±0.0064	0.0300±0.0008	419.4222±0.6040	0.0836±0.0005
W	0.0335±0.0006	11.4497±0.0066	1205.6261±0.6540	1.3009±0.0036	33.2979±0.0068	0.0262±0.0004	322.3907±0.6010	0.0000
K	0.0000	15.5538±0.0043	1331.7747±0.6770	1.7181±0.0054	31.7889±0.0037	0.0075±0.0009	295.4237±0.5420	0.5014±0.0027
Mean	0.0124±0.0138	10.8274±4.3987	1045.2904±259.2496	1.9193±1.2999	38.0983±6.9631	0.0240±0.0260	382.4753±76.4179	0.2340±0.1995

The mean content of cadmium in the shoots of wandering jew was 0.0124±0.0138 mg/kg with a range from BDL to 0.0335±0.0006 mg/kg; mean content of chromium was 10.8274±4.3987 mg/kg and had a range from 3.8419±0.0017 mg/kg to 15.5538±0.0043 mg/kg; nickel mean content was 1045.2904±259.2496 mg/kg with a range from 748.6601±0.7670 mg/kg to 1331.7747±0.6770 mg/kg and the lead mean content was 1.9193±1.2999 mg/kg with a range from 0.4907±0.0042 mg/kg to 3.9836±0.0074 mg/kg. The same wandering jew shoots had zinc mean content of 38.0983±6.9631 mg/kg with values ranging from 31.7889±0.0037 mg/kg to 48.3358±0.0074 mg/kg; mean content of arsenic was 0.0240±0.0260 mg/kg and had values ranging from BDL to 0.0562±0.0003 mg/kg; manganese mean content was 382.4753±76.4179 mg/kg with values ranging from 295.4237±0.5420 mg/kg to 486.2256±0.4070 mg/kg whereas the selenium mean content was 0.2340±0.1995 mg/kg with a range from 0.0000 to 0.5014±0.0027 mg/kg.

The content of the heavy metals in the shoots of wandering jew from Mwea irrigation scheme rice farms did not portray any trend in the various rice growing section despite rice farming in the various sections having begun at different years. However, it was observed that the wandering jew shoots from Karaba section (K) had highest amount of chromium, nickel and selenium whereas those from Mwea section (M) had highest amount of zinc and manganese. The amount of heavy metals in wandering jew decreased in the order Ni>Mn>Zn>Cr>Pb>Se>As>Cd. Little has been reported on amount of heavy metals found in shoots of *Tradescantia fluminensis* (wandering jew) in polluted or unpolluted soils but Cay *et al.* (2019) and Cay & Engin (2018) reported that cadmium is translocated from roots to above ground portion of wandering jew.

4.4.1.3 Selected Heavy Metals in Plant Shoots of Echinochloa crus-galli (cockspur grass)

The heavy metals content in shoots of cockspur grass found in rice farms of Mwea irrigation are given in Table 54.

Table 54: Amount (mg/kg) of Selected Heavy Metals in Cockspur Grass Shoots

Section	Cd	Cr	Ni	Pb	Zn	As	Mn	Se
T	0.0017±0.0002	20.7971±0.0055	3027.7398±2.1160	1.4601±0.0059	26.7914±0.0083	0.0187±0.0007	402.0247±0.3350	0.4179±0.0059
M	0.0033±0.0004	15.6317±0.0052	3418.1607±8.7310	1.1150±0.0028	39.1460±0.0019	0.0600±0.0007	370.9534±0.6020	0.4179±0.0089
H	0.0050±0.0001	6.0983±0.0034	981.8656±0.5970	2.1593±0.0036	27.6637±0.0066	BDL	301.0755±1.9800	0.5014±0.0026
W	0.0385±0.0008	5.9214±0.0045	1058.7946±0.7080	1.8866±0.0041	37.2412±0.0046	BDL	357.2850±0.3390	BDL
K	0.0084±0.0006	5.1807±0.0017	1160.8248±0.7460	2.8118±0.0077	35.1874±0.0027	BDL	362.9684±0.4440	BDL
Mean	0.0114±0.0154	10.7258±7.0842	1929.4771±1190.5085	1.8866±0.7545	33.2060±5.6427	0.0157±0.0260	358.8614±36.6328	0.2674±0.2465

The mean content of cadmium in the shoots of cockspur grass was 0.0114±0.0154 mg/kg with a range from 0.0017±0.0002 mg/kg to 0.0385±0.0008 mg/kg. The mean content of chromium was 10.7258±7.0842 mg/kg and had a range from 5.1807±0.0017 mg/kg to 20.7971±0.0055 mg/kg. Nickel had mean content of 1929.4771±1190.5085 mg/kg with values ranging from 981.8656±0.5970 mg/kg to 3418.1607±8.7310 mg/kg and lead mean content was 1.8866±0.7545 mg/kg with a range of values from 1.1150±0.0028 mg/kg to 2.8118±0.0077 mg/kg. These cockspur grass shoots also had zinc mean content of 33.2060±5.6427 mg/kg with values ranging from 26.7914±0.0083 mg/kg to 39.1460±0.0019 mg/kg. The mean content of arsenic was 0.0157±0.0260 mg/kg and had values ranging from BDL to 0.0600±0.0007 mg/kg. Manganese mean content was 358.8614±36.6328 mg/kg with values ranging from 301.0755±1.9800 mg/kg to 402.0247±0.3350 mg/kg whereas selenium mean content was 0.2674±0.2465 mg/kg with a range of values from BDL to 0.5014±0.0026 mg/kg.

The heavy metals amount in the shoots of the cockspur grass did not exhibit any regular trend in the various rice growing section of Mwea irrigation scheme even though rice growing was started in different years. However, it was noted that the cockspur grass shoots from Mwea section (M) had highest amount of three heavy metal which were nickel, zinc and arsenic. It was also noted that Tebere section (T) cockspur grass shoots had highest content of chromium and manganese. The amount of heavy metals in cockspur grass decreased in the order Ni>Mn>Zn>Cr>Pb>Se>As>Cd. The current study obtained very low mean amount of lead, chromium and arsenic in plant shoots compared to Sultana *et al.* (2022) who reported 46, 51 and 101.96 mg/kg of these metals respectively. This may be due to the highly polluted soils where their study was carried out. Jung *et al.* (2020) reported that substantial amount of heavy metals were transferred to cockspur grass.

4.4.1.4 Selected Heavy Metals in Plant Shoots of Cyperus rotundus (nut grass)

The heavy metals content in shoots of nut grass found in rice farms of Mwea irrigation are given in Table 55.

Table 55: Amount (mg/kg) of Selected Heavy Metals in Nut Grass Shoots

Section	Cd	Cr	Ni	Pb	Zn	As	Mn	Se
T	0.0067±0.0006	5.7672±0.0044	1256.0294±0.5740	0.8361±0.0044	22.3110±0.0037	0.0600±0.0005	59.2684±0.4110	0.2507±0.0046
M	BDL	3.2710±0.0036	754.5017±0.6650	1.7439±0.0084	21.6080±0.0091	BDL	87.2471±0.0490	0.0836±0.0006
H	0.0067±0.0006	3.3030±0.0044	620.4004±0.4990	4.1763±0.0038	24.2239±0.0075	BDL	62.6593±0.0420	BDL
W	0.0151±0.0005	1.8392±0.0015	947.0551±0.7980	8.3728±0.0079	27.2551±0.0043	BDL	88.3512±0.0880	0.0836±0.0005
K	0.0050±0.0005	5.0144±0.0083	653.2543±0.6260	5.7524±0.0085	19.9245±0.0038	BDL	41.3753±0.0080	0.0836±0.0007
Mean	0.0067±0.0054	3.8390±1.5579	846.2482±262.0849	4.1763±3.5199	23.0645±2.8042	0.0012±0.0027	67.7803±19.9876	0.1003±0.0915

The mean content of cadmium in the shoots of nut grass was 0.0067±0.0054 mg/kg with a range from BDL to 0.0151±0.0005 mg/kg; the mean content of chromium was 3.8390±1.5579 mg/kg and had a range from 1.8392±0.0015 mg/kg to 5.7672±0.0044 mg/kg; nickel mean content was 846.2482±262.0849 mg/kg with a range from 620.4004±0.4990 mg/kg to 1256.0294±0.5740 mg/kg and lead mean content was 4.1763±3.5199 mg/kg with a range from 0.8361±0.0044 mg/kg to 8.3728±0.0079 mg/kg. The same nut grass shoots had zinc mean content of 23.0645±2.8042 mg/kg with values ranging from 27.2551±0.0043 mg/kg to 27.2551±0.0043 mg/kg; arsenic mean content of 0.0012±0.0027 mg/kg and had values ranging from BDL to 0.0600±0.0005 mg/kg; manganese mean content of 67.7803±19.9876 mg/kg with values ranging from 41.3753±0.0080 mg/kg to 88.3512±0.0880 mg/kg and selenium mean content of 0.1003±0.0915 mg/kg with a range from BDL to 0.2507±0.0046 mg/kg.

The values of the selected heavy metals in the shoots of the nut grass did not show any trend in the various rice growing section. However, it was noted that the nut grass shoots from Tebere section (T) had highest amount of four heavy metal which were chromium, nickel, arsenic and selenium. It was also conspicuously noted that Wamumu section (W) nut grass shoots also had highest content of four heavy metals which were cadmium, lead, zinc and manganese. The amount of heavy metals in nut grass decreased in the order Ni>Mn>Zn>Pb>Cr>Se>Cd>As. This study has reported much lower values of heavy metals in shoots of nut grass compared to what was reported by Shingadgoan & Chavan (2019) and Sabo & Ladan (2018). This may be attributed to polluted sites where their studies were carried out in or the heavy metal contaminated waste water that the plants were exposed to. Llyas *et al.* (2021) also reported higher value of lead in the shoots of nut grass but much lower value of manganese which may be attributed to high manganese content in the soils of the site where the current study was conducted.

4.4.1.5 Selected Heavy Metals in Plant Shoots of Ludwigia adscendens (water primrose)

The heavy metals content in shoots of water primrose found in Mwea irrigation are given in Table 56.

Table 56: Amount (mg/kg) of Selected Heavy Metals in Water Primrose Shoots

Section	Cd	Cr	Ni	Pb	Zn	As	Mn	Se
T	0.0084±0.0003	2.1535±0.0029	702.4199±0.5870	2.1733±0.0026	24.3037±0.0066	BDL	834.3567±0.7440	0.0836±0.0004
M	0.0234±0.0002	14.2041±0.0044	771.0070±0.6890	0.2774±0.0041	33.5080±0.0072	0.0150±0.0003	1091.3930±0.9030	0.3343±0.0094
H	BDL	6.2141±0.0077	762.5385±0.7810	0.4588±0.0053	29.5813±0.0054	0.0225±0.0004	1074.2200±0.8780	0.0000
W	BDL	8.6126±0.0085	998.6680±0.7460	1.7629±0.0084	25.1492±0.0051	BDL	649.2999±0.5980	BDL
K	BDL	BDL	620.4014±0.5210	2.2299±0.0037	28.3663±0.0028	BDL	856.9579±0.9520	0.1671±0.0047
Mean	0.0064±0.0102	6.2369±5.5833	771.0070±140.7902	1.3805±0.9437	28.1817±3.6945	0.0075±0.0106	901.2455±184.3830	0.1170±0.1398

The mean content of cadmium in the shoots of water primrose was 0.0064±0.0102 mg/kg and values were ranging from BDL to 0.0234±0.0002 mg/kg; mean content of chromium was 6.2369±5.5833 mg/kg and had a range from BDL mg/kg to 14.2041±0.0044 mg/kg; nickel mean content was 771.0070±140.7902 mg/kg with a range from 620.4014±0.5210 mg/kg to 998.6680±0.7460 mg/kg and lead mean content was 1.3805±0.9437 mg/kg with values ranging from 0.2774±0.0041 mg/kg to 2.2299±0.0037 mg/kg. These same water primrose shoots had zinc mean content of 28.1817±3.6945 mg/kg with values ranging from 24.3037±0.0066 mg/kg to 33.5080±0.0072 mg/kg; mean content of arsenic was 0.0075±0.0106 mg/kg and had values ranging from BDL to 0.0225±0.0004 mg/kg; manganese mean content was 901.2455±184.3830 mg/kg with values ranging from 649.2999±0.5980 mg/kg to 1091.3930±0.9030 mg/kg whereas selenium mean content was 0.1170±0.1398 mg/kg with a range from BDL to 0.3343±0.0094 mg/kg.

The mean values of the heavy metals in the shoots of the water primrose did not possess any uniform trend in the various rice growing section of Mwea irrigation scheme. However, it was observed that the water primrose shoots from Mwea section (M) had highest amount of five heavy metals which were cadmium, chromium, zinc, manganese and selenium. This was an interesting observation since Mwea section was the second oldest section for rice farming to commence after Tebere. It was noted that the content of arsenic for all plant species was quite low in all the sections with majority of sections giving BDL value. It was also observed that all the plant species had relatively high amounts of nickel and manganese. The amount of heavy metals in water primrose decreased in the order Mn>Ni>Zn>Cr>Pb>Se>As>Cd. Little has been reported on the amount of heavy metals in shoots of water primrose. However, Rachmidian & Sholikah (2019) reported values of cadmium in water primrose shoots ranging from 0.06 to 0.11 mg/kg which were higher than the values obtained in the current study.

In general, plant shoots from Tebere (T) and Mwea (M) rice growing sections had higher heavy metal content and the amount of the eight heavy metals in the five plants species commonly found in rice farms of Mwea irrigation scheme decreased in the order Ni>Mn>Zn>Cr>Pb>Se>As>Cd showing that the plants had highest nickel amount and least cadmium.

4.4.1.6 Comparison Tests for the Amounts of Heavy Metals in the Five Plants Species Commonly Found in Mwea Irrigation Scheme Rice Farms

One-way ANOVA was conducted to determine whether there were discernible differences in the amount of the eight heavy metals in the shoots of the five common plants found in rice farms of Mwea irrigation scheme. The results of examination of whether there was discernible differences in the amount of Cd in the shoots of five common plants found in rice farms of Mwea irrigation scheme are presented in Table 57.

Table 57: ANOVA results for Amount of Cd in Shoots of Five Common Plants Found in Rice Farms of Mwea Irrigation Scheme

	Sum of Squares	Df	Mean Square	F	Sig.	F-Crit
Between Groups	.003	4	.001	2.691	.061	2.87
Within Groups	.006	20	.000			
Total	.010	24				

Table 57 revealed that there was no discernible difference in the mean amount of Cd in the shoots of five plants commonly found in rice farms of Mwea irrigation scheme [$F(4,20) = 2.691$, $p = 0.61$]. Similarly, one-way ANOVA revealed that there was no considerable difference in the amount of Cr [$F(4,20) = 1.383$, $p = 0.275$]; Pb [$F(4,20) = 1.563$, $p = 0.223$]; As [$F(4,20) = 0.597$, $p = 0.669$]; and Se [$F(4,20) = 0.954$, $p = 0.454$] in the shoots of the five plant species commonly found in Mwea irrigation scheme rice farms.

However, one-way ANOVA established that there was statistically significant difference in the amount of Ni in the five plants commonly found in rice farms of Mwea irrigation scheme [$F(4,20) = 3.801$, $p = 0.019$]. A Tukey's HSD post hoc test was run to reveal where the difference in amount of Ni was located and the results are presented in Table 58.

Table 58: Tukey's HSD Post Hoc Test of Amount of Ni in the Five Plants Found in Mwea Irrigation Scheme Rice Farms

(I) Sample	(J) Sample	Mean Difference (I-J)	Std. Error	Sig.
Rice Sedge	Wandering Jew	-267.0461	356.0634	.462
	Cockspur Grass	-1151.2328*	356.0634	.004
	Nut Grass	-68.0039	356.0634	.850
	Water Primrose	7.2372	356.0634	.984
Wandering Jew	Rice Sedge	267.0461	356.0634	.462
	Cockspur Grass	-884.1867*	356.0634	.022
	Nut Grass	199.0421	356.0634	.582
	Water Primrose	274.2834	356.0634	.450
Cockspur Grass	Rice Sedge	1151.2328*	356.0634	.004
	Wandering Jew	884.1867*	356.0634	.022
	Nut Grass	1083.2289*	356.0634	.006
	Water Primrose	1158.4701*	356.0634	.004
Nut Grass	Rice Sedge	68.0039	356.0634	.850
	Wandering Jew	-199.0421	356.0634	.582
	Cockspur Grass	-1083.2289*	356.0634	.006
	Water Primrose	75.2412	356.0634	.835
Water Primrose	Rice Sedge	-7.2372	356.0634	.984
	Wandering Jew	-274.2834	356.0634	.450
	Cockspur Grass	-1158.4701*	356.0634	.004
	Nut Grass	-75.2412	356.0634	.835

**The mean difference is significant at the 0.05 level*

The results in Table 58 revealed that cockspur grass had significantly higher amount of Ni than each of the other four plants commonly found in rice farms of Mwea irrigation scheme. One-way ANOVA test also established that there was considerable difference on the amount of Zn found in the shoots of the five different species of plants commonly found in rice farms [$F(4,20) = 5.652$, $p = 0.003$]. The post hoc test located significant difference in amount of Zn in the five plants between nut grass and rice sedge; nut grass and wandering jew; nut grass and cockspur grass; and between wandering jew and water primrose. Similarly, one-way ANOVA revealed significant difference in the amount of Mn in the shoots of five different plant species that are commonly found in rice farms of Mwea irrigation scheme [$F(4,20) = 47.857$, $p < 0.001$]. The Tukey's HSD post hoc test pinpointed significant difference of the amount of Mn between shoots of wandering jew and rice sedge; nut grass and rice sedge; nut grass and wandering jew; nut grass and cockspur grass; nut grass and water primrose; water primrose and rice sedge; water primrose and wandering jew; and water primrose and cockspur grass (see Appendix V).

These post hoc tests revealed that cockspur grass shoots had considerably higher amount of Ni than all the other plants; rice sedge, wandering jew and cockspur grass had reasonably higher amount of Zn in shoots than nut grass shoots; wandering jew shoots had reliably higher amount of Zn than those of water primrose; water primrose shoots had discernibly higher amount of Mn than shoots of nut grass, rice sedge, wandering jew and cockspur grass; wandering jew shoots had considerably higher amount of Mn than those of rice sedge and nut grass; and rice sedge and cockspur grass shoots had reasonably higher amount of Mn than shoots of nut grass. However, it was noted that none of the five plants shoots had considerably higher amount of Cd, Cr, Pb, As and Se than the other.

4.4.2 Heavy Metal Phytoremediation potential of Nonedible Plants Commonly Found in Mwea Irrigation Scheme

4.4.2.1 Phytoextraction of Cadmium by the Selected Common Plants Found in Mwea Irrigation Scheme Rice farms

The mean cadmium content in soil, rice sedge, wandering jew, cockspur grass, nut grass, water primrose and their Cd EFs are given in Table 59.

Table 59: Mean Cd Contents (mg/kg) and Cd Enrichment Factors (EFs) of Selected Common nonedible plants

Section	Soil	Rice sedge	Wandering jew	Cockspur grass	Nut grass	Water primrose
Mean	0.0672	0.0381	0.0124	0.0114	0.0067	0.0064
EF	-	0.5670	0.1845	0.1696	0.0997	0.0952

The mean content of cadmium in soil from farms of the five main rice growing section of Mwea irrigation scheme was 0.0672 mg/kg. In the same sections, the mean cadmium content in rice sedge was 0.0381 mg/kg, in wandering jew was 0.0124 mg/kg, in cockspur grass was 0.0114 mg/kg, in nut grass was 0.0067 mg/kg and in water primrose was 0.0064 mg/kg. Among the plants, rice sedge had the highest content of cadmium and water primrose had the lowest. The amount of cadmium increased in the order water primrose<nut grass<cockspur grass<wandering jew<rice sedge.

Cadmium enrichment factor (EF) for rice sedge, wandering jew, cockspur grass, nut grass and water primrose were 0.5670, 0.1845, 0.1696, 0.0997 and 0.0952 respectively. The cadmium EFs for nut grass and water primrose were very low (<0.1). Rice sedge had a cadmium EF greater than half (>0.5) which was the highest among the five plants species studied and water primrose had the least. The cadmium EF decreased in the order rice sedge>wandering jew>cockspur grass>nut grass>water primrose. However, none of the five plants species showed cadmium phytoremediation capacity through cadmium phytoextraction from the soil since all of them had cadmium EF of less than one (1). This study concurs with Ramos & Manangiki (2021) who reported absence of cadmium in rice sedge that showed that it was not a phytoremediator, Cay *et al.* (2019) who reported that wandering jew could not be categorised as a cadmium hyperaccumulator and Shingadgoan & Chavan (2019) who reported cadmium EF less than 1.

4.4.2.2 Phytoextraction of Chromium by the Selected Common Plants Found in Mwea Irrigation Scheme Rice farms

The mean chromium content in soil, rice sedge, wandering jew, cockspur grass, nut grass, water primrose and their Cr EFs are given in Table 60.

Table 60: Mean Cr Content (mg/kg) and Cr EFs of Selected Common Nonedible Plants

Section	Soil	Rice sedge	Wandering jew	Cockspur grass	Nut grass	Water primrose
Mean	32.4352	10.1244	10.8274	10.7258	3.8390	6.2369
EF	-	0.3121	0.3338	0.3307	0.1184	0.1923

The chromium mean content in soil from farms of the five main rice growing section of Mwea irrigation scheme was 32.4352 mg/kg. In the same sections of the irrigation scheme, the mean content of chromium in rice sedge was 10.1244 mg/kg, in wandering jew was 10.8274 mg/kg, in cockspur grass was 10.7258 mg/kg, in nut grass was 3.8390 mg/kg and in water primrose was 6.2369 mg/kg. Among the plants studied, wandering jew had the highest mean content of chromium and nut grass had the lowest. The mean amount of chromium increased in the order nut grass<water primrose<rice sedge <cockspur grass<wandering jew.

Chromium EFs for rice sedge, wandering jew, cockspur grass, nut grass and water primrose were 0.3121, 0.3338, 0.1184, 0.1184 and 0.1923 respectively. Wandering jew had the highest chromium EF (0.3338) while nut grass had the lowest (0.1184) one. Chromium EFs decreased in the order wandering jew>cockspur grass>rice sedge>water primrose>nut grass. It was observed that chromium EFs for the plant species studied were quite low (<0.4) and so none of the five plants demonstrated chromium phytoremediation capacity of contaminated soil through phytoextraction. The present study agrees with Shingadgoan & Chavan (2019) and Sultana *et al*. (2022) who reported chromium EF below 1 and unsuitability of nut grass and cockspur grass as phytoextractors.

4.4.2.3 Phytoextraction of Nickel by the Selected Common Plants Found in Mwea Irrigation Scheme Rice farms

The mean nickel content in soil, rice sedge, wandering jew, cockspur grass, nut grass, water primrose and their Ni EFs are given in Table 61.

Table 61: Mean Ni Contents (mg/kg) and Ni EFs of Selected Common Nonedible Plants

Section	Soil	Rice sedge	Wandering jew	Cockspur grass	Nut grass	Water primrose
Mean	76.0047	778.2444	1045.2904	1929.4771	846.2482	771.0070
EF	-	10.2394	13.7530	25.3863	11.1342	10.1442

The soil from the main rice growing sections of Mwea irrigation scheme had a mean nickel content of 76.0047 mg/kg. In these same sections, the mean content of nickel in rice sedge was 778.2444 mg/kg, in wandering jew was 1045.2904 mg/kg, in cockspur grass was 1929.4771 mg/kg, in nut grass was 846.2482 mg/kg and in water primrose was 771.0070 mg/kg. Among the five plant species studied, Cockspur grass had the highest mean content of nickel and water primrose had the lowest. The amount of nickel increased in the order water primrose<rice sedge< nut grass<wandering jew <cockspur grass. It was observed that the mean content of nickel was higher in all the five plant species than in the soil.

The EFs for nickel in rice sedge, wandering jew, cockspur grass, nut grass and water primrose were 10.2394, 13.7530, 25.3863, 11.1342 and 10.1442 respectively. Cockspur grass had the highest nickel EF (25.3863) whereas water primrose had the lowest (10.1442). It was observed that all the five plant species studied had a high nickel EF (>10) implying that these plant species uptake and accumulate nickel to higher concentration than is present in the soil. It was also noted that cockspur grass has such a higher nickel EF which was almost double that of each of the other plant species. The nickel EFs decreased in the order cockspur grass>wandering jew>nut grass>rice sedge>water primrose. It was observed that the five plants species which were commonly found in rice farms of Mwea irrigation scheme may be useful in phytoremediation of nickel polluted soils through phytoextraction. The current study aligns with Jung *et al.* (2020) who reported that cockspur grass had nickel removal efficiency (phytoextraction) being the best among the other heavy metals studied. It also aligns with Shingadgoan & Chavan (2019) who reported nut grass nickel EF above 1 showing that nut grass has nickel phytoextraction potential.

4.4.2.4 Phytoextraction of Lead by the Selected Common Plants Found in Mwea Irrigation Scheme Rice farms

The mean lead content in soil, rice sedge, wandering jew, cockspur grass, nut grass, water primrose and their Pb EFs are given in Table 62.

Table 62: Mean Pb Content (mg/kg) and Pb EFs of Selected Common Nonedible Plants

Section	Soil	Rice sedge	Wandering jew	Cockspur grass	Nut grass	Water primrose
Mean	11.7648	2.5613	1.9193	1.8866	4.1763	1.3805
EF	-	0.2177	0.1631	0.1604	0.3550	0.1173

The mean content of lead in soil from rice farms of Mwea irrigation scheme was 11.7648 mg/kg. In the same sections, the mean lead content in the studied plant species was 2.5613 mg/kg for rice sedge, 1.9193 mg/kg for wandering jew, 1.8866 mg/kg for cockspur grass, 4.1763 mg/kg for nut grass and 1.3805 mg/kg for water primrose. Among the five plants species studied, nut grass had the highest mean content of lead (4.1763) and water primrose had the lowest mean content (1.3805). The mean amount of lead increased in the order water primrose <cockspur grass<wandering jew<rice sedge<nut grass. It was observed that all the five plants species had lead mean content that was less than the mean lead content of soil.

Lead EFs were 0.2177, 0.1631, 0.1604, 0.3550 and 0.1173 for rice sedge, wandering jew, cockspur grass, nut grass and water primrose respectively. The lead EFs were quite low and were ranging between 0.1 to 0.4. Nut grass had the highest lead EF (0.3550) and water primrose had the lowest EF (0.1173). The lead EFs decreased in the order nut grass>rice sedge>wandering jew>cockspur grass>water primrose. None of the five plants species showed lead phytoremediation potential through lead phytoextraction from the soil since all of them had enrichment factors less than one (1). The study concurs with Llyas *et al.* (2021) and Shingadgoan & Chavan (2019) who obtained nut grass lead EFs below 1 implying that nut grass is not an efficient lead phytoextractor.

4.4.2.5 Phytoextraction of Zinc by the Selected Common Plants Found in Mwea Irrigation Scheme Rice farms

The mean zinc content in soil, rice sedge, wandering jew, cockspur grass, nut grass, water primrose and their Zn EFs are given in Table 63.

Table 63: Mean Zn Content (mg/kg) and Zn EFs of Selected Common Nonedible Plants

Section	Soil	Rice sedge	Wandering jew	Cockspur grass	Nut grass	Water primrose
Mean	40.0770	32.3023	38.0983	33.2060	23.0645	28.1817
EF	-	0.8060	0.9506	0.8286	0.5755	0.7032

The mean content of zinc in soil from farms of the five main rice growing section of Mwea irrigation scheme was 40.0770 mg/kg. The mean zinc content in rice sedge was 32.3023 mg/kg, in wandering jew was 38.0983 mg/kg, in cockspur grass was 33.2060 mg/kg, in nut grass was 23.0645 mg/kg and in water primrose was 28.1817 mg/kg. All the five plant species shoots had a zinc mean content that was less than the mean zinc content of soil. Wandering jew had the highest content of zinc mean content and nut grass had the lowest mean value. The mean amount of zinc increased in the order nut grass< water primrose<rice sedge < cockspur grass<wandering jew.

Zinc EFs for rice sedge, wandering jew, cockspur grass, nut grass and water primrose were 0.8060, 0.9506, 0.8286, 0.5755 and 0.7032 respectively. All the five plant species shoots had zinc EFs ranging between 0.5 and 1. Wandering jew had the highest zinc EF (0.9506) while nut grass had the lowest (0.5755). The zinc EFs decreased in the order wandering jew>cockspur grass>rice sedge>water primrose>nut grass. However, none of the five plants species showed zinc phytoremediation potential through zinc phytoextraction from the soil since all of them had zinc enrichment factor of less than one (1). This study agrees with Sabo & Ladan (2018) and Shingadgoan & Chavan (2019) who obtained zinc EFs about 1 which showed that nut grass may not be an efficient zinc phytoextractor.

4.4.2.6 Phytoextraction of Arsenic by the Selected Common Plants Found in Mwea Irrigation Scheme Rice farms

The mean arsenic content in soil, rice sedge, wandering jew, cockspur grass, nut grass, water primrose and their As EFs are given in Table 64.

Table 64: Mean As Content (mg/kg) and As EFs of Selected Common Nonedible Plants

Section	Soil	Rice sedge	Wandering jew	Cockspur grass	Nut grass	Water primrose
Mean	2.1088	0.0067	0.0240	0.0157	0.0012	0.0075
EF	-	0.0032	0.0114	0.0074	0.0006	0.0036

Arsenic mean content in the soil from farms of the five main rice growing section of Mwea irrigation scheme was 2.1088 mg/kg. From the same farms, the mean arsenic content in rice sedge was 0.0067 mg/kg, in wandering jew was 0.0240 mg/kg, in cockspur grass was 0.0157 mg/kg, in nut grass was 0.0012 mg/kg and in water primrose was 0.0075 mg/kg. All these plant species had very low mean amount of arsenic in their shoots. Wandering jew had the highest content of arsenic while nut grass had the lowest mean content. The amount of arsenic increased in the order nut grass<rice sedge<water primrose<cockspur grass<wandering jew. It was noted that all the plant species shoots had arsenic mean content that is far much lower than the mean content in the soil.

The arsenic EFs were 0.0032, 0.0114, 0.0074, 0.0006 and 0.0036 for rice sedge, wandering jew, cockspur grass, nut grass and water primrose respectively. It was observed that the arsenic EFs for all the plant species studied were quite low (<0.02) but for nut grass was very low (<0.001). The arsenic EFs decreased in the order wandering jew>cockspur grass>water primrose>rice sedge>nut grass. It was noted that none of the five plants species showed arsenic phytoremediation capacity through arsenic phytoextraction from the soil since all of them had arsenic enrichment factors far much less than one (1). The present study aligns with Ariyachandra *et al.* (2023) and Jung *et al.* (2020) who showed that nut grass and cockspur grass may not be very useful in arsenic phytoextraction.

4.4.2.7 Phytoextraction of Manganese by the Selected Common Plants Found in Mwea Irrigation Scheme Rice farms

The mean manganese content in soil, rice sedge, wandering jew, cockspur grass, nut grass, water primrose and their Mn EFs are given in Table 65.

Table 65: Mean Mn Content (mg/kg) and Mn EFs of Selected Common Nonedible Plants

Section	Soil	Rice sedge	Wandering jew	Cockspur grass	Nut grass	Water primrose
Mean	788.2404	227.3844	382.4753	358.8614	67.7803	901.2455
EF	-	0.2885	0.4852	0.4553	0.0860	1.1434

The mean content of manganese in soil from farms of the five main rice growing section of Mwea irrigation scheme was 788.2404 mg/kg. In the same farms, the mean manganese content in rice sedge was 227.3844 mg/kg, in wandering jew was 382.4753 mg/kg, in cockspur grass was 358.8614 mg/kg, in nut grass was 67.7803 mg/kg and in water primrose was 901.2455 mg/kg. Among the plant species studied, water primrose had the highest mean content of manganese and nut grass had the lowest manganese mean content. The mean amount of manganese increased in the order nut grass<rice sedge<cockspur grass<wandering jew<water primrose. It was observed that only water primrose had manganese mean content that was greater than soil manganese mean content.

Manganese EFs for rice sedge, wandering jew, cockspur grass, nut grass and water primrose were 0.2885, 0.4852, 0.4553, 0.0860 and 1.1434 respectively. The manganese EFs for nut grass was quite low (<0.1) showing that nut grass may be quite poor in manganese phytoextraction. The manganese EFs for rice sedge, wandering jew and cockspur grass were higher than that of nut grass but were still lower than 0.5. Water primrose had the highest manganese EF that was greater than 1 which shows that it could uptake and accumulate manganese to concentration higher than that in the soil. The manganese EFs decreased in the order water primrose>wandering jew>cockspur grass>rice sedge>nut grass. It was therefore noted that of the five plants species studied, only water primrose may be useful in reducing manganese amount in the soil through phytoextraction. This study concurs with Jung *et al.* (2020) who reported relatively poor manganese removal efficiency from the soil by cockspur grass. However, Llyas *et al.*

(2021) and Shingadgoan & Chavan (2019) reported nut grass manganese EFs slightly higher than 1 but they are not sufficient enough to show nut grass as a manganese phytoextractor.

4.4.2.8 Phytoextraction of Selenium by the Selected Common Plants Found in Mwea Irrigation Scheme Rice farms

The mean selenium content in soil, rice sedge, wandering jew, cockspur grass, nut grass, water primrose and their Se EFs are given in Table 66.

Table 66: Mean Se Content (mg/kg) and Se EFs of Selected Common Nonedible Plants

Section	Soil	Rice sedge	Wandering jew	Cockspur grass	Nut grass	Water primrose
Mean	6.2437	0.1839	0.2340	0.2674	0.1003	0.1170
EF	-	0.0295	0.0375	0.0428	0.0161	0.0187

The mean selenium content of in soil from farms of the five main rice growing section of Mwea irrigation scheme was 6.2437 mg/kg. In the same main rice growing sections, the mean selenium content in rice sedge was 0.1839 mg/kg, in wandering jew was 0.2340 mg/kg, in cockspur grass was 0.2674 mg/kg, in nut grass was 0.1003 mg/kg and in water primrose was 0.1170 mg/kg. Among the five plants species studied, cockspur grass had the highest content of selenium and nut grass had the lowest. The amount of selenium increased in the order nut grass<water primrose<rice sedge<wandering jew <cockspur grass. It was observed that all the plant species studied had selenium mean content lower than the content in the soil.

Selenium EFs for rice sedge, wandering jew, cockspur grass, nut grass and water primrose were 0.0295, 0.0375, 0.0428, 0.0161 and 0.0187 respectively. Cockspur grass had the highest selenium EF (0.0428) and nut grass had the lowest (0.0161). The selenium EFs decreased in the order cockspur grass>wandering jew>rice sedge>water primrose>nut grass. It was however noted that all the selenium EFs of the plant species studied were very low (<0.05). It was therefore noted that none of the five plants species showed selenium phytoremediation capacity through selenium phytoextraction from the soil since all of them had selenium EFs that were far much less than one (1).

4.4.2.9 Summary of Studied Heavy Metals EFs

The enrichment factors (EFs) of the eight selected heavy metals for the five studied common weeds that are found in Mwea irrigation scheme rice farms are presented in Table 67.

Table 67: EFs of the Five Common Weeds Found in Rice Farms in Mwea Irrigation Scheme

Heavy Metal	Rice Sedge	Wandering jew	Cockspur grass	Nut Grass	Water primrose
Cd	0.5670	0.1845	0.1696	0.0997	0.0952
Cr	0.3121	0.3338	0.3307	0.1184	0.1923
Ni	10.2394	13.7530	25.3863	11.1342	10.1442
Pb	0.2177	0.1631	0.1604	0.3550	0.1173
Zn	0.8060	0.9506	0.8286	0.5755	0.7032
As	0.0032	0.0114	0.0074	0.0006	0.0036
Mn	0.2885	0.4852	0.4553	0.0860	1.1434
Se	0.0295	0.0375	0.0428	0.0161	0.0187

It was found that all the heavy metal EFs of the studied plant species were below one (1) except for nickel (for all five plants species) and for manganese (for water primrose). Actually, all the nickel EFs were greater than ten (10) implying that the five studied plant species may be useful in nickel phytoextraction in soils contaminated with nickel metal., It was noted that none of the five studied plants would be useful in phytoextraction of Cd, Cr, Pb, Zn, As, Mn and Se since their heavy metal EFs were less than or just slightly above one (1). The present study agrees with Ariyachandra *et al.* (2023), Garba *et al.* (2018) and Sabo & Ladan (2018) who reported that nut grass may not be an efficient heavy metal phytoextractor (but may be potential phytostabilizer). The current study also concurs with Cay *et al.* (2019) who asserted that wandering jew may not be categorised as a hyperaccumulator although it may be effective in translocating cadmium from roots to above ground parts. This study also aligns with Jung *et al.* (2020) who affirmed that cockspur grass heavy metal removal efficiency is highest for nickel.

On a closer look at all the five plants species studied, it was observed that rice sedge had the highest cadmium EF and second highest lead EF. Wandering jew had highest zinc and arsenic EFs and also had second highest cadmium, chromium, nickel, manganese and selenium EFs. Cockspur grass had the highest chromium, nickel and selenium EFs and also had second highest zinc and arsenic EFs. Nut grass had highest lead EF and water primrose had highest manganese EF. Considering these observations, it was noted that from the five plants species studied, wandering jew would be the best heavy metal phytoextractor followed by cockspur grass. However, since most of the heavy metal EFs of wandering jew and cockspur grass were still low, these two plants species should be modified so that their phytoextraction potential can be increased. This may be done by modifying their genetic make-up by introducing genes that are responsible for heavy metal uptake and accumulation in the above ground parts of wandering jew and cockspur grass.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of Research Findings

The study involved assessment of sources of heavy metal contamination at Mwea irrigation scheme and determination of the amounts of eight (8) selected heavy metals (which were cadmium, chromium, nickel, lead, zinc, arsenic, manganese and selenium) in fertilizers commonly used in rice farming; water and sediment from rivers Thiba and Nyamindi; paddy water; soils from the five main rice growing sections; rice straw, husks and grains; and five common nonedible plants commonly found in rice farms.

The survey found that more men (60.57 %) than women (39.43%) were involved in rice farming; over half (56.85 %) of the rice farmers being aged between 31 and 50 years which represent middle age; and slightly over three quarters (75.71 %) aged up to 50 years. Majority of the rice farmers (57.71 %) had received secondary or tertiary education and a total of 90.85 % had at least primary school education. Majority of rice farmers (72 %) had small pieces of land (two acres and below) and about half of the farmers (50.57 %) have been farming for a short time of less than 10 years. The study also found that rice was the type of food mostly consumed by people of Mwea which was followed by maize, beans and peas. The commonly used fertilizers during planting of rice were TSP and DAP; common fertilizers during top dressing were SA and urea; manures mainly used were from cows and goats; and other substances used during rice farming were ash and tobacco. Pests and diseases were mainly controlled using chemicals such as Goldazim, Absolute, Topsin, Ranger and Alphatox among others. There were other chemicals used in rice farming such as foliar sprays and herbicides. The weeds that were commonly found in rice farms were grasses, oxalis, rice sedge, cockspur grass, nut grass, wandering jew, water primrose and several others.

All the eleven fertilizers contained traces of some or all of the eight heavy metals that were determined. The amount of Cd ranged from BDL to 8.1649, Cr from 2.5838 to 67.3844, Ni from BDL to 955.5323, Pb from 0.1206 to 1.8572, Zn from BDL to 3144.7381, As from 0.0338 to 11.1469, Mn from 2.9614 to 479.7057 and Se from BDL to 34.4719 mg/kg. It was found that TSP, DAP and Baraka plant contained Cd amount above 0.5 mg/kg; TSP, Baraka plant, NPK 23:23:0 and Mavuno plant contained Cr above 10 mg/kg, TSP, DAP, Mavuno plant, Baraka Plant, NPK 23:23:0, SA and Mavuno top contained Ni amount above 100 mg/kg; DAP, Mavuno plant, Baraka plant NPK 23:23:0 and Amidas top contained Pb amount above 1 mg/kg; TSP, DAP, Mavuno plant and Baraka plant contained Zn amount above 500 mg/kg; DAP, Mavuno plant, Baraka plant and NPK 23:23:0 contained As amount above 1 mg/kg; TSP, Mavuno plant and NPK 23:23:0 contained Mn amount above 50 mg/kg; and Mavuno plant and NPK 23:23:0 contained Se above 1 mg/kg. From these results, TSP, DAP, Mavuno plant, Baraka plant and NPK 23:23:0 contained relatively high amounts of five or six of the heavy metals determined. Generally, the eleven fertilizers studied were found to contain the studied heavy metals within the acceptable limits for use in Kenya except NPK 23:23:0 and Mavuno plant which contained Se amount above the set limit of 1 mg/kg.

The sediment from all the sampling points of both rivers contained some amount of each of the eight heavy metals determined. During the rainy season, river Thiba sediment contained mean amounts of Cd, Cr, Ni, Pb, Zn, As, Mn and Se as 0.992, 40.3216, 86.4723,10.3969, 42.5625, 2.2985,1727.3884 and 5.4340 mg/kg respectively whereas river Nyamindi had 0.0882,41.1219, 91.7718, 10.7445, 41.8297, 2.4561, 1753.2844 and 5.7648 mg/kg respectively. During the dry season, river Thiba sediment had mean amounts as 0.0689, 44.6644, 381.4318, 3.9903, 59.6221, 2.8336, 1665.5941 and 6.1913 mg/mg respectively whereas river Nyamindi had 0.0590, 39.1176, 559.0917, 0.3781, 75.7192, 3.0114, 1714.4195 and 6.5488 mg/kg of the metals respectively. In both rivers, there was no significant difference in the amounts of Cd, Cr, Mn and Se in sediment between rainy and dry seasons but there were significant differences in the amounts of Ni, Pb and As between the two seasons. However, there was no significant difference in the amount of Zn between rainy and dry seasons in the sediment of river Thiba but there was significant difference in that of river Nyamindi. It was also found that was no significant difference in the amounts of all the heavy metals between rivers Thiba and Nyamindi.

The water from both rivers contained some amount of each of the eight heavy metals determined in at least one sampling point except Zn whose all sampling points recorded values BDL. During the rainy season, river Thiba water contained mean amounts of

Cd, Cr, Ni, Pb, Zn, As, Mn and Se as 0.0001, 0.0732, 0.9147,0.0362, BDL, 0.0020, 1.2916 and 0.0037 ppm respectively whereas river Nyamindi had 0.00005, 0.0167, 0.1943, 0.0223, BDL, 0.0002, 0.1379 and BDL ppm respectively. During the dry season, river Thiba water had mean amounts as 0.0010, BDL, BDL, 0.0058, BDL, 0.00003, 0.0071 and BDL ppm respectively whereas river Nyamindi water had 0.0009, 0.0005, 0.0148, 0.0184, BDL, 0.00003, 0.0080 and 0.00003 ppm of the metals respectively. In both rivers, there was no reliable difference in the concentration of Cd, Ni, Pb, Zn and Se in water between rainy and dry season. However, there were reliable differences in the concentration of Cr, As and Mn in water of river Thiba between rainy and dry season but there was no such difference in river Nyamindi. It was also found that there were no reliable differences in concentrations of these heavy metals in the water of the two rivers. The mean concentration of Cd, Cr, Ni, Pb, Zn, As, Mn and Se in paddy water was found to be 0 0037, 0.4385, 5.2260, 0.0036, 0.1589, 0.0080, 1.8226 and 0.0231 ppm respectively. The concentrations of Cd, Cr, Ni, Pb, Zn, As and Se in paddy water were comparatively higher than the adjacent river water during both rainy and dry seasons. The concentration of Cr, Ni and Mn in paddy water was significantly higher than they were in adjacent river water.

The mean amounts of Cd, Cr, Ni, Pb, Zn, As, Mn and Se in soil from Mwea irrigation scheme were 0.0672, 32.4352, 76.0047, 11.7648, 40.0770, 2.1088, 788.2404 and 6.2437 mg/kg respectively. On comparison with soil from areas where farming has never taken place (but within the irrigation scheme), it was found that there were no statistically significant differences in the amounts of the eight studied heavy metals.

The mean amounts of Cd, Cr, Ni, Pb, Zn, As, Mn and Se in rice straw were 0.0144, 21.9750, 45.9120, 0.5728, 25.5997, 0.1705,559.7741 and 0.2591 mg/kg respectively; amount in rice husks were 0.0205, 0.7324, 57.3621, 9.1858, NA, 0.0055, NA and 0.1142 mg/kg (NA = not available) respectively; and amount in rice grains were 0.0386, 1.2144, 2.2862, 0.1739, 1.6146, 0.0316, 19.9962 and 0.0302 mg/kg respectively. From the available data, rice grains had the least amount of Ni, Pb, Zn, Mn and Se. The BAFs for all the eight heavy metals for rice straw were less than 0.75, for rice husks less than 0.8 and for rice grains less than 0.6. In fact, the BAFs for rice grains were below 0.05 for all the heavy metals except for Cd. This implies that very little amounts of the heavy metals were transferred from soil to rice grains. The amount of Cd, Cr, Ni, Pb, Zn and As in rice grains from Mwea irrigation scheme was below the upper recommended limit of WHO/FAO.

The amount of Cd in the shoots of *Cyperus difformis* (rice sedge), *Tradescantia fluminensis* (wandering jew), *Echinochloa crus-galli* (cockspur grass), *Cyperus rotundus* (nut grass), *Ludwigia adscendens* (water primrose) was 0.0381, 0.0124, 0.0114, 0.0067 and 0.0064 mg/kg respectively; amount of Cr was 10.1244, 10.8274, 10.7258,3.8390 and 6.2369 mg/kg respectively; amount of Ni was 778.2444, 1045.2904, 1929.4771, 846.2482, 771.0070 mg/kg respectively; Pb amount was 2.5613, 1.9193, 1.8866, 4.1763 and 1.3805 mg/kg respectively; amount of Zn was 32.3023, 38.0983, 33.2060, 23.0645 and 28.1817 mg/kg respectively; amount of As was 0.0067,0.0240, 0.0157, 0.0012 and 0.0075 mg/kg respectively; amount of Mn was 227.3844, 382.4753, 358.8614, 67.7803, 901.2455 mg/kg respectively; and amount of Se was 0.1839, 0.2340, 0.2674, 0.1003 and 0.1170 mg/kg respectively. Apart from Ni, all the other heavy metals mean amounts in the five plant species shoots were less than the amounts in the soil. As a result of this, the EFs of all the metals (apart from Ni EFs) in all the studied plant species were close to 1.0 (Mn EF was found to be 1.1434) or less than 1.0 implying that the five species plant were poor Cd, Cr, Pb, Zn, As, Mn and Se phytoremediators through phytoextraction. However, the five species of plants had Ni EFs above 10 with cockspur grass having the highest Ni EF of 25.3863. This shows that cockspur grass was the best Ni phytoremediator and specifically Ni phytoextractor. It was noted that from the five species of plants studied, wandering jew would be the best heavy metal phytoextractor followed by cockspur grass.

5.2 Conclusion

Survey carried out showed that more men than women are involved in rice farming; young and educated people are taking up rice farming; and subdivision of rice farms is taking place that may lead to farmers possessing small uneconomical rice farms. Rice is the main type of food consumed by people of Mwea irrigation scheme with maize and beans closely following. During rice planting, high phosphatic fertilizers are used with little or no manures being applied. During rice growing, many chemicals are used to control pests, diseases and weeds. Fertilizers used during planting of rice such as

DAP, TSP, NPK 23:23:0, Mavuno plant and Baraka plant contained relatively high amounts of five or six of the heavy metals determined and so continuous use of these fertilizers in rice farming may lead to accumulation of the heavy metals in the soil which may lead to bioaccumulation. The fertilizers used for top dressing such as MoP, SA, urea, CAN, Amidas top and Mavuno top contained fairly low amounts of the studied heavy metals and so do not contribute much to heavy metal pollution. Generally, the fertilizers used during rice farming at Mwea irrigation scheme contains amounts of Cd, Cr, Ni, Pb, Zn, As, Mn and Se that are below KEBS permissible limits and therefore the fertilizers are appropriate for use in rice farming in Kenya.

Sediment from rivers Thiba and Nyamindi was found to contain the eight heavy metals at varying levels. The amount of Cd, Pb and Zn were found to be below the permissible limit of WHO and US EPA for unpolluted sediment but Cr, Ni and Mn amounts were above the limits. During rainy season, the amount of Cd, Pb, Zn, As and Se in water from both rivers were below the permissible limit set by WHO and KEBS/WASREB but Cr (in river Thiba) and Mn (in both rivers) amounts were above the limits. However, during dry season, all the eight heavy metal amounts in water from both rivers were below WHO and KEBS/WASREB permissible limit which shows that water from these rivers may not be polluted with these heavy metals and so may be used as potable water (as far as the eight heavy metals are concerned). Paddy water was found to contain relatively higher concentrations of Cd, Cr, Ni, Zn, As and Se than river water implying that rice farming activities may be contributing to addition of these heavy metals in Mwea Irrigation scheme ecosystem.

The mean amounts of all the eight heavy metals determined in the soils from the main rice growing sections of Mwea irrigation schemes were found not to be significantly different from the amount in soil from areas within the irrigation scheme where rice farming has never taken place. This implies that rice farming has not significantly contributed to increase in these heavy metals in the soil. The study found that paddy soils in Mwea irrigation scheme are not polluted with Cd, Cr, Pb, Zn, As and Mn according to WHO and US EPA permissible limits but Ni and Se amounts in the paddy soils are above WHO permissible limits but their higher amounts are attributed to natural sources and not rice farming.

The amount of the heavy metals in rice straw, rice husks and rice grains were less than the amounts in the soil. This shows that there are little amounts of the heavy metals that are transferred from soil and accumulated to the above ground parts with rice grains accumulating the least (apart from Cd). The amounts of Ni and Pb were higher in rice husks than in rice straw and rice grains indicating that rice husks traps these two metals and prevents much of them from reaching the rice grains. The amount of Cd, Cr, Ni, Pb, Zn and As in rice grains from Mwea irrigation scheme were below WHO/FAO permissible limits and so the rice may be consumed without fear as far as these heavy metals are concerned. The heavy metals amount in the shoots of the five studied plant species were lower than the amounts in the soil (apart from Ni). The EFs were found to be close to or less than 1 apart from Ni which had EFs above 10. From the five plants species studied, wandering jew had the highest potential for phytoremediation through phytoextraction of heavy metals from soils followed by cockspur grass.

5.3 Recommendations

The following can be recommended based on the findings of this study:

i. Reduce subdivisions of rice farms to ensure rice farming remain economical, involve more women in rice farming, reduce intensive use of chemicals during rice farming and keep monitoring rice contaminants since rice is the food type mostly consumed by people from Mwea.
ii. Rice farming using the commonly used fertilizers may continue since they satisfy the set heavy metal standards (except NPK 23:23:0 and Mavuno plant) but if possible, fertilizers with less amount of heavy metals especially those used during planting may be sourced.
iii. People should avoid drinking water from rivers Thiba and Nyamindi during rainy season since the amounts of Cr and Mn were found to be above WHO and KEBS/WASREB limits.
iv. People may continue consuming rice grown in Mwea irrigation scheme without worry (as far as the studied heavy metals are concerned) since these heavy metal amounts were below WHO and FAO limits in rice grains.
v. Cockspur grass may be used for Ni phytoextraction since it was found to be a better Ni phytoextractor among the studied plants.

5.4 Suggestions for Further Studies

The following are suggestions for further studies based on findings of this study:

i. Research is needed to develop high quality organic fertilizers/manures to replace the inorganic fertilizers especially those used during planting of rice.
ii. More studies need to be conducted to determine the amounts of other toxic heavy metals in soil, sediment, water and other plants from Mwea irrigation scheme.
iii. Further studies require to be conducted to determine other water parameters (physical, biological and chemical) to confirm whether water from rivers Thiba and Nyamindi is potable.
iv. Research should be carried out to develop techniques for removing heavy metals in water to make water from rivers Thiba and Nyamindi potable during rainy season.
v. Studies need to be carried out to determine heavy metals quantities in pesticides and other substances used during rice farming in Mwea irrigation scheme.
vi. Heavy metal risk assessment studies should be carried out on consumers of rice and animal products from animals feeding on rice straw from Mwea irrigation scheme.
vii. More studies are required with an aim of genetically modifying wandering jew and cockspur grass so that their phytoextraction potential can be improved to enable the modified plants be used for phytoremediation of heavy metal contaminated soils

REFERENCES

Abdel-Haleem, S., Sroor, A., El-Bahi, M., & Zohny, S. (2001). Heavy Metals and Rare Earth Elements in Phosphate Fertilizer Components Using Instrumental Neutron Activation Analysis. *Applied Radiation and Isotopes*, 55, 569-573.

Abdulahi, M., Masakazu, M., Seiji, T., Akira, G. & Hiroyuki, M. (2003). Changes in Water Management Practices in the Mwea Irrigation Scheme, Kenya from 1994-1998. *Rural & Environmental Engineering*, 44,60-67

Abura, M., Ouma, G. & Oyatta, B. (2019). Effect of Gender, Age, Education and Marital Status of Rice Farmers at Ahero Irrigation Scheme, Kenya on Rice Yield. *International Journal of Innovative Research and Advanced Studies*, 6(11), 64-67.

Adriano, C. (2003). Trace Elements in Terrestrial Environments: Biogeochemistry, Bioavailability and Risks of Metals, 2nd ed, Springer, New York, NY, USA.

Afzal, A. & Mahreen, N. (2024). Emerging insights into the Impacts of Heavy Metal Exposure on Health, Reproductive and Productive Performance of Livestock. *Frontiers in Pharmacology*, 15,1-18

Agarwal, S., Abbeeshr, F., Mahboobb, S., Atique, U., Pramanick, P. & Mitra, A. (2022). Bioaccumulation Factor (BAF) of Heavy Metals in Green Seaweed to Assess Phytoremediation Potential., *Journal of King Saudi University-Science*, 34(5),1-7.

Ahmed, M., Matsumoto, M., & Kurosawa, K. (2018). Heavy Metal Contamination of Irrigation Water, Soil and Vegetables in a Multi-Industry District of Bangladesh. *International Journal of Environmental Research*, 12(3), 10.

Ajayi, O., Odesanya, O., Avwioroko, O., Adebambo, S., & Okafor, B. (2012). Effects of a Long Term Fertilizers Use on Trace Metal Levels of Soils in Farm Settlements. *Journal of Agricultural Research and Development*, 2, 44-51.

Akoko, G., Kato, T. & Tu, H. (2020). Evaluation of Irrigation Water Resources Availability and Climate Change Impacts- A Case Study of Mwea Irrigation Scheme, *Water.* 12(9), 2330

Aktar, W., Sengputa, D., & Chowdhury, A. (2009). Impact of Pesticides Use in Agriculture: their Benefits and Hazards, *Interdisciplinary Toxicology*, 2(1), 1-12.

Al-Horayes, O. (2013). Concentration of Some Micronutrients Heavy Metals in Selected Commonly Used Fertilizers in Saudi Arabia. 2nd International Conference on Chemical, Ecology & Environmental Sciences. (ICEES' 2013) June 17-18. London, U.K.

Ali, H., Khan, E., & Sajad, A. (2013). Phytoremediation of Heavy Metals-Concepts and Applications. *Chemosphere*, 91, 869–881.

Al-Jaf, H. & Del, K. (2019). Effects of Different Feed Additives on Growth Performance and Production in Livestock. *International Journal of Agriculture and Forestry*, 9(1), 16-31.

Alloway, B. (2013). Heavy Metals in Soils: Trace Metals and Metalloids in Soils and their Bioavailability. 10.1007/978-94-007-4470-7

Alrawiq, N., Khairiah, J., Talib, L., Ismail, S. & Anzan, I. (2014). Accumulation and Translocation of Heavy Metals in Soil and Paddy Plant Samples Collected from Rice Fields Irrigated from Recycled and Non-recycled Water in MADA Kedah, Malaysia. *International Journal of ChemTech Research*, 6(4),2347-2356.

Ameh, S., Anna, N. & Halahala, S. (2016). Heavy Metal Seasonal Distribution in Shore Sediment Samples Along the Coastline of Erongo Region, Western Namibia. *European Journal of Scientific Research*, 139(1),49-63.

Anda, M. (2012). Cation Imbalance and Heavy Metal Content of Seven Indonesian Soils as Affected by Elemental Composition of Parent Rocks. *Geoderma.* 190, 388-396.

Ariyachandra, P., Alwis, S. & Wimalasiri, M. (2023). Phytoremediation Potential of Heavy Metal by *Cyperus rotundus*. *Reviews in Agricultural Science*, 11,20-35.

Arnarson, A. (2017). Rice 101: Nutrition Facts and Health Effects. Medical News Today. Available at http://www.medicalnewstoday/com/article/318699phd. Accessed on 04/04/2018

Arunakumara, U., Walpola, C., & Yoon, M. (2013). Current Status of Heavy Metal Contamination in Asia's Rice Lands. *Reviews in Environmental Science Bio/Technology*, 12, 355-377.

Asif, M. (2017). Role of Heavy Metal in Health and Particularly in Respect to Diabetic Patients. *TANG* (*Humanitas Medicine*), 7(1), 1-10.

Avila, S., Puntel, L. & Aschner, M. (2013). Manganese in Health and Disease. *Metal Ions in Life Sciences*, 13,199-227.

Balali-Mood, M., Naseri, K., Tahergorabi, Z., Khazdair, R. & Sadeghi, M. (2021). Toxic Mechanisms of Five Heavy Metals: Mercury, Lead, Chromium, Cadmium and Arsenic. *Frontiers in Pharmacology*, 12,643972

Balaram, V. (2020). Microwave Plasma Atomic Emission Spectrometry (MP-AES) and its Application- A Critical Review. *Microchemical Journal*, 159,105483

Bawwab, M., Qutob, A., Al Rhatib, M., Malassa, H., Shawahna, A & Qutob, M. (2022). Evaluation of Heavy Metal Concentrations in Soil and Edible Vegetables Grown in Compost of Unknown Sources in Al-Jifthink, Palestine. *Journal of Evironmental Protection*, 13,112-125

Bhargava, A., Carmona, F., Bhargava, M., & Srivastava, S. (2012). Approaches for Enhanced Phytoextraction of Heavy Metals. *Journal of Environmental Management*, 105, 103–120.

Bhatia, S. (2002). Handbook of Industrial Pollution and Control. CBS Publishers & Distributors. New Delhi. Pp. 377-390.

Bhuiyan, U., Min, S. R., Jeong, J., Sultana, S., Choi, S., & Song, Y. (2011). Overexpression of Yeast Cadmium Factor (YCF1) Enhances Heavy Metal Tolerance and Accumulation in *Brassica juncea*. *Plant Cell Tissue Organ Culture*, 105, 85-91.

Bizily, P., Rugh, L., & Meagher, B. (2000). Phytodetoxification of Hazardous Organomercurials by Genetically Engineered Plants. *Nature Biotechnology*, 18, 213-217.

Bolan, S., Ko, G., Anderson, N., & Vogeler, I. (2008): Solute Interactions in Soils in Relation to Bioavailability and Remediation of the Environment. *Journal of Soil Science and Plant Nutrition*, 8,1-5

Borg, R., & Gall, M. (1989). Educational Research: An Introduction. 4th ed. New York. Longman

Borg, R., Gall, D., & Gall, P. (2003). Educational Research: An Introduction, 7th ed, Boston. Ally-Bacon.

Brewer, P., Saunders, A., Scott, J., Chaney, L., & McIntosh, S. (1999). Somatic Hybridization Between the Zinc Accumulator *Thlaspi caerulescens* and *Brassica napus*. *Theoretical and Applied Genetics*, 99, 761-771.

Bryman, A. (2012). Social Research Methods, 4th ed. New York, Oxford University Press

Brzoska, M. & Moniuszko-Jakoniuk, J. (2001). Interactions between Cadmium and Zinc in the Organism. *PubMed*, 39(10),967-80.

Budambula, N. L. M. & Mwachiro, E. C. (2006). Metal Status of Nairobi River Water and their Bioaccumulation in *Labeo cylindricus*. *Water, Air and Soil Pollution*, 169,275-291

Budaraga, I. K. & Salihat, R. A. (2021). Analysis of Metal (Pb, Mn, Cd, Zn, Cu) in Purple Rice and Purple Rice Stems Cultivated Organically Using Biogas Slug in Padang Pariaman, West Sumatra Province. *IOP Conf Series: Earth and Environmental Science*, 709,012071

Budianta, D., Napoleon, A. & Bolan, N. (2022). Heavy Metals in Indonesian Paddy Soils. Available at Doi:10.5772/intechopen.109027 Assessed on 24/06/2023

Caglieri, A., Goldoni, M., Acampo, O., Andreoli, R., Vettori, M. V., Corradi, M., Apostoli, P. & Mutti, A. (2006). The Effect of Inhaled Chromium on Different Exhaled Breath Condensate Biomarkers Among Chrome-Plating Workers. *Environmental Health Perspectives*, 114(4),542-546.

Callahan, A. G., Baker, A. J. M., Kolen, S. D., & Wedd, A. G. (2006). Metal Ion Ligands in Hyperaccumulating Plants. *Journal of Biological Inorganic Chemistry*, 11, 2-12.

Callahan, R. L., Kolev, S. D., O'Hair, R. A., Salt, D. E., & Baker, A. J. (2007). Relationship of Nicotianamine and Other Amino Acids with Nickel, Zinc and Iron in *Thlaspi* Hyperaccumulators. *New Phytologist*, 176, 836-848.

Cameron, K. S., Buchner, V. & Tchounwou, P. B. (2011). Exploring the Molecular Mechanisms of Nickel-Induced Genotoxicity and Carcinogenicity: A Literature Review. *Reviews on Environmental Health*, 26(2), 81-92

Cay, S. & Engin, M. S. (2018). Effect of EDTA on the Removal of cadmium from Artificially Contaminated Water by *Tradescantia fluminensis*. *The Black Sea Journal of Science*, 8(2),200-2006.

Cay, S., Engin, M. S., Uyanik, A., Cay, C. & Guney, S. (2019). Phytoremediation of Cadmium in Soil and Hydrophonics by *Tredescantia fluminensis*. *Carpathian Journal of Earth and Environmental Sciences*, 14(2),269-274.

Chakraborty, R., Renu, K., Eladl, M., El-Sherrbiny, M., ELsherbini, D. M. A., Mirza, A. K., Vellingiri, B. Lyer, M., Dey, A. & Gopalakrishnan, A. (2022). Mechanism of Chromium-Induced Toxicity in Lungs, Liver and Kidney and their Ameliorative Agents. *Biomedicine & Pharmacotherapy*, 151,113-119.

Chang, C. Y. M. R., Zhang, H & Yao, L. (2019). Bioaccumulation and Health Risk Assessment of Heavy Metals in the Soil-Rice System in a Typical Seleniferous Area in Central China. *Environmental Toxicology and Chemistry*, 38(7),1577-1584.

Chen, J., He, F., Zhang, X., Sun, X., Zheng, J., & Zheng, J. (2014). Heavy Metal Pollution Decreases Microbial Abundance, Diversity and Activity Within Particle-Size Fractions of a Paddy Soil. *FEMS Microbiology Ecology*, 87, 164-187.

Chen, J., Wang, J. Wang, Y. W., Yao, Q. X. & Su, D. (2021). Influencing Factors of Cadmium Bioaccumulation Factor in Crops. *Search life-Sciences Literature*, 42(4),2031-2039

Chen, M., Chen, J., Wang, H., Liu, X., Luo, X. & Wang, M. (2023). Bioaccumulation of Selenium, Heavy Metals and Rare Earth Elements with Different Rice Cultivators Grown on Seleniferous Soils in Lianchen County, Fujian Province, China. *Environments*, 10,114

Cherian, S., & Oliveira, M. (2005). Transgenic Plants in Phytoremediation: Recent Advances and New Possibilities. *Journal of the American Chemical Society*, 39, 9377-9390.

Chibuike, G. U. & Obiora, S. C. (2014). Heavy Metal Polluted Soils: Effect on Plants and Bioremediation Methods. *Applied and Environmental Soil Science*, 2014, 1-12

Clemens, S. (2006). Toxic Metal Accumulation Responses to Exposure and Mechanisms of Tolerance in Plants. *Biochimie*, 88, 1707-1719.

Collin, S. M., Venkatraman, S. k., Vijayakumar, M. N. Kanimozhi, V., Arboaz, S. M., Stacey, R. G. S., Anusha, J., Choudhary, R., Lvov, V., Tovar, G. I., Senator, F., Koppales, S. & Swamiappans, S. (2022) Bioaccumulation of Lead (Pb) and its Effects on Human: A Review. Journal of Hazardous Materials Advances. Available at https:/doi.org/10.1016/j.hazadv.22.100094.

Creswell, J. W. (2014). Research Design: Qualitative, Quantitative and Mixed Methods Approach. 4th ed, Thousand Oaks, CA, SAGE Publications, Califonia.

Cunningham, S. D., & Ow, D. W. (1996). Promises and Prospects of Phytoremediation. *Plant Physiology*, 110, 715–719.

Czarnecki, S., & During, R. A. (2015). Influence of Long Term Mineral Fertilization on Metal Contents and Properties of Soil Samples Taken from Different Locations in Hesse, Germany. *Soil Journal*, 1, 23-33.

Dalcorso, G., Fasani, E., Manara, A. Visioli, G., & Furini, A. (2019). Heavy Metal Pollutions: State of the Art and Innovation in Phytoremediation. *International Journal of Molecular Sciences*, 20(14), 3412-3420.

Dalcorso, G., Manara, A. & Furini, A. (2013). An Overview of Heavy Metal Challenge in Plants from Roots to Shoots. *Metallomics*, 5, 1117-1172.

Dalefield, R. (2017). Toxikinetics. In: Rosalind Dalefield (ed), Veterinary Toxicology for Australia and New Zealand, Elsevier, Masterton, New Zealand. Available at https://doi.org/10.1016/B978-0-12-420227-6.00024-4.

Danika, L., & LeDuc, N. T. (2005). Phytoremediation of Toxic Trace Elements in Soil and Water; *Journal of Industrial Microbiology and Biotechnology*, 32, 514-520.

Dara S. S., & Mishra D. D. (2010). Environmental Chemistry and Pollution Control. S. Chand & company Ltd, New Delhi. Pp. 116-119, 159-184.

Daulta, R., Sridevi, T. & Garg, V. K. (2020). Spatial Distribution of Heavy Metals in Rice Grains, Rice Husk and Arable Soil, their Bioaccumulation and Associated Health Risks in Haryana, India. *Toxins Reviews*, 40(4),859-871.

David, I. J., & Adehi, M. U. (2014). Effectiveness of Split-Plot Design Over Randomized Complete Block Design in Some Experiments. *Journal of Biology, Agriculture and Health Care*, 4(19)**,** 75-80.

Day, J. A., & Cohen, S. M. (2013). Investigating the Selectivity of Metalloenzyme Inhibitors. *Journal of Medicinal Chemistry*, 56(20), 1021.

De Souza, M. P., Pilon-Smits, E. A. H., Lytle, C. M., Hwang, S., Tai, J., Honma, T. S. U., Yeh, L., & Terry, N. (1998). Rate-limiting Steps in Selenium Assimilation and Volatilization by Indian mustard. *Plant Physiology.*, 117**,** 1487-1494.

Defarge, N., Spinuk de Vendomois, J. & Seraline, G. E. (2018). Toxicity of Formulants and Heavy Metals in Glyphosate Based Herbicides and other Pesticides. *Toxicology Reports*, 5,156-153.

Desmarais, T. L. & Costa, M. (2019). Mechanisms of Chromium Induced Toxicity. *Current Opinion on Toxicology,* 14,1-7.

Dhankher, O. P., Li, Y., Rosen, B. P., Shi, J., Salt, D., Senecoff, J. F., Sashti. N. A., & Meagher, R. B. (2002). Engineering Tolerance and Hyperaccumulation of Arsenic in Plants By Combining Arsenate Reductase and γ-Glutamylcysteine Synthetase Expression. *Nature Biotechnology*, 20(11), 1140-1145.

Dimkpa, C., Bindraban, P., Mclean, J. E., Gatere, L., Singh, U., & Hellums, D. (2017). *Methods for Rapid Testing of Plant and Soil Nutrients*. In: E. Lichtouse (ed). Sustainable Agriculture Review. Vol 25. Springer, Cham. Pp 1-43.

Donongelo, C. M. & King, J. C. (2012). Maternal Zinc Intakes and Homeostatic Adjustment During Pregnancy and Lactation, *Nutrients*, 4(7),782-798.

Douchkov, D., Gryczka, C., Stepha, U. W., Hell, R., & Baumlein, H. (2005). Ectopic Expression of Nicotianamine Synthase Genes Results in Accumulation and Increased Nickel Tolerance in Transgenic Tobacco. *Plant, Cell & Environment*, 28, 365-374.

Douvris, C., Vaughan, T., Bassan, D., Bartzaz, G. & Thomas, R. (2023). How ICROES Changed the Face of Trace Element Analysis: Review of the Global Application Landscape. *Science of Total Environment*, 905, 167242

Duggal, K. N. (2007). Elements of Environmental Engineering. S. Chand and Company Ltd, Ram Nagar, New Delhi. Pp. 97.

Dushenkov, S., Skarzhinskaya, M., Glimelius, K., Gleba, D., & Raskin, I. (2002). Bioengineering of a Phytoremediation Plant by Means of Somatic Hybridization. *International Journal of Phytoremediation*, 4, 117-126.

Ebah, E., Tersagh, I. & Okpokwasili, G. C. (2016). Studies on Seasonal Variation and Effect of Heavy Metal Pollution on Microbial Load of Marine Sediment. *American Journal of Marine Science,* 4(1),4-10.

Ebbs, B., Lan, I., Ahner, B., & Kochian, L. (2002). Phytochelatin Synthesis is Not Responsible for Cd Tolerance in the Zn/Cd Hyperaccumulator *Thlaspi caerulescens*. *Planta,* 214, 197-205.

El-Bahi, S. M., El-Dine, N. W., El-Shersshaby, A., & Sroor, A. (2004). Elemental Analysis of Egyptian Phosphate Fertilizer Components. *Health Physics*, 86, 303-307.

Eugenio, N. R., Mclaughlin, M., & Rennock, D. (2018). Soil Pollution. A Hidden Reality. FAO. Rome, Pp 142.

Evanko, C. R., & Dzombak, D. A. (1997). Remediation of Metal Contaminated Soils and Ground Water. Technology Evaluation Report (GWRTAC). Pp 25-42.

Fabjola, B., Marco, L., Laura, B., Alberto, B., Laura, E. D., & Elza, B. (2015). Evaluation of Heavy Metals Contamination from Environment to Food Matrix by TXRF: The Case of Rice and Rice Husk. *Journal of Chemistry*, 2015, 1-12.

Fallah, A., Mohammad-Hassani, A. & Colager, A. H. (2018). Zinc is an Essential Element for Male Fertility: A Review of Zinc Roles in Men's Health, Germination, Sperm Quality and Fertilization. *Journal of Reproduction Infertility*, 19(2), 69-81.

Fang, S. B., Hu, H., Sun, W. C & Pan, J. J. (2011). Spatial Variation of Heavy Metals in the Soils of Vegetable Growing Land Along Urban-Rural Gradient of Nanjing, China. *International Journal Environmental Research, Public Health.* 8, 1805-1816.

Faridullah, F., Umar, M., Alam, A., Sabir, M. A. & Khan S. (2017). Assessment of Heavy Metal Concentrations in Phosphate Rock Deposits, Hazan Basins Lesser Himalaya Pakistani. *Geosciences Journal*, 21,743-752.

Fasani, E. (2012). *Plants that Hyperaccumulate Heavy Metals*. Furini A., Ed. Plants and Heavy Metals. Springer; Cham, Switzerland. pp. 55–74.

Fasani, E., Manara, A., Martini, F., Furini, A., & Dalkorso, G. (2018). The Potential of Genetic Engineering of Plants for the Remediation of Soils Contaminated with Heavy Metals. *Plant Cell and Environment*, 41, 1201-1232.

Ferraro, A., Van, E. D., Huguenot, D., Fabbricino, M. & Esposito, G. (2015). Application of an Electrochemical Treatment for EDDS Soil Washing Solution Regeneration and Reuse in a Multi-Step Soil Washing Process: Case of a Cu Contaminated Soil. *Journal of Environmental Management*, 163, 62–69.

Food and Agriculture Organization (FAO) (2006). Food Security Policy Brief. Issue 2.

Food and Agriculture Organization (FAO). (2023). Dimensions of Need- Staple Foods: What do People Eat? Available at www.fao.org/3/4848oe/4848oe7.htm. Accessed on 20/04/2023.

Fosmire, G. J. (1990). Zinc Toxicity. *American Journal of Clinical Nutrition*., 51(2),227-7.

Franzen, D. W., & Cihacek, L. J. (1998). Soil Sampling as a Basis for Fertilizer Application. NDSU Extension Service, North Dakota State University, Fargo, ND 58105. Pp 4.

Freeman, J. L., Persans, M. W., Nieman, K., Albrecht, C., Peer, W., Pickering, I. J., & Salt D. E. (2004). Increased Glutathione Biosynthesis Plays a Role in Thlaspi Nickel Hyperaccumulator, Arabidopsishallen. *The Plant Cell*, 16, 2176-2191.

Fuksova, Z., Szakova, J., & Tlustos, P. (2009). Effects of Co-cropping on Bioaccumulation of trace elements in *Thlaspi caenilescens* and *Salix dasyclados*. *Plant Soil and Environment*, 55(11), 461-467.

Fulekar, M. H.; Singh, A., & Bhaduri, A. M. (2008). Genetic Engineering Strategies for Enhancing Phytoremediation of Heavy Metals. *African Journal of Biotechnology*, 4**,** 529-535.

Gambus, F., & Wieczorek, J. (2012). Pollution of Fertilizers with Heavy Metals. *Ecological Chemistry and Engineering A*, 19(4-5)**,** 353-360.

Gan, Z. T., Yao, T., She, X. S., Zhang, P. Q., Wang, Y., Tan, Y. Y., & Qi, N. (2019). Simultaneous Determination of Multiple Elements of Tea Garden Soil Using Inductively Coupled Plasma Mass Spectrometry. *IOP Conf. Series: Earth and Environmental Sciences*, 267, 1-9.

Garba, S. T., Gudusu, M. & Inawa, L. (2018). Accumulation Ability of the Native Grass Species, *Cyperus rotundus* for the Heavy Metals; Zinc (Zn), Cadmium (Cd), Nickel (Ni) and Lead (Pb). *International Research Journal of Pure & Applied Chemistry*, 17(1),1-15.

Garbinski, L. D., Rosen, B. P. & Chen, J. (2019). Pathways of Arsenic Uptake and Efflux. *Environment International*, 126,585-597

Garbisu, C., & Alkorta, I. (2001). Phytoextraction: a Cost-Effective Plant-Based Technology for the Removal of Metals from the Environment. *Bioresource Technology*, 77(3), 229–236.

Gathumbi, J. K., Kanja, L. W., Maitho, T. E., Mbaria, J. M., Nduhiu J. G., Gitau, F. K., Nderitu, J. G., Lucy, M. W. & Maloba, K. (2013). Assessment of Lead and Copper in Fish and Soil Sediments in Kirinyaga South District, Kenya. *Journal of Applied Sciences in Environmental Sanitation*, 8(3),145-150

Genchi, G., Lauria, G., Catalano, A. & Sinicropi, M. S. (2021). The Double Face of Metals: The Intriguing Case of Chromium. *Applied Sciences*, 11(2),638.

Genchi, G., Lauria, G., Catalano, A., Sinicropi, M. S. & Carocci, A. (2023). Biological Activity of Selenium and its Impact on Human Health. *International Journal of Molecular Science*, 24(3),2633.

Ghosh, M., & Singh, S. P. (2005). A Review on Phytoremediation of Heavy Metals and Utilization of its Byproducts. *Applied Ecology and Environmental Research*, 6, 214–231.

Gianessi, L. (2014). *International Pesticide Benefits Case Study No. 108*. Crop Protection Reasearch Institute, Croplife Foundation. Pp 1-5.

Gicheru, M. N. (2016). Barriers and Enablers to Uptake and Implementation of System of Rice Intensification. M. Sc. Thesis, Department of Environmental & Geographical Science, University of Cape Town. Pp 25-26

Gimeno-Garcia, E. Andreu, V. & Boluda, R. (1996). Heavy Metal Incidences in Application of Inorganic Fertilizers and Pesticides to Rice Farming Soils. *Environmental Pollution*, 92(1), 19-25.

Girard, J. E. (2014). Principles of Environmental Chemistry.3rded. Jones & Bartlett Learning, Burlington. Pp. 385-438.

Gitonga, J., Home, P., Murage, H. & Mwangi, J. (2019). Effects of Irrigation Water Regimes, Soil types and Their Interaction on Water Use and Water Productivity from Rice (*Oryza Sativa* L.) Cultivation in Mwea, Central, Kenya. *Jomo Kenyatta University of Agriculture and Technology (JAGST)*, 19(1), 100-117

Goldman, R. D. (2013). Zinc Supplementation for Acute Gastroenteritis. *Canadian Family Physician*, 59(4),363-364.

Grant, T. (2013). Randomized Complete Block Design (Tutorial), Ohio State University. Available at articlesextension.Or/pages/32509/randomized-complete-block-design.

Gratoa, L. P., Prasad, M. N. V., Cardoso, P. F., Lea, P. J., & Azevedo, L. P. (2005). Green Technology for the Clean Up of Toxic Metals in the Environment. *Brazilian Journal of Plant Physiology*, 17, 53-64.

Grungreiff, K., Gottstein, T. & Reinhold, D. (2020). Zinc Deficiency – An Independent Risk Factor in the Pathogenesis of Haemorrhagic Stroke? *Nutrients*, 12(11), 3548.

Guan, T. X., He, H. B., Zhang, X. D., & Bai, Z. (2011). Cu Fractions, Mobility and Bioavailability in Soil-Wheat System After Cu-enriched Livestock Manure Applications. *Chemosphere*, 82, 215-222.

Guilherme, L. R. G., Corguinha, A. P. B., Valle,L. A. R. & Marchi, G. (2019). Heavy Metals in Phosphatic FertilizersMarketed in Brazil: Is This a Concert in Our Agroecosystem? "SYMPHOS 2019", 5th International Symposium on Innovation and Technology in the Phosphate Industry. Pp 1-16.

Guo, W. J., Meetam, M., & Goldsbrough, P. B. (2008). Examining the Specific Contribution of Individual Arabidopsis Metallothioneins to Copper Distribution and Metal Tolerance. *Plant Physiology*, 46, 1697-1706.

Guo, X., Wei, Z., Wu, Q., Li, C., Qian, T., & Zheng, W. (2016). Effect of Soil Washing with Only Chelators or Combining with Ferric Chloride on Soil Heavy Metal Removal and Phytoavailability: Field Experiments. *Chemosphere*, 147, 412–419.

Gupta, Y., Hossain, M., Islam, M. R., Talukder, M. H., Khokon, A. R., Uddin, M. M., Kabir, H., Carey, M., Ralphs, K., Moraes, N. V., Meharg, A. A. & Meharg,C. (2023). Recycled Household Ash in Rice Paddies of Bagladesh for Sustainable Production of Rice Without Altering Grain Arsenic and Cadmium. *Exposure to Health*, 2003,1-13

GWRTAC (1997) Remediation of Metals-Contaminated Soils and Groundwater. Tech. Rep. TE-97 01, GWRTAC, Pittsburgh, Pa, USA, GWRTAC-E Series.

Haddad, M., Nassar, D. & Shtaya, M. (2023). Heavy Metal Accumulation in Soil and Uptake by Barley (*Hordeum Vulgare*) Irrigated with Contaminated Water. *Scientific Reports*, 13(1):4121 doi:10.1038/s41598-022-18014-0

Hadrup, N. & Ravn-Haren, G. (2020). Acute human Toxicity and Mortality After Selenium Ingestion: A Review. *Journal of Trace Elements in Medicine and Biology*, 5,126435.

Hall, J. L. (2002). Cellular Mechanisms for Heavy Metal Detoxification and Tolerance. *Journal of Experimental Botany*, 53**,** 1-11.

Hariharan, S. & Dharmaraj, S. (2020). Selenium and Selenoproteins: Its Role in Regulation of Inflammation. *Inflammopharmacology*, 28,667-695.

Harnung, S. E., & Johnson, M. S. (2012). Chemistry and the Environment. Cambridge University Press, New York. Pp 310-326.

Hasan, G. M. M. A., Das, A. K. & Satter, M. A. (2022). Accumulation of Heavy Metal in Rice (*Oryza sativa* L.) Grains Cultivated in Three Major Areas of Bangladesh. *Journal of Environmental and Public Health*, 2022(2),1-8

Haydon, M. J., & Cobbelt, C. S. (2007). Transporters of Ligands for Essential Metal Ions in Plants. *New Phytologist*, 174, 499-506.

He, Z. Q., Endale, D. M., Schomberg, H. H., & Jenking M. B (2009). Total Phosphorus, Zinc, Copper and Manganese Concentrations in Cecil Soil Through 10 Years of Poultry Litter Application. *Soil Science*, 174, 687-695.

Hema, S. & Sangeeta, G. (2019). Arsenic Concentration in Rice Husk Produced in Trasns Indo-Gangetic Plain of India. *Annals Food Science and Technology*, 20(30),513-519.

Hessel, E. V. S., Staal, Y. C. M., Piersma, A. H., Braver-Sewrady, S. P. & Ezendam, J. (2021). Occupational Exposure to Hexavalent Chromium Part I. *Hazard Assessment of Non-Cancer Health Effects*, 126,105048

Hoogsteen, M. J. J., Lantinga, A., Bakker, E. J., Groot, J. C. J., & Titonell, P. A. (2015). Estimating Soil Organic Carbon Through Loss on Ignition: Effects of Ignition Conditions and Structural Water LOSS. *European Journal of Soil Science*, 66, 320-328.

Huang, B., Kuo, S., & Bembenek, R. (2004). Availability of Cadmium in Some Phosphorous Fertilizers to Field–Grown Lettuce. *Water Air Soil & Pollution*, 158**,** 37-51.

Hughes, M. F., Beck, B. D., Chen, Y., Lewis, A. S. & Thomas, D. J. (2011) Arsenic Exposure and Toxicology: A Historical Perspective. *Toxicological Sciences*, 123(2),305-332.

IARC (International Agency for Research on Cancer) (1987). Monograph on the Evaluation of the Carcinogenic Risk of Chemicals for Humans: Arsenic and Arsenic Compounds (Group I) Vol. 7. Lyon, France: World Health Organization: Pp 100-106.

Ibitayo, O. O. (2006). Egyptian Farmers' Behaviours Regarding Agricultural Pesticides Implications for Pesticides with Communication. *Risk Analysis*, 26, 989-995.

Ibrahim, D., Froberg B., Wolf A., & Rusynick, D. E. (2006). Heavy Metal Poisoning: Clinical Presentations and Pathophysiology. *Clinics in Laboratory Medicine*, 26(1), 67-97.

Idiriah, T. J. K., David-Omiema, S. & Ogbonna, D. N. (2012). Distribution of Heavy Metals in Water and Sediment Along Abonnema Shoreline, Nigeria. *Resources and Environment*, 2(1),33-40.

Jack, E., Hakvoot, H. W. J., Reumer, A., Verkleij, J. A. C., Schat, H., & Ernst, W. H. O. (2007). Real-Time PCR Analysis of Metallothionein-2b Expression in Metallicolours Populations of Silene vulgaris (Moench) Garcke. *Environmental & Experimental Botany*, 59, 84-91.

Jaishanker, M., Tseten, T., Abalagam, N., Mathew, B. B., & Beeregowda, K. N. (2014). Toxicity, Mechanism and Health Effects of Some Heavy Metals. *Interdisciplinary Toxicology*, 7(2), 60-72.

Jana, M., Dasgupta, S., Saha, R. N., Liu, X. & Paham, K. (2007). Introduction of Tumour Necrosis Factor-α (TNT-α) by Interleukin-12 P 40 Monomer and Homodimer in Microglia and Macrophages. *Journal of Neurochemistry*, 86(2),519-528.

Jankaite, A., & Saulius, V. (2005). Remediation Technologies for Soils Contaminated with Heavy Metals. *Journal of Environmental Engineering & Landscape Management*, 13(2), 109-113.

Jarup, L. H. (2003). Hazards of Heavy Metals Contamination. *British Medical Bulletin*, 68(1), 167-182.

Javaid, S., Ashraf, K., Sultan, K., Siddiqui, M. H., Ali, H. M., Chen, Y. & Zaman Q. (2022). Risk Assessment of Potentially Toxic Metals and Metalloids in Soil, Water and Plant Continuum of Fragrant Rice. *Agronomy*, 12(10), 2480.

Javier, M., Sara, M. Z., & Turral, H. (2017). Water Pollution from Agriculture. A Global Review. Food & Agriculture Organization of the United Nation, Rome. Pp 1-5.

Jayaprakach, G., Bains, A., Chawla, P., Fogarasi, M. & Fogarasi, S. (2022). A Narrative Review on Rice Proteins: Current Scenario and Food Industrial Application. Polymers, 14(15),3003.

Jayasumana, C., Fonseka, S., Fernando, A., Jayalath, K., Amarasinghe, M., Siribadden, S., Gunatilake, S., & Paranagama, P. (2015). Phosphate Fertilizer in the Main Source of Arsenic in Areas Affected with Chronic Kidney Disease of Unknown Etiology in Sri Lanka. *SpringerPlus* 4:90, https://doi10.1186/540064-015-0868-2.

Jepkoech, J. K., Simiyu, G. M. & Arusei, M. (2013). Selected Heavy Metals in Water and Sediment and their Bioaconcentrations in Plant (*Polygonum pulcrum*) in Sosiani River, Uasin Gishu County, Kenya. *Journal of Environmental Protection*. 4,796-802.

JICA (Japan International Cooperation Agency) (1988). Feasibility Study on the Mwea Irrigation Development Project Main Report. Republic of Kenya, Main Report. Pp 5-6.

Jumba, I. I., & Likimani, T. A. (2001). Chemistry and its Application. Nairobi University Press, Nairobi. Pp. 170-174, 249-257.

Jung, S., Kim, M., Moon, H. Park, Y., Rinklebe, J., Park, C. & Kwon, E. E. (2020). Valorization of Phytoremediation Byproduct via Synthesis of Biodiesel from Cockspur Grass (*Echinochloa crus-galli*) Seed. *American Chemical Society*, 8(31),11588-11595.

Kabir, E. M., Johansen, C. & Bell, R. W. (2016). Effect of Phosphorous Fertilizer Placement on Emergence and Early Growth of Chickpea (*Cicer arietinum L.*). *Khulna University Studies*, 13(1):65-78

Kabir, E., Ray, S., Kim, K. H., Yoon, H. O., Jeon, E. C., Kim, Y. S., Cho, Y. S., Yun, S. T., & Brown, R. J. C. (2012). Current Status of Trace Metal Pollution in Soils Affected by Industrial Activities. *The Scientific World Journal*, 2012, 916705.

Kamoni, P. T. (1992). Detailed Soil Survey of Mwea Irrigation Agricultural Development Project (MIAD) (Mwea Division Kirinyaga District) No. D56, Kenya Agricultural Research Institute, National Agricultural Research Laboratories, Kenya Soil Suevey. Nairobi, Kenya. Pp 3-7

Kananu, J. (2015). Effects of Long Term Use of Inorganic Fertilizers on Accumulation of Selected Heavy Metals and Primary Macronutrients on Maize Farm Soils: A Case Study of Kerita Farm in Transzoia County of Kenya. Master of Science Thesis, University of Nairobi, Kenya, Pp 64.

Kar, D., Sur, P., Mandal, S., Saha, T., & Kole, R. (2008). Assessment of Heavy Metal Pollution in Surface Water. *International Journal of Science and Technology*. 5, 119-124.

Karishnma, B., & Prasad, S. H. (2014). Effect of Agrochemicals Application on Accumulation of Heavy Metals on Soils of Different Land Uses with Respect to its Nutrient Status. *IOSR-Journal of Environmental Science, Toxicology and Food Technology,* 8(7), 46-54.

Karthikeyan, R., Davis, C. D., Erickson, P. L., Hutchirison, S. L., & Nurzhanova, A. A. (2004). Potential for Plant-Based Remediation of Pesticide-Contaminated Soil and Water Using Nontarget Plants such as Trees, Shrubs and Grasses. *Critical Reviews in Plant Sciences*, 23(1), 91-101.

Katz, S. A. (2019). On the Use of Hair Analysis for Assessing Arsenic Intoxication. *International Journal of Environmental Research and Public Health*, 16(6),977.

Kaya-Akyzuzlu, D., Kayaalt, Z., Dogan, D, & Soylemezoglu, T. (2016). Does Material MDRI C123T Polymorphism have an Effect on Placental Arsenic Levels? *Environmental Toxicology & Pharmacology*, 41,142-146.

Keller, C., & Hammer, D. (2004). Metal Availability and Soil Toxicity after Repeated Croppings of *Thlaspi Caerulescens* in Metal Contaminated Soils. *Environmental Pollution*, 131, 243–254.

Kenya Bureau of Standards (KEBS) (2018). Kenya Standard Soluble Compound Fertilizer-Specification. 1st ed, Nairobi, Kenya.

Kenya National Bureau of Statistics (KNBS) (2019). 2019 Kenya Population and Housing Census Vol 1: Population by County and Subcounty, Nairobi, Kenya. Pp 15.

Kenya National Bureau of Statistics (KNBS) (2024). Economic Survey of Kenya, Nairobi, Kenya. Pp 194-195.

Khalid, S., Shalid, M., Niazi, N. K., Murtaza, R., Bibi, I., & Dumal, C. (2016). A Comparison of Technologies for Remediation of Heavy Metals Contaminated Soils. *Journal of Geochemical Exploration,* 182, 247-268.

Khan, S. R.., Sharma, B., Chawla, P. A. & Bhatia, R. (2021). Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES): A Powerful Analytical Technique for Elemental Analysis. *Food Analytical Methods,* 15, 666-688

Khani, M., Muhammad, A. R. & Omar, D. (2012). Insecticidal Effects of Papermint and Black Pepper Essential Oils Against Rice Weevil, Sitopholus Oryzae L. and Corcyra Cephalonica (st). *Journal of Medicinal Plants*. 11(43), 97-110

Kiarie, G. (2003). Assessment of Crop-Livestock Interactions and Production of Rice Based Feed Resources in Mwea Irrigation Scheme, Kirinyaga District, Central Province, Kenya. Master of Science Thesis, University of Nairobi, Nairobi, Kenya.

Kieliszek, M. & Blazejack S. (2016). Current Knowledge on Importance of Selenium in Food for Living Organisms: A Review. *Molecules*, 21(5),609.

Kieliszek, M., Bano, I. & Zare, H. (2011). A Comprehensive Review on Selenium and its Effects on Human Health and Distribution in Middle Eastern Countries. *Biological Trace Elements Research*, 200,971-987.

Kihara, J., & Huising, J. (2016). Understanding Variability in Crop Response to Fertilizer and Amendments in Sub-Sahara Africa. *Agriculture, Ecosystems & Environment*, 229, 1-12.

Kihoro, J., Bosco, N. J., Murage, H., Ateka, E., & Makihara, D. (2013). Investigating the Impact of Rice Blast Disease on the Livelihood of the Local Farmers in the Greater Mwea Region of Kenya. *Springerplus,* 2(1), 1-13.

Kilongi, E. M. (2017). Phytoremediation of Heavy Metals in Sewage Sludge by Brassicae Family Plants; Turnip, Sunflower and Mustard. Master of Science Thesis, University of Nairobi, Kenya.

Kim, D. Takahashi, M., Higuschi, K., Tsunoda, K., Nakanishi, H., Yoshimura, E., Mori, S., & Nashizawa, N. K. (2005). Increased Nicotiamine Biosynthesis Confers Enhanced Tolerance to High Levels of Metals in Particular Nickel, to Plants. *Plant Cell Physiology*, 46, 1809-1818.

Kimari, C. (2019). Challenges and Opportunities of Land Tenure and Subdivision on Rice Production in Irrigation Schemes in Kenya: A Case of Mwea Irrigation Scheme. Master of Arts Thesis, University of Nairobi, Kenya. Pp 17-20

Kingston, H. M. & Walter, P.J. (1998). The Art and Science of Microwave Sample Preparations for Trace and Ultratrace Elemental Analysis in Inductively Coupled Mass Spectrometry, A. Montaser, Wiley-VCH, New York. Pp 33-81.

Kirkley, R. B., Popichak, K.D., Afzali, M. F., Legare, M. E. & Tjalkens, R. B. (2017). Microglia Amplify Inflammatory Activation of Astrocytes in Manganese Neurotoxicity. *Journal of Neuroinflammation*, 14,99

Kirpichtchikova, T. A., Manceau, A., Spadini, L., Panfili, F., Marcus, M. A., & Jacquet, T. (2006). Speciation and Solubility of Heavy Metals in Contaminated Soil Using X-ray Microfluorescence, EXAFS Spectroscopy, Chemical Extraction, and Thermodynamic Modeling. *Geochimica et Cosmochimica Acta*, 70(9), 2163–2190.

Kombo, D. & Tromp, D. (2006). Proposal and Thesis Writing: An Introduction. Paulines Publications Africa, Nairobi. Pp 814-30.

Kong, X., Liu, T.,Yu,Z.,Chen, Z.,Lei, D., Wang, Z., Zhang, H., Li, Q. & Zhang, S. (2018). Heavy Metal Bioaccumulation in Rice from a High Geological Background Area in Guizhou Province,China. *International Journal of Environmental Research and Public Health*, 15(10),2281.

Koskei, K. V. (2016). Diversity of Weeds and their Integrated Management Practices in Paddy Rice (Oryza sativa) Production. Master of Science Thesis, University of Nairobi, Nairobi, Kenya. Pp 20-23

Kozminska, A., Wiszniewska, A. Ewa, H., & Muszynska, E. (2018). Recent Strategies of Increasing Metal Tolerance and Phytoremediation Potential Using Genetic Transformation of Plants. *Plant Biotechnology Reports*, 12(1), 1-14.

Kramar, U. (2005). Phytoremediation: Novel Approaches to Cleaning Up Polluted Soils. *Current Opinion in Biotechnology***,** 16, 133-141.

Kramer, U., Pickering, I. J.; Prince, R. C.; Raskin, I., & Salt, D. E. (2000). Subcellular Localization and Speculation of Nickel in Hyperaccumulator and Non-accumulator *Thlaspi* Species. *Plant Physiology,* 122**,** 1343-53.

Kuiper, I., Lagendijk, E. L., Bloemberg, G. V., & Lugtenberg, B. J. J. (2004). Rhizoremediaion: A Beneficial Plant-microbe Interaction. *The American Phytopathological Society,* 17(1), 6-15.

Kumar, P. B. A. N., Dushenkov, V., Motto, H., & Raskin, T. (1995). Phytoextraction: The Use of plants to Remove Heavy Metals from Soils. *Environmental Science & Technology*., 29, 1232-1238.

Kundu, C. A., Ishii, M., Sato, K., Wanjogu, R. K., Makihara, D., Yamauchi, A. & Masunaga, T. (2017). An Assessment of Paddy Production System in Central Kenya with Special Reference to Micronutrients, *Journal of Agricultural Science,* 9(6), 49-63.

Kunhikrishna, A., Go, W., Park, J., Kim, K., Kim, H., Kim, K.,Kim, W. & Cho, N.. (2015). Heavy Metal(loid) Levels in Paddy Soils and Brown Rice in Korea. *Korean Journal of Soil science and Fertilizer*, 48(5), 515-521.

Kuria, J. N. (2004). An Economic Analysis of Rice Production in Mwea Irrigation scheme. Master of Science Thesis, University of Nairobi, Nairobi, Kenya. Pp 46-49.

Lalah, J. O., Otieno, P. O., Odira, Z. & Ogunah J. A. (2022). Pesticides: Chemistry, Manufacturing, Regulation, Usage and Impacts on Population in Kenya. In: M. L. Larramendy and S. Soloneski (Eds.). Pesticides – Updates on Toxicity, Efficacy and Risk Assessment. IntechOpen. Pp 1-51

Lewicki, S., Zdanowski, R., Krzzowska, M., Lewicka, A., Debski, B., Niemcewicz, M. & Goniewicz, M. (2014). The Role of Chromium III in the Organism and its possible Use in Diabetes and Obesity Treatment. *Annals of Agricultural and environmental Medicine*, 21(2),331-335.

Li, X., Du, J., Sun, L., Zhang, L., Zhang, Y., Feng, Y., Zhang, L. Wang, G. & Huang. X. (2022). Derivation of Soil Criteria of Cadmium for Safe Rice Production Applying Soil-Plant Transfer Model and Species Sensitivity Distribution. *International Journal of Environmental Research and Public Health*, 19(14),8854

Liu. W. H., Zhao J. Z., Ouyang, Z. Y., Soderhand L., & Liu, G. H. (2005). Impacts of Sewage Irrigation on Heavy Metal Distribution and Contamination in Beijing, China. *Environmental International Journal*, 31(6)**,** 805-812.

Llyas, S., Sabo, A. & Akomolafe, G. F. (2021). Assessment of Metal, Accumulation in Plant and Soil at Eggon Community Mining Site, Nasarawa. *Nigeria Journal of Research in Forestry, Wildlife & Environment*, 13(3),11-21.

Lu, A., Li, B., Li, J., Chen, W. & Xu, L. (2018). Heavy Metals in Paddy Soil-Rice Systems of Industrial and Township Areas from Subtropical China: Levels, Transfer and Health Risk. *Journal of Geochemical Exploration*, 194,210-217

Lu, Y., Deng, X., Quan, L., Xia, Y., & Shen, Z. (2015). Metallothioneins BcMT1 and BcMT2 from *Brassica campestris* Enhanced Tolerance to Cadmium and Copper and Decrease Production of Reactive Oxygen Species in *Arabidopsis thaliana*. *Plant Soil*, 367, 507-519.

Lucas, A. M. & Mbiti, I. M. (2012). Access, Sorting and Achievement: The Short-Run Effects of Free Primary Education in Kenya. *American Economic Journal: Applied Economics*, 4(4):226-253

Ma, Y., Zhang, N., Li, Y., Zhao, H., Zhou, F., Xue, M., Lyu, L., Yang, J., Ban, Y. B., Wi, F. & Liang, D. (2023). Differences in Selenium Concentration and Bioavailability Between Paddy and Dryland Soils of China: A Study Based on Literature Collection and Field Sampling, *Journal of Hazardous Materials*, 445,130467

Machiwa, J. F. (2020). Heavy Metal Levels in Paddy Soils and Rice (*Oryza sativa* (L)) from Wetlands of Lake Victoria Basin, Tanzania. *Tanzanian Journal of Science*, 36,59-72

Mahar, A., Wang, P., Ali, A., Kumar, M., Hussain, A., Wang, Q., Li, R., & Zhang, Z. (2016). Challenges and Opportunities in the Phytoremediation of Heavy Metals Contaminated Soils: A Review. *Ecotoxicology Environmental Safety***,** 126, 111–121.

Mahmud, H. N. M., Huq, A. K. O. & Yahya, R. (2016). Removal of Heavy Metal Ions from Waste Water/Aqueous Solution by Polypyrrole-based Adsorbent. A Review. *RSC Advances*, 6, 14778

Makino, T., Takano, H., Kamiya, T., Itou, T., Sekiya, N., Inahara, M., & Sakurai, Y. (2010). Restoration of Cadmium-Contaminated Paddy Soils by Washing with Ferric Chloride: Cd Extraction Mechanism and Bench-Scale Verification. *Chemosphere*, 70, 1035–1043.

Mallampati, S. R., Mitoma, Y., Okuda, T., Simion, C., & Lee, B. K. (2015). Dynamic Immobilization of Simulated Radionuclide 133 Cs in Soil by Thermal Treatment/Vitrification with Nanometallic Ca/Cao Composites. *Journal of Environmental Radioactivity*, 139, 118–124.

Mamyrbaev, A. A., Dzharkenov, T. A., Imangazina, Z. A. & Satybaldieva, U. A. (2015). Mutagenic and Carcinogenic Actions of Chromium and its Compounds. *Environmental Health and Preventive Medicine*, 20(3),159-167.

Manahan, S. E. (2010). *Environmental Chemistry*, 9thed. New York, CRC Press. Pp. 434-440.

Mangun, S. J. (2009). Microwave Digestion – EPA Method 3052 on the Multiwave 3000. Field Application Report, PerkinElmer Inc, Shelton, CT 06484. USA.

Mani, D., & Kumar, C. (2014). Biotechnological Advances in Bioremediation of Heavy Metals Contaminated Ecosystem: An Overview with Special Reference to Phytoremediation. *International Journal of Environmental Technology*., 11, 843-872.

Manjunatha, N. (2019). Descriptive Research. *Journal of Emerging Technologies and Innovative Research*, 6(6), 863-867.

Marcovecchio, J. E., Botte, S. E., & Freije, R. H. (2007). *Heavy Metals, Major Metals, Trace Elements*. Handbook of Water Analysis, L. M. Nollet (ed). 2nd ed. London, CRC Press. Pp 275-300.

Margui, E., Queralt & Almeida, E. (2022).X-ray Fluorescence Spectroscopy for Environmental Analysis: Basic Principles, Instrumentation, Applications and Recent Trends. *Chemosphere*, https://doi.org/10.1016/j.chemosphere.2022.135006

Maroney, M. J. & Hondal, R. J. (2018). Selenium versus Sulfur: Reversibility of Chemical Reactions and Resistance to Permanent Oxidation in Proteins and Nucleic Acids. *Free Radical Biology and Medicine*. 1(127),228-237.

Marques, A. P. G. C., Rangel, A. O. S. S., & Castro, P. M. L. (2009). Remediation of Heavy Metal Contaminated Soils: Phytoremediation as a Potentially Promising Clean-Up Technology. *Critical Review of Environmental Science & Technology*, 39, 622–654.

Martin, K. V., Edmondson, D., Cecil, K. M., Bezi, C., Vance, M. L., McBride, D. & Haynes, E. N. (2020). Manganese Exposure and Neurologic Outcomes in Adult Populations. *Neurolocic Clinics*, 38(4),9133-936.

Martinez-Finley, Gavin, C. E., Aschner, M. & Gunter, T. R. (2013). Manganese Neurotoxicity and the Role of Reactive Oxygen Species. *Free Radical Biology and Medicine*, 62,65-75.

Martnez, M., Bernal, P., Almela, C., Velez, D., Garcia-Agustin, P., Serrano, R., & Navarro-Avino, I. (2006). An Engineered Plant that Accumulates Higher Levels of Heavy Metals than *Thlaspi Caerulescens*, with Yields of 100 Times More Biomass in Mine Soils. *Chemosphere*, 64(3), 478-485.

Masson, P., Dalix, T., & Bussiere, S. (2010). Determination of Major and Trace Elements in Plant Samples by Inductively Coupled Plasma- Mass Spectrometry. *Communication in Soil Science and Plant Analysis,* 419(3), 231-243.

Mati, B. M., Wanjogu, R., Odongo, B. & Home, P. G. (2011). Introduction of the System of Rice Intensification in Kenya Experiences from Mwea Irrigation Scheme. *Paddy and Water Environment*, 9, 145-154.

Mburu, B. K. & Ngucia, C. W. (2022). Adoption of Climate Change Friendly New Rice for Africa (NERICA) varieties Among Farmers in Mwea West Subcounty, Kenya, *African Journal of Environmental Science and Technology*, 16(2), 71-78

Mclaughlin, M. J., Parker, D. R., & Clarke, J. M. (1999). Metals and Micronutrients-Food Safety Issues. *Field Crops Research*, 60**,** 143-160.

Medagbe, F. M. K., Komatsu, S., Mujawamariya, G. & Saito, K. (2020). Men and Women in Rice Farming in Africa: A Cross-Country Investigation of Labour and its Determinants. *Frontiers in Sustainable Food Systems*, 4, 17

Michalak, M., Pierzak, M., Krecisz, B. & Suliga, E. (2021). Bioactive Compounds for Skin Health: A Review. *Nutrients*, 13(1),203.

Ministry of Agriculture (MOA) (2008). National Rice Development Strategy (2008-2018). KARI, Nairobi: Information and Documentation Services. Republic of Kenya. http://ke/handle/12345679/2068.

Ministry of Agriculture, Livestock, Fisheries & Cooperatives (MoALFC) (2020). National Rice Development Strategy-2 (2019-2030). State Department for Crop Development and Agricultural Research, Nairobi, Kenya. Government of Kenya. Pp 4-5.

Minuye, A., Zenge, F. & Chandravanshi, B. S. (2020). Levels of Selenium in Selected River, Well and Bottled Waters in Ethiopia by Microwave Plasma-Atomic Emission Spectroscopy. *Bulletin of the Chemical Society of Ethiopia*, 34(2),215-226.

Montgomery, D. C. (2017). Design and Analysis of Experiments. 9th ed, John Wiley & Sons, New York.

Moywaywa, B. A. (2018). Heavy Metal Pollution Sediment, Water and Flora Along Thika River. Master of Science Thesis, University of Nairobi, Kenya. Pp 44-48

Muhunyu, J. G. (2012). Is Doubling Rice Production in Kenya by 2018 Achievable? *Journal of Developments in Sustainable Agriculture*, 7, 46-54.

Muiruri, J. M., Nyambaka, J. M. & Nawiri, M. P. (2013). Heavy Metal in Water and Tilapia Fish from Athi-Galana-Sabaki Tributaries, Kenya. *International Food Research Journal*, 20(2), 891-896.

Mulware, S. J. (2013). Trace Elements and Carcinogenicity: A Subject in Review. *Biotechnology*, 8(2), 55-64.

Munyua, J. M. (2020). Mwea Irrigation Scheme in Kenya: Did the Religious Institutions Abandon Their Members During and Before the Mwea Rice Farmers Revolt of 1998? *JJEOSHS*, 3(1),1-11.

Mustafa, U. N. (2019). Assessment of Heavy Metal Pollution in Water, Soil & Rice Grown Around River Yobe, Nigeria. Master of Science Thesis, Kampala International University, Kampala, Uganda. Pp 37-42.

Muzaffar, S., Khan, J., Srivastava, R., Gorbatyuk, M. S. & Ather, M. (2023). Mechanistic Understanding of the Toxic Effects of Arsenic and Warfare Arsenicals on Human Health and Environment. *Cell Biology and Toxicology*, 39(1),85-110.

Mwegoha, W. J. S., & Kihampa, C. (2010). Heavy Metal Contamination in Agricultural Soils and Water in Dar es Salaam City, Tanzania. *African Journal Environmental Science and Technology*, 4(11)**,** 763-769.

Narayanan, P. (2014). Environmental Pollution: Principles, Analysis and Control. CBS Publishers Distributors PVT Ltd. New Delhi. Pp. 189-199.

National Irrigation Board (NIB). (2016). National Irrigation Board Irrigation Projects. Available from www.nib.or.ke/93-irrigation-projects-per-county/118-irrigationscheme.

Ndeda, L., & Manohar, S. (2014). Bio Concentration Factor and Translocation Ability of Heavy Metals with Different Habitats of Hydrophytes in Nairobi Dam, Kenya. *IOSR-Journal of Environmental Science, Toxicology and Food Technology*, 8(5), 42-45.

Ndiiri, J. A., Mati, B. M., Home, P. G., Odongo, B., & Uphoff, N. (2012). Comparison of Water Savings of Paddy Rice Under System of Rice Intensification (SRI) Growing Rice in Mwea, Kenya, *International Journal of Current Research and Review*, 4(6), 63-73.

Ndolo, M. A.., Simatwa, E. M. W. & Ayodo, T. M. O. (2016). Impact of Free Secondary Education Policy on Access to Secondary School Education in Kenya. A Case Study of Mbita and Suba Sub-Counties. *Greener Journal of Education Research*, 6(2):67-85

Ndungu, A. W., Yan, X., Makokha, V. A., Githaiga, K. B. & Wang, J. (2019). Occurrence and Risk Assessment of Heavy Metals and Organochlorine Pesticides in Surface Soils, Central Kenya, *Journal of Environmental Health Science & Engineering*, 17(1),63-73.

Ngige, J. K. (2004). An Economic Analysis of Rice Production in Mwea Irrigation Scheme. M Sc. Thesis in Agriculture Economics, University of Nairobi, Kenya. Pp 62-65.

Nicholson, F. A., Smith, S. R., Alloway, B. J., Carlton-Smith, C., & Chambers, B. J (2003). An Inventory of Heavy Metals Input to Agricultural Soils in England and Wales, *Science of the Total Environment*, 311, 205-219.

Nicholson, R. J., Webb, J., & Moore, A. (2002). A Review of the Environmental Effects of Different Livestock Manure Storage Systems and a Suggested Procedure for Assigning Environmental Ratings. *Biosystems Engineering*, 81(4), 363-377.

Njue, W. M., Aduda, L. A., Mwangi, H., & Swaleh, S. (2019). Assessment of Potential Human Exposure to Arsenic in Imported and Locally Produced Rice in Kenya. *EC Nutrition*, 14(11), 86-95.

Njuguna, S. M., Gitonga, K. B., Onyango, J. A., Gituru, R. W. & Yan, X. (2021). Ecological and Health Risk Assessment of Potentially Toxic Elements in Ewaso Nyiro River Surface Water, Kenya. *SN Applied Sciences*, 3,148

Nsikak, U. B., Winfred, U. A., & Usoro, M. E. (2014). Trace Metal Levels in Inorganic Fertilizers Commercially Available in Nigeria. *Journal of Scientific Research & Reports*, 3(4), 610-620.

Nyabonyi, O. J (2016). Suitability Assessment of Effluents from Mwea Irrigation Scheme for Reuse in Irrigation for Rice Production, Kirinyaga County, Kenya. Master of Science Thesis, Kenyatta University, Nairobi, Kenya. Pp 50.

Nyakairu, W. A. G., & Christian, K. (2000). Mineralogical and Chemical Composition and Distribution of Rare Earth Elements in Clay-Rich Sediments from Central Uganda. Institute of Geochemistry, University of Vienna, Althanastrasse 14, A-1090 Vienna, Austria.

Nzonzo, D. M. (2016). Information Communication Technologies Adoption in Irrigated Rice Production: Case Study of Mwea Irrigation Scheme. Master of Arts Thesis, University of Nairobi, Nairobi, Kenya. Pp 23-27.

O'Neal, S. L. & Zheng, W. (2015). Manganese Toxicity Upon Overexposure: A Decade in Review. *Current Environmental Health Reports*, 2(3),315-328.

Obwa, M. A. (2016). Determinants of Rice Production in Ahero Irrigation Scheme in Kisumu County, Kenya. Master of Arts Thesis, Maseno University, Kenya. Pp 37-40.

Ogabiela, E. E., Paul, E. D., Adesina, O. B., Okonkwo, E. M., Ogbonna, J. O. & Amana, S. M. (2009). Heavy Metal Composition of Commercial Fertilizers from Zaira, Northern Nigeria. *Global Journal of Pure and Applied Sciences*, 15(1),15-19.

Ogawa-Wong, A. N., Berry, M. J. & Seale, L. A. (2016). Selenium and Metabolic Disorders: An Emphasis on Type 2 Diabetes Risk. *Nutrients*, 8(2),80.

Ogun, A. S., Joy, N. V. & Valentine, M. (2023). Biochemistry of Heme Synthesis. In: Statpears (ed), Treasure Island (Fl): Statpearls Publishing. Available at https://wwncb.nlm.nih.gov/books/NBK537329/.

Ogunkunle, A. T. J., Bello, O. S., & Ojofeitimi, O. S. (2014). Determination of Heavy Metal Contamination of Street-vended Fruits and Vegetables in Lagos State, Nigeria. *International Food Research Journal*, 21(6)**,** 2115-2120.

Okalebo, J. R., Gathua, K. W., & Woomer, P. L. (2002). Laboratory Methods of Soils and Plants Analysis. A working Manual, 2nd ed, Sacred Africa, Nairobi. Pp. 12-17.

Okalebo, J. R., Othieno, C. O., Nekesa, A. O. & Wairimu, K. (2009). Potential for Agricultural Lime on Improved Soil Health and Agricultural Production in Kenya. *Journal of African Crop Science*, 9,339-341.

Okumu, M. N. (2020). The Role of Women in Irrigation: A Case Study of the Ahero Irrigation Scheme in Kenya. Doctor of Philosophy Thesis, University of Kwazulu-Natal

Oladipo, O. G., Awotoye, O. O., Olayinka, A., Buzuidenhont, C. C., & Maboeta, M. S. (2018). Heavy Metal Tolerance Traits of Filamentous Fungi Isolated from Gold & Gemstone Mining Sites. *Brazilian Journal of Microbiology*, 49(1), 29-37.

Omondi, C. (2017). Distribution of Heavy Metals in Water and Sediments of Lower River Nzoia, Master of Science Thesis, University of Nairobi, Kenya. Pp 30-36.

Omondi, S. O. & Shikuku, K. M. (2013). An Analysis of Technical Efficiency of Rice Farmers in Ahero Irrigation Scheme, Kenya. *Journal of Economics and Sustainable Development*, 4(10), 2222-2855.

Onyango, K., Njagi, T., Kinyumu, N. & Kirimi, l. (2016). Changing Consumption Patterns Among Rural and Urban Households in Kenya. Policy Brief No. 23. Tegemeo Institute of Agricultural Policy and Development. Nairobi, Kenya.

Osobamiro, T., Awolesi, O., Alabi, O., Oshinowo, A.,Idris, M. & Busari, F. (2019). Heavy Metal Levels of Soil Samples Collected from a Major Industrial Area in Abeokuta, Southwest Nigeria, *Indian Journal of Scientific Research*, 9,914-919.

Oti, W. J. O. (2016). Review of Principles and Applications of AAS, PIXE and XRF and their Usefulness in Environmental Analysis of Heavy Metals. *IOSR Journal of Applied Chemistry*, 9(6), 15-17

Owiti, O. T. (2015). Assessment of Selected Plants Growing Along Nairobi River for Uptake of Copper, Zinc and Cadmium, Nairobi County, Kenya. M Sc Thesis, Jomo Kenyatta University of Science and Technology.

Oyange, W. A., Chemining'wa, G. N., Kanya, J. I. & Njiruh, P. N. (2019). Azolla Fern in Mwea Irrigation Scheme and its Potential Nitrogen Contribution in Paddy Rice Production. *Journal of Agricultural Science*, 11(18),30-44.

Park, B., & Son, Y. (2016). Ultrasonic and Mechanical Soil Washing Processes for the Removal of Heavy Metals from Soils. *Ultrasonics Sonochemistry*, 35(pt B), 640-645.

Parveen, S., Nakagoshi, N., & Kimura, A. (2003). Perception and Pesticides Use Practices of Rice Farmers in Hiroshima Prefeture, Japan. *Journal of Sustainable Agriculture*, 22(4), 5-30.

Pechova, A. & Pavlata, L. (2007). Chromium as an Essential Nutrient: A Review. *Veterinarni Medicina*, 52,1-18.

Peng, J. S., Ding, G., Meng, S., Yi, H. Y., & Gong, J. M. (2017). Enhanced Metal Tolerance Correlates with Heterotypic Variations in SpMTL, a Metallothionein-like Protein from the Hyperaccumulator *Sedium plumbizincicola*. *Plant, Cell and Environment*, 40(8), 1368-1378.

Persans, M. W., Yan, X., Patnoe, J. M., Kramer, U., & Salt, D. E. (1999). Molecular Dissection of the Role of Histidine in Nickel Hyperaccumulation on *Thlaspi goesingense*. *Plant Biology,* 121, 1117-1126.

Peuke, A. D., & Rennenberg, H. (2005). Phytoremediation. *EMBO Rep*, 6(6)**,** 497-501.

Phillips, J. D. (2019). Heme Biosynthesis and the Porphyrias. *Molecular Genetics Metabolism*, 128(3), 164-177.

Pieczynska, J., Placzkowska, S., Sozanski, R., Skorska, K. & Soltysik, M. (2021). Effect of Nickel on Red Blood Cell Parameters and on Serum Vitamin B12, Folate and Homocysteine Concentrations During Pregnancy with and without Anemia. *Journal of Trace Elements in Medicine and Biotechnology*. Doi:10.1016/jtemb.2021.126839

Pilon-Smits, E. & Pilon, M. (2002). Phytoremediation of Metals Using Transgenic Plants. *Critical Reviews in Plant Sciences,* 21(5), 439-456.

Plum, L. M., Rink, L. & Haase, H. (2010). The Essential Toxin: Impact of Zinc on Human Health. *International Journal of Environmental Research and Public Health*. 7(4),1342-1365.

Prasad, A. S. (1985). Clinical Manifestations of Zinc Deficiency. *Annual Review of Nutrition,* 5,341-63.

Prasad, A. S. (2013). Discovery of Human Zinc Deficiency: Its Impact on Human Health and Disease. *Advances in Nutrition*, 4(2),176-190.

Prasad, M. N.V., & Freitas, H. (2003) Metal Hyperaccumulation in Plants - Biodiversity Prospecting for Phytoremediation Technology. *Electronic Journal of Biotechnology,* 6, 275-321.

Qu, F. & Zheng, W. (2024). Cadmium Exposure: Mechanisms and Pathways of Toxicity and Implication for Human Health. *Toxics,* 12,388

Quyoom, S. (2014). An Overview of Inhibition of Enzymatic Activities by Heavy Metal Ions. *Chemical Science Review and Letters*,3(11), 381-387

Rachmidian, F. & Sholikah, M. (2019). Effectiveness of *Ludwigia adscendens* and *Ludwigia grandiflora* as Cadmium (Cd) Phytoremediator. Available at Doi:10.4108/eai.12-10-2019.2296356. Accessed on 18/07/2023.

Rael, L. T., Ayala-Fierro, F., Bar-Or, R., Carter, D. E. & Barber, D. S. (2006). Interaction of Arsine with Haemoglobin in Arsine-Induced Hemolysis. *Toxicology Science*, 90(1),142-148.

Rahaman, S., Sinha, A. C., Pati, R. & Mukho, P. (2013). Arsenic Contamination: A Potential Hazard to the Affected Areas of West Bengal, India. *Environmental Geochem Health*, 35(1),119-132.

Rahimi, G., Kolahchi, Z., Charkhabi, A. (2017). Uptake and Translocation of Some Heavy Metals by Rice Crop (Oryza sativa) in Paddy Soils. *Agriculture*, 63(4),163-175

Rahman, A. K.M. R., Hossain, S. M. & Akramuzaman, M. (2010). Distribution of Heavy Metals in Rice Plant Cultivated in Industrial Effluent Receiving Soil. *Environment Asia*, 3(2),15-19.

Rajakumar, S., Abhishak, A., Selvan, G. S. & Nachiappan, V. (2020). Effect on Cadmium on Essential Metals and their Impact on Lipid Metabolism in *Saccharomyces Cerevisiae*. *Cell Stress Chaperones*, 25(1),19-33.

Ramos, P. S. & Manangiki, O. E. (2021). Potential Remediators in Rice Production Area of Zambales, Phillipines, Contaminated with Mine Tailings. Phillipine Rice Research Institute. Available at Doi;https://doi-org/1021203/rs.3rs-1175959/vi. Accessed on 19/07/2023.

Rashid, A., Schutts, B. J., Ulery, A., Deyholds, M. K., Sanogo, S. Lehnhoff, E. A. & Beck, L. (2023). Heavy Metal Contamination in Agricultural Soil: Environmental Pollutants Affecting Crop Health. *Agronomy*, 13(6), 1521 https://doi.org/10.3390/agronomy13061521

Rawat, H., Bhat, S. A., Dhanjal, D. S., Singh, R. Ghandi, Y., Mishra, S. K. Kumar, V., Shakya, S. K., Narasimhaji, C. V., Singh, A., & Achrya, R. (2024). Emerging Techniques for the Trace Elemental Analysis of Plants and Food-based Extracts: A Comprehensive Review. *Talanta Open* 10,100341

Ray, R. R. (2016). Adverse Hematological Effects of Hexavalent Chromium: An Overview. *Interdisciplinary Toxicology*, 9(2),55-65.

Reetz, H.F. (2016). Fertilizers and their Efficient Use. International Fertilizers Industry Association (IFIA) Paris, France. Pp10-14

Reza, R., & Singh, G. (2010). Heavy Metal Contamination and its Indexing Approach for River Water. *International Journal of Environmental Science and Technology*, 7(4)**,** 785-792.

Rickman, J. F. & Gummert, M. (2010). Rice Milling Teaching Manual. Agricultural Engineering, International Rice Research Institute. http://www.knowledgebank.irri.org>fact.sheets>item

Roa, K. V. R. & Norenberg, M. D. (2004). Manganese Induces the Mitochondrial Permeability Transition in Cultured Astrocytes. *Journal of Biological Chemistry*, 279(31),32333-8.

Robison, T. J., Brenneman, W. A., & Myers W. R. (2009). An Intuitive Graphical Approach to Understanding the Split–Plot Experiment. *Journal of Statistics Education*, 17(1), 1-12.

Roccotiello, E., Marescotti, P., Di Piazza, S.,Cecchi, G., Mariotti, M. G., & Zatti, M. (2015). Biodiversity in Metal-Contaminated Sites-Problem and Perspective- A Case Study: In: Y.H. Lo and S. Roy. Biodiversity in Ecosystem – Linking Structure and Function (Pp 563-585). Intechopen.

Rodrigues, S. M. & Romkens, P. F. A. (2018). Human Health Risks and Soil Pollution. In: Duarte, A. C., Cachada, A. & Rocha-Santos, T. (eds). Soil Pollution. Academic Press, Science Direct. Pp 217-250.

Rola, A. C., & Pingali, P. L. (1993). Pesticide, Rice Productivity and Farmers Health: An Economic Assessment. IRRI, Manila. Pp 31-39.

Roohani, N., Hurrol, R., Kelihadi, R. & Schulin, R. (2013). Zinc and its Importance for Human Health: An Integrative Review. *Journal of Research in Medical Sciences*, 18(2),142-157.

Rosenzweig, W. D., & Pramer, D. (1980). Influence of Cadmium, Zinc and Lead on Growth, Trap Formation and Collagenase Activity of Nematode-Trapping Fungi. *Applied Environmental Microbiology*, 40(4)**,** 694-696.

Rubino, F. M. (2015). Toxicity of Glutathione-Binding Metals: A Review of Targets and Mechanisms. *Toxics*, 3, 20-62.

Rudzi, S. K., Ho, Y. B. & Kharni, I. I. A. (2018). Heavy Metal Contamination in Paddy Soil and Water and Associated Dermal Health Risks Among Farmers, *Malaysian Journal of Medicine and Health Sciences*, 14(SP2), 2-10

Rugh, C. L., Senecoff, J. F., Meagher, R. B., & Merkle, S. A. (1998). Development of Transgenic Yellow Poplar for Mercury Phytoremediation. *Nature Biotechnology*, 16, 925–928.

Sabir, M., Waraich, E. A., Hakeem, K. R., Ozturk, M., Ahmad, H. R., & Shahid, M. (2015). Phytoremediation, *Soil Remediation and Plants*. 2015, 85-105.

Sabo, A. & Ladan, M. (2018). Phytoremediation Potential of Some Indigeneous Herbaceous Plant Species Growing on Metalliferous Mining Sitesat Nahuta, Bauchi State, Nigeria. *Journal of Environmental Science, Toxicology and Food Technology*,12(4),41-46.

Sadiku, O. O. & Rodrigues-Seijo, A. (2022). Metabolic and Genetic Derangement: A Review of Mechanisms Involved in Arsenic and Lead Toxicity and Genotoxicity. *Archives of Industrial Hygiene and Toxicology*, 73(4),244-255.

Sager, M. (2007). Trace and Nutrient Elements in Manure, Dung and Compost Samples in Austria. *Soil Biology and Biochemistry*, 39, 1383-1390.

Sakakibara, M., Ohmori, Y., Ha, N. T. H., Sano, S., & Sera, K. (2009). Phytoremediation of Heavy Metal-Contaminated Water and Sediment by *Eleocharis acicularis*. *Clean: Soil, Air, Water*. 39, 735–741.

Samal, L. & Mishra, C. (2011). Significance of Nickel in Livestock and Production. *International Journal for Agro Veterinary and Medical Sciences*, 5,349-361

Samlafo, B. V. (2006). Levels of Cadmium in Soil, Sediment and Water Samples from Tarkwa and its Environs. *African Journal of Educational Studies in Mathematics and Sciences*, 4,53-59.

Sammy, G. M. (2019). Effect of Nitrogen Fertilizer Rate and Split Application on Growth and Yield of Selected Rice Varieties in Mwea Irrigation Scheme. Master of Science Thesis, University of Nairobi, Kenya. Pp 17-21.

Sarret, G. Saumiton-Laprade, P., Bert, V., Proux, O., Hazemann, J. L., Traverse, A., Marcus, M. A., & Mancean, A. (2002). Forms of Zinc Accumulated in the Hyperaccumulator *Arabidopsis hallen*. *Plant Physiology*, 130**,** 1815-1826.

Satpathy, D., Reddy, M. V. & Dhal S. P. (2014). Risk Assessment of Heavy Metals Contamination in Paddy Soil, Plants and Grains (*Oryza Sativa* L.) at the East Coast of India. *BioMed Research International*, 2014:545473.

Saturug, S., Vesey, D. A. & Gobe, G. C. (2017). Kidney Cadmium Toxicity, Diabetes and High Blood Pressure: The Perfect Storm. *The Tohoki Journal of Experimental Medicine*, 241(1),65-87.

Scaller, A. & Dietz, T. (1991). Plant Specific Aspect of Heavy Metal Uptake and Comparison with Quality Standards for Food and Forage Crops. *Der Einflub Von Testen Abfallen Auf Boden, Pflanzen*, 92-125

Schat, H., Llugany, M., Vooijs, R., Hartly-Whitaker, J., & Bleeker, P. M. (2002). The Role of Phytochelatin in Constitutive and Adaptive Heavy Metal Tolerances in Hyperaccumulator Metallophytes. *Journal of Experimental Botany*, 53, 2381-2392.

Schnoor, J. L. (1997). Phytoremediation: Technology Evaluation Report, GWRTAC, Pittsburg.

Shahnaj, P. (2010). Rice Farmers' Knowledge about the Effects of Pesticides on Environmental Pollution in Bangladesh. *Bangladesh Research Publications Journal*, 3(4), 1214-1227.

Shao, Y., Zie, B., Li, M. Zhang, X. & Xiao, H. (2020). Selenium Fractionation and Speciation in Paddy Soils and Accumulation in Rice Under Field Conditions in Jinhua Zhejinang Province, China. E3S Wet Conferences, 143,02014.

Sharma, S. S. & Dietz, K. J. (2009). The Relationship Between Metal Toxicity and Cellular Redox Imbalance. *Trends Plant Science*, 14, 3-50

Shayler, H., McBridge, M., & Harrison, E. (2009). Sources and Impacts of Contaminated Soils. Cornell Waste Management Institute, Department of Crop and Soil Sciences. Available at http://cwmi.css.cornell.edu. Accessed on 14/8/2017.

Sheoran, V., Sheoran, A. S., & Poonia, P. (2016). Factors Affecting Phytoextraction: A Review. *Pedosphere*, 26 (2), 148–166.

Shingadgoan, S. S. & Chavan, B. L. (2019). Evaluation of Bioaccumulation Factor (BAF), Bioconcentration Factor (BCF), Translocation Factor (TF) and Metal Enrichment Factor (MEF) Abilities of Aquatic Macrophytes Species Exposed to Metal Contaminated Wastewater. *International Journal of Innovative Research in Science, Engineering and Technology*, 8(1),329-347.

Siklar, Z., Tuna, C., Dallar, Y. & Tanyer, G. (2003). Zinc Deficiency: A Contributing Factor in Short Stature in Growth Hormone Deficient Children. *Journal of Tropical Pediatrics*, 49(3), 187-8

Sing, J., & Kalamdhad, A.S. (2011). Effects of Heavy Metals on Soil, Plants, Human Health and Aquatic Life. *International Journal of Research in Chemistry and Environment*, 1(2), 15-21.

Singh, J., Upadhyay, S. K.,Pathak, R. K. & Gupta, V. (2011). Accumulation of Heavy Metals in Soil and Paddy Crop (*Oryza sativa*), Irrigated with Water of Ramgarh Lake Gorakhpur, UP, India. *Toxicological and Environmental Chemistry*, 93(3),462-473.

Singh, P. K., Kumar, M., Yadav, K. G. & Pal (2017). Effect of Integrated Weed Management on Weed Dynamics and Nutrient Uptake by Weeds in Rice Crop. *Journal of Pharmacognosy and Phytochemistry*, SP1,478-480.

Sinkovic, L., Pipan, B., Neji, M., Rakszegi, M. & Meglic, V. (2023). Influence of Hulling, Cleaning and Brushimg of (Pseudo) Cereal Grains on Composition Characteristics. *Foods*, 12(13), 2452.

Sirotkin, A. V. & Kolesarova, A. (2022). Environmental Contaminants and their Influence on Health and Female Production. Academic Press, Elsevier. Pp 21-79

Skoog, D. A., Holler, F. J. & Crouch, S. R (2017). Principles of Instrumental Analysis, 7th ed. Chicago, Harcourt Brace College Publishers. Pp. 200-310.

Smith, R. J. Jr. (1981). Weeds of Major Economic Importance in Rice and Yield Losses Due to Weed Competition. AGRIS, International Weed Science Society, Corvallis, Oregon (USA). Available at agris.fao.org/agris-search/search. do?recordID=XB8110640. Accessed on 24/04/2023.

Soetan, K. O., Olaiya, C. O. & Oyewole, O. E. (2010). The Importance of Mineral Element for Humans, Domestic Animals and Plants: A review. *African Journal of Food Science*, 4(5),200-222.

Solidum, J., Dykimching, E., Agaceta, C., & Cayco, A. (2012). Assessment and Identification of Heavy Metals in Different Types of Cooked Rice Available in the Phillipine Market. 2nd International Conference on Environmental and Agriculture Engineering (IPCBEE) Vol. 37 @ (2012). IACSIT Press, Singapore. Pp 35-39.

Sriram, K. & Lonchyna, V. A. (2013). Micronutrient Supplementation in Adult Nutrition Therapy: Practical Considerations. *Journal of Parenteral and Enteral Nutrition*. 33(5),548-462.

Staff, N. P. & Windebank, A. J. (2014). Peripheral Neuropathy due to Vitamin Deficiency, Toxins and Medications. *American Academy of Neurology*, 20(5),1293-1306.

Stephan, U. W., & Scholz, G. (1993). Nicotianamine Mediator of Transport of Iron and Heavy Metals in the Phloem? *Physiologia Plantum*, 88, 522-529.

Stroikova, V., Regul, D. & Meder, B. (2020). Rare Case of Selenite Poisoning Manifesting as Non-ST-segment Elevation Mycardial Infarction. *JACC: Case Reports*, 3(5), 811-815.

Sultana, R. Ahmed, T., Islam, S. M. N. & Uddin, N. (2022). Banyard Grass (*Echnochloa crus-galli* L.) as a Candidate Plant for Phytoremediation of Arsenic from Arsenic-Ammended and Industrially Polluted Soils. *Frontiers in Soil Science*, 2:927589, doi:103389/fsoil2022927589.

Suman, J., Uhlik, O., Viktorova, J., & Macek, T. (2018). Phytoextraction of Heavy Metals: A Promising Tool for Clean Up of Polluted Environment. *Frontiers of Plant Sciences*, https://doi.org/10.3389/fp/s2018.01476.

Sylvain, B., Mikael, M. H., Florie, M., Emmanuel, J., Marilyne, S., Sylvain, B., & Domenico, M. (2016). Phytostabilization of As, Sb and Pb by Two Willow Species (S. Viminalis and S. Purpurea) on Former Mine. *Technosols. Catena*, 136, 44–52.

Taiz, L. & Zeiger, E. (2002). Plant Physiology, 3rd ed, Sinauer Associates Sunderland MA. USA.

Tang, L., Qiu, R., Tang, Y. & Wang, S. (2014). Cadmium-Zinc Exchange and their Binary Relationship in the Structure of Zn-Related Proteins: A Mini Review. *Metallomics*, 6,1-12

Tchounwou, P. B., Yedjou, C. G., Patlolla, A. & Sutton, D. J. (2012). Heavy Metal Toxicity and the Environment. *Molecular, Clinical and Environmental Tovicology 3: Environmental Toxicology*, 101, 133-164.

Thakur, M., Rachamalla, M., Niyogi, S., Datusolia, A. K. & Flora, J. S. (2021). Molecular Mechanism of Arsenic-Induced Neurotoxicity including Neuronal Dysfunctions, *International Journal of Molecular Science*, 22(18),10077

Thompson, L. J. (2012). Lead. In: Ramesh C. Gupta (ed). Veterinary Toxicology, 2nd ed. Academic Press. Available at https://doi,org/10.1016/C2010-0-67763-7

Thompson, L. J., Hall, J. O. & Meerdink, G. L. (1991). Toxic Effects of Trace Elements Excess. *Veterinary Clinics of North America: Food Animal Practice*, 7(1),277-306.

Tomno, R. M., Nzeve, J. K., Mailu, S. N., Shitanda, D. & Waswa, F. (2020). Heavy Metal Contamination of Water, Soil and Vegetables in Urban Streams in Machakos Municipality, Kenya. *Scientific African*, 9,1-9

Tripathy, S. K., Dash, M., Behera, S. K., Ithape, D. M., & Maharana, M. (2017). Nutrient Rich Quality Rice- a Journey to Healthy Life. *Advances in Plants & Agriculture Research*, 7(5), 364-367.

Tseng, C. H., Chong, C. K., Chen, C. J. & Tai, T. Y. (1996). Dose-Response Relationship between Peripheral Vascular Disease and Ingested Inorganic Arsenic Among Residents in Blackfoot Disease Endemic Villages in Taiwan. *Atherosclerosis*, 120(1-2),125-33.

Tuorma, T. E. (2002). Chromium, Selenium, Copper and other Trace Minerals in Health and Reproduction. *The Journal of Orthomolecular Medicine*, 15, 145.

Ukpabi, C. F., Akubugwo, E. I., Agbafur, K. N., Lebe, N. A. Nwanlari, N. J. & Nneka, E. D. (2012). Appraisal of Heavy Metal Content in Commercial Inorganic Fertilizes Blended and Marketed in Nigeria. *American Journal of Chemistry*, 2(4), 228-233.

United Nations Environmental Programme (UNEP). (2002). Global Environmental Outlook 3 (GEO 3). London: Earthscan Publications Ltd. Pp 15.

Van Derveer, W. D. & Canton, S. P. (2009). Selenium Sediment Toxicity Thresholds and Derivation of Water Quality Criteria for Fresh Water Biota of Western Streams. *Environmental Toxicology and Chemistry*, 16(6), 1260-1268.

Velmurugan, G. (2012. Rhizoremediation: A Pragmatic Approach for Remediation of Heavy Metals in Soil. KMCH Research Foundation, pp148-161.

Ventura, M., Melo, M. & Carrilho, F. (2017). Selenium and Thyroid Disease: From Pathophysiology to Treatment. *International Journal of Endocrinology* 2017,1297658

Verbruggen, N., Hermans, C., & Schat, H. (2009). Molecular Mechanisms of Metal Hyperaccumulation in Plants. *New Phytologist*, 181, 759–776.

Vinceti, M., Wei, E. T., Malagoli, C., Bergomi, M. & Vivoli, G. (2001). Adverse Health Effects of Selenium in Humans. *Reviews on Environmental Health*, 16(4),233-51.

Violante, A., Cozzoline, V., Perelomov, L. Caporale, A. G. & Pigna, M. (2010). Mobility and Bioavailability of Heavy Metals and Metalloids in Soil Environments. *Journal of Soil Science and Plant Nutrition*, 10(3), 268-292

Visser, D. (2021). Atomic Absorption Spectrometry; Principles and Applications. *Technology Networks- Analysis and Separation*, Accessed on 11/07/2024 from technologynetworks.comm/analysis/articles/atomic-absorption-spectroscopy-principles-and-applications-356828.

Vogel-Mikus, K., Pongrac, P., Kump, P., Necemer, M., & Regvar, M. (2006). Colonisation of a Zn, Cd and Pb Hyperaccumulator Thlaspi Praecox Wulfen with Indigenous Arbuscular Mycorrhizal Fungal Mixture Induces Changes in Heavy Metal and Nutrient Uptake. Environmental *Pollution*, 139, 362–71.

Vukovic, Z., Radenkovic, M., Stankovic, S., & Vukovic, D. (2011). Distribution and Accumulation of Heavy Metals in Water and Sediments of the River Sava. *Journal of Serbian Chemical Society*, 76, 795-803.

Wada, O. (2004). What are Trace Elements?- Their Deficiency and Excess States. *Trace Elements*, 47(8),351-358.

Wafula, V. (2017). Ask Your Agronomist: Fertilizer Application on Rice Grown on Paddy Field. Daily Nation, Friday June 16, 2017.

Wahab, A., Mushtag, K., Borak, S.G. & Bellam, N. (2020). Zinc Induced Copper Deficiency, Sideroblastic Anaemia and Neutropenia: A Perplexing Facet of Zinc Excess. *Clinical Cases Reports,* 8(2),1666-1671

Waheen, EL. M. & Selim, N. M. M. (2017) Determination of Heavy Metals (Pb, Cd & As) in Some Types of Fungicides, *Journal of Biological Chemistry and Environmental Sciences*, 12(3), 97-111.

Wang, Y., Su, H., Gu, Y., Song, X. & Zhao, J. (2017). Carcinogenicity of Chromium and Chemoprevention: a Brief Update. *Onco Targets and Therapy*, 10, 4065-4079.

Wang, Z., Pang, F. & Huang, W. (2021). Accumulation and Translocation of Selenium in a Soil-Rice System in Guangxi, China, *Soil Science and Plant Nutrition,* 67(5),557-565.

Wani, A. I., Ara, A. & Usmani, J. A. (2015). Lead Toxicity: A Review. *Interdisciplinary Toxicology*, 8(2), 55-64

Wanjogu, S. N., Muya, E. M., Macharia, P. N. & Kamoni P. T. (2006). Kenya Soil Survey: Sustainable Land Management in Kiambindu, Kiarukungu, Kyeekolo and Kisioki Smallholder Irrigation Schemes (Mbeere, Kirinyaga, Makueni and Kajiado District). Kenya Agricultural Research Institute, National Agricultural Research Laboratories, Nairobi, Kenya. Pp 40-41

Warra, A. & Jimoh, W. (2011). Overview of an Inductively Coupled Plasma (ICP) System. *International Journal of Chemical Research*, 3(2),41-48

Warren, E. Bryan, M., Morcillo, P., Hardeman, K. Aschner, M. & Bowman, A. B. (2020). Manganese-Induced Mitochondrial Dysfunction is Not Detectable at Exposures Below the Acute Cytotoxic Threshold in Neuronal Cell Types: *Toxicological Sciences*, 176(2),446-459.

Wasike, P., Nawiri, M. & Wanyonyi, A. (2019). LEVELS of Heavy Metals (Pb, Mn, Cu & Cd) in Water in River Kuywa and Adjacent Wells. *Environment and Ecology Research*, 7(3), 135-138.

Watanabe, M., Sumita, Y., Azechi, I., Ito, K. & Noda, K. (2021). The Value Chain of Locally Grown Japonica Rice in Mwea, Kenya. *Agriculture*, 11(10),974.

Water Services Regulatory Board (WASREB) (2008). Guidelines on Water Quality and Effluent Monitoring, Nairobi, Kenya. Pp 25-27.

Wei, Z., Guo, X., Wu, Q., Long, X., & Penn, C. (2011). Phytoextraction of Heavy Metals from Contaminated soils by Co-cropping with Chelator Application and Assessment of Associated Leaching. *International Journal of Phytoremediation*, 13(7)**,** 717-729.

Were, F.., Wafula, G., &Wairungu, S. (2017). Phytoremediation Using Bamboo to Reduce the Risk of Chromium Exposure from a contaminated Tannery Site in kenya. *Journal of Health Pollution*, 16, 12-25.

Wessels, I., Maywald, M. & Rink, L. (2017). Zinc as a Gatekeeper of Immune Function. *Nutrients*, 9(12),1286.

Westfall, D., Mortvedt, J., Peterson G. & Gangloff, W. (2005). Efficient and Environmentally Safe Use of Micronutrients in Agriculture. *Communication in Soil Science and Plant Analysis*, 36,169-182.

Wiklund, J. (2017). Effects of Wood Ash on Soil Fertility and Plant Perfomance in South Western Kenya. Master of Science Thesis, Swedish University of Agricultural Sciences. Pp 34-40.

Williams, N., Lei, M., Sun, G., Huang, Q., Lu, Y., Deeacon, C., Mehang, A., & Zhu, Y. (2009). Occurrence and Partitioning of Cadmium, Arsenic and Lead in Mine Impact Rice: Hunan, China. *Environmental Science & Technology*, 43(3), 637-642.

Wilschefski, C. & Baxter, R. (2019). Inductively Coupled Plasma Mass Spectrometry: Introduction to Clinical Aspect. *The Clinical Biochemist Reviews*, 40(3),115-133.

World Health Organization (WHO) (2010). Childhood Lead Poisoning, WHO, Geneva, Switzerland. Pp 20-30.

Wuana, R. A., & Okieimen, F. E. (2011). Heavy Metals in Contaminated Soils. A Review of Sources, Chemistry, Risks and Best Available strategies for Remediation. *International Scholarly Research Network Ecology*, 1-20, 211.

Wyszkowska, J., Boronik, A., Kucharski, M., & Kucharski, J. (2013) Effect of Cadmium, Copper and Zinc on Plant, Soil Microorganism and Soil Enzymes. *Journal of Elementology,* 5, 769-796.

Xia, Y., Qi, Y., Yuan, Y., Wang, G., Gui, J., Chen, Y., Zhang, H., & Shen, Z. (2012). Overexpression of *Elsholtzia haichowensis* Metallothionein 1 (EhMT1) in Tobacco Plant Enhances Copper Tollerance and Accumulation in Root Cytoplasm and Decreases Hydrogen Peroxide Production. *Journal of Hazardous Materials*, 234, 65-71.

Xie, W., Che, L., Zhou, G., Yang, L. & Hu, M. (2016). The Bioaccumulation Ability of Heavy Metal Research for 50 Kinds of Rice Under the Same Test Conditions. *Environmental Monitoring and Assessment*, 188,675

Xu, S., & Tao, S. (2004). Co- Regionalization Analysis of Heavy Metals in the Surface Soil of Inner Mongolia. *Science of Total Environment*, 320, 73-87.

Yan, L. & Allen, D. C. (2021). Cadmium Induced Kidney Injury: Oxidative Damage as a Unifying Mechanisms. *Biomolecules*, 11(11),1575

Yang, J., Wang, Y., Liu, G., Yang, C., & Li, C. (2011). *Tamarix hispida* Metallothionein-like ThMT3, a Reactive Oxygen Species Scavenger, Increases Tolerance Against Cd^{2+}, Zn^{2+}, Cu^{2+} and NaCl in Transgenic Yeast. *Molecular Biology Reports*, 38, 1567-1574

Yang, Z., Yan, C., Liu, G., Niu, Y., Zhang, W., Lu, S., Li, X., Zhang, H., Ning, G., Fan, J., Qin, L. & Su, Q. (2016). Plasma Selenium Levels and Nonalcoholic Fatty Liver Disease in Chinese Adults: A Cross-sectional Analysis. *Scientific Reports*, 6,37288.

Yao, A. C., Bomisso, E. L., Angaman, D. M., Ipou, I. J., & Kone, M. W. (2019). Farmers Knowledge and Management Practices of Weeds in Rice Fields in Cote D'Ivoire. *African Crop Science Journal*, 27(2),165-182.

Yao, Z., Li, J., Xie, H., & Yu, C. (2012). Review on Remediation Technologies of Soil Contaminated by Heavy Metals. *Procedia Environmental Science*, 16, 722–729.

Yu, H., Zhen, J., Leng, J., Cai, L., Ji, H. & Keller, B. B. (2021). Zinc as a Countermeasure for Cadmium Toxicity. *Acta Pharmacological Sinica*, 42(3),340-346

Zahra, N., Kalim, I., Mahamood, M. & Naeem, N. (2017). Perilous Effects of Heavy Metals Contamination on Human Health. *Pakistan Journal of Analytical and Environmental Chemistry*, 18(1),1-17.

Zane, M. (2023). What is the Working Age Population in the US? Statistics on Prime Working Age Population in America. Zippra.com.Jan30.2023. Accessed on 20/04/2023.

Zhang, C., Appel, E., & Qiao, O. (2012). Heavy Metal Pollution in Farmland Irrigated with River Water Near a Steel Plant—Magnetic and Geological Signature. *Geophysical Journal International*, 192(3), 963-974.

Zhang, J., Zhang, M., Tian S., Lu, L., & Shohang, M. T. (2014). Metallothionein 2 (SaMT2) from *Sedium alfredii* Hance Confers Increased Cd tolerance and Accumulation in Yeast and Tobacco. *PLoS One*, 9(7), 102750.

Zhang, M. K., Liu, Z. Y., & Wang, H. (2013). Use of Single Extraction Methods to Predict Bioavailability of Heavy Metals in Polluted Soils to Rice. *Communications in Soil Science and Plant Analysis*, 41(7), 820–831.

Zhao, H. (2017). Migration of Selenium in Soil-Rice-Human System and its Health Risk Assessment in Enshi. *Asian Agricultural Research*, 9(11),32-40

Zhao, H., Shi, K., Qin, J., Pen, Z. & Yang, G. (2023). Non-carcinogenic Risk Assessment for Heavy Metals in the Soil and Rice in the Vicinity of Dabaoshan Mine, South China. *Processes*, 11,1970

Zhong, W., & Zhao, L. (2016). Determination of Pb (lead), Cd (cadmium), Cr (chromium), Cu (copper) and Ni (nickel) in Chinese Tea with High-resolution Continuum Source Graphite Furnace Atomic Absorption Spectrometry. *Journal of Food and Drug Analysis*, 24(1), 46-55.

Zhu, L., Ding, W., Feng, L., Kong, J., Xu, Y., Xu, J., & Yang, X. (2012). Isolation of Aerobic Denitrifiers and Characterization for their Potential Application in the Bioremediation of Oligotrophic Ecosystem. *Bioresource. Technology*, 108, 1–7.

Zorov, D.B., Juhaszova, M. & Sollott, S.T. (2014). Mitochondial Reactive Oxygen Species (ROS) and ROS-Induced ROS-Release. *Physiological Reviews*, 94(3),909-50.

Zulkafflee, N. S., Redzuan, N. A. M., Hanafi, Z., Selemet, J., Ismail, M. R., Prameena, S. M. & Razis, A. F. A. (2019). Heavy Metal in Paddy Soil and its Bioavailability in Rice Using in Vitro Digestion Model for Health risk Assessment. *International Journal of Environmental Research and Public Health*, 16, 4769-4781.

APPENDICES

Appendix I: Introduction Letter

Department of Physical Sciences,

Chuka University,

P.O. Box 109-60400,

Chuka.

21th August 2021

Dear Respondent,

The bearer of this letter is a student of Chuka University carrying out a study on ‘‘Assessment of Heavy Metal Pollution in Mwea Irrigation Scheme and Development of Transgenic Plant for Phytoremediation of Heavy Metal Contaminated Soils’’. I kindly request your contribution through providing him with relevant information and assistance to make this study a success.

The information provided will only be used for academic purposes and will be treated confidentially

Thank you in advance.

Yours faithfully,

Prof. O. Ombaka

COD, Department of Physical Sciences

Appendix II: Questionnaire for Rice Farmers

This questionnaire is intended to obtain information on agrochemicals and other substances used by farmers in paddy rice farming at Mwea irrigation scheme that may contribute to heavy metal pollution of the soil. The information obtained will be used for academic purposes only and will be treated confidentially. Do not write your name or any other form of identification on this questionnaire.

Section I: Demographic Information

Please, tick or write appropriately

1) What is your gender?

   Male [ ]   Female [ ]

2) How old are you (years)?

   21-30 [ ]   31-40 [ ]   41-50 [ ]   51-60 [ ]   61 and above [ ]

3) What is your highest education level?

   Primary school [ ]   Secondary [ ]   Tertiary [ ]   None [ ]

4) What is the size of your rice farm (in acres)?

   Less than 1 [ ]   1-2 [ ]   2-3 [ ]   3-4 [ ]   Over 4 [ ]

5) How long have you been farming rice on this piece of land (in years)?

   0-9 [ ]   10-19 [ ]   20-29 [ ]   30-39 [ ]   40-49 [ ]   50 and above [ ]

6) How many seasons do you produce rice in a year?

   1 [ ]   2 [ ]   3 [ ]   4 [ ]

7) Which agrovet shop do you mainly buy fertilizers and chemicals from and where is it located?

   ……...

8) List ten types of foods that are commonly consumed by people in this area?

   i) ………………………………………………………
   ii) ………………………………………………………
   iii) ………………………………………………………

iv) ……………………………………………………
v) ……………………………………………………
vi) ……………………………………………………
vii) ……………………………………………………
viii) ……………………………………………………
ix) ……………………………………………………
x) ………………………………………………………

Section II: Agrochemicals Used for Rice Farming and Non-edible Plants Growing in Mwea Irrigation Scheme

Please, tick or give a brief response to the following questions.

1) About how many 50 kg bags of rice do you harvest per season? …………………………………………………………………………….

2) Which fertilizers do you use when planting rice?
   Diammonium Phosphate (DAP) [ ]
   Tri-superphosphate (TSP) [ ]
   Muriate of Potash (MOP) [ ]
   Any other [ ] Specify ………………………………
   ………………………………
   ………………………………

3) Which fertilizers do you top dress rice with?
   Calcium Ammonium Nitrate (CAN) [ ]
   Sulphate of Ammonia (SA) [ ]
   Ammoniun Sulphate Nitrate (ASN) [ ]
   Urea [ ]
   Any other [ ] Specify ……………………………
   ……………………………
   ……………………………

4) What type of manures do you use for rice farming?
   Cattle [ ]
   Goats [ ]

Chicken [ ]

None [ ]

Any other [ ] specify……………………………

5) Which chemicals do you use to control diseases during rice farming (use any language)?

Chemical	Disease targeted	Mode of application

6) Which chemicals do you use to control pests during rice farming (use any language)?

Chemical	Pest targeted	Mode of application

7) Apart from commercial chemicals, which other substances do you use in rice farming (use any language)?

Substance	Target	Mode of application

8) Give any other information on chemicals/substances that are used in rice farming

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

9) Give five non-edible weeds that are commonly found within rice plantations (use any language)

i) …………………………………………….
ii) …………………………………………….
iii) ……………………………………………
iv) …………………………………………….
v) ………………………………………………

10) Give five non-edible shrubs/trees that are common within rice plantations (use any language)

i) ……………………………………………
ii) ……………………………………………
iii) ……………………………………………
iv) ……………………………………………
v) ……………………………………………..

11) Give ten (10) common non-edible plants (weeds/shrubs/trees) that are found in sections where any kind of farming is not done around the irrigation scheme (use any language).

i) ………………………………………………
ii) ………………………………………………..
iii) ………………………………………………….
iv) …………………………………………………..
v) ………………………………………………….
vi) …………………………………………………..
vii) ………………………………………………….
viii) ………………………………………………….
ix) …………………………………………………..
x) …………………………………………………..

Appendix III: ANOVA for Heavy Metals Amounts in Soil, Rice Straw, Rice Husks and Rice Grains

1. Cd

	Sum of Squares	Df	Mean Square	F	Sig.	F Crit
Between Groups	.033	3	.011	21.892	.000	2.77
Within Groups	.028	56	.001			
Total	.061	59				

(I) Sample	(J) Sample	Mean Difference (I-J)	Std. Error	Sig.
ice Husks	Rice Straw	.009825815571907	.008173797559529	.234
	Soil	-.051794320234993*	.008173797559529	.000
	Rice Grain	-.015582249238616	.008173797559529	.062
Rice Straw	Rice Husks	-.009825815571907	.008173797559529	.234
	Soil	-.061620135806900*	.008173797559529	.000
	Rice Grain	-.025408064810523*	.008173797559529	.003
Soil	Rice Husks	.051794320234993*	.008173797559529	.000
	Rice Straw	.061620135806900*	.008173797559529	.000
	Rice Grain	.036212070996377*	.008173797559529	.000
Rice Grain	Rice Husks	.015582249238616	.008173797559529	.062
	Rice Straw	.025408064810523*	.008173797559529	.003
	Soil	-.036212070996377*	.008173797559529	.000

*.The mean difference is significant at the 0.05 level

2. Cr

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	11333.137	3	3777.712	242.311	.000
Within Groups	873.059	56	15.590		
Total	12206.197	59			

(I) Sample	(J) Sample	Mean Difference (I-J)	Std. Error	Sig.
Rice Husk	Rice Straw	-21.715743151910758*	1.441774190418598	.000
	Soil	-31.779132721623746*	1.441774190418598	.000
	Rice Grain	-.397701023967239	1.441774190418598	.784
Rice Straw	Rice Husk	21.715743151910758*	1.441774190418598	.000
	Soil	-10.063389569712992*	1.441774190418598	.000
	Rice Grain	21.318042127943520*	1.441774190418598	.000
Soil	Rice Husk	31.779132721623746*	1.441774190418598	.000
	Rice Straw	10.063389569712992*	1.441774190418598	.000
	Rice Grain	31.381431697656513*	1.441774190418598	.000
Rice Grain	Rice Husk	.397701023967239	1.441774190418598	.784
	Rice Straw	-21.318042127943520*	1.441774190418598	.000
	Soil	-31.381431697656513*	1.441774190418598	.000

*.The mean difference is significant at the 0.05 level

3. Ni

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	76580.732	3	25526.911	9.673	.000
Within Groups	147786.823	56	2639.050		
Total	224367.555	59			

(I) Sample 7	(J) Sample 7	Mean Difference (I-J)	Std. Error	Sig.
Rice Husk	Rice Straw	50.635184575843030*	18.758288514783430	.009
	Soil	20.476970805304887	18.758288514783430	.280
	Rice Grain	94.957590704689070*	18.758288514783430	.000
Rice Straw	Rice Husk	-50.635184575843030*	18.758288514783430	.009
	Soil	-30.158213770538133	18.758288514783430	.114
	Rice Grain	44.322406128846055*	18.758288514783430	.022
Soil	Rice Husk	-20.476970805304887	18.758288514783430	.280
	Rice Straw	30.158213770538133	18.758288514783430	.114
	Rice Grain	74.480619899384180*	18.758288514783430	.000
Rice Grain	Rice Husk	-94.957590704689070*	18.758288514783430	.000
	Rice Straw	-44.322406128846055*	18.758288514783430	.022
	Soil	-74.480619899384180*	18.758288514783430	.000

*.The mean difference is significant at the 0.05 level

4. Pb

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	1499.609	3	499.870	23.189	.000
Within Groups	1207.156	56	21.556		
Total	2706.765	59			

(I) Sample	(J) Sample	Mean Difference (I-J)	Std. Error	Sig.
Rice Husk	Rice Straw	7.742017852221474*	1.695340957038908	.000
	Soil	-3.450207063244047*	1.695340957038908	.047
	Rice Grain	8.190390329614380*	1.695340957038908	.000
Rice Straw	Rice Husk	-7.742017852221474*	1.695340957038908	.000
	Soil	-11.192224915465520*	1.695340957038908	.000
	Rice Grain	.448372477392907	1.695340957038908	.792
Soil	Rice Husk	3.450207063244047*	1.695340957038908	.047
	Rice Straw	11.192224915465520*	1.695340957038908	.000
	Rice Grain	11.640597392858426*	1.695340957038908	.000
Rice Grain	Rice Husk	-8.190390329614380*	1.695340957038908	.000
	Rice Straw	-.448372477392907	1.695340957038908	.792
	Soil	-11.640597392858426*	1.695340957038908	.000

*. The mean difference is significant at the 0.05 level

5. Zn

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	12039.103	2	6019.552	346.760	.000
Within Groups	729.096	42	17.359		
Total	12768.199	44			

(I) Sample	(J) Sample	Mean Difference (I-J)	Std. Error	Sig.
Rice Straw	Soil	-14.163932612021082*	1.521377350095828	.000
	Rice Grain	25.374890871943660*	1.521377350095828	.000
Soil	Rice Straw	14.163932612021082*	1.521377350095828	.000
	Rice Grain	39.538823483964740*	1.521377350095828	.000
Rice Grain	Rice Straw	-25.374890871943660*	1.521377350095828	.000
	Soil	-39.538823483964740*	1.521377350095828	.000

*. The mean difference is significant at the 0.05 level

6. As

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	46.998	3	15.666	183.885	.000
Within Groups	4.771	56	.085		
Total	51.769	59			

(I) Sample	(J) Sample	Mean Difference (I-J)	Std. Error	Sig.
Rice Husk	Rice Straw	-.172545361928311	.106579999804629	.111
	Soil	-2.104773035955680*	.106579999804629	.000
	Rice Grain	-.026906088542408	.106579999804629	.802
Rice Straw	Rice Husk	.172545361928311	.106579999804629	.111
	Soil	-1.932227674027368*	.106579999804629	.000
	Rice Grain	.145639273385904	.106579999804629	.177
Soil	Rice Husk	2.104773035955680*	.106579999804629	.000
	Rice Straw	1.932227674027369*	.106579999804629	.000
	Rice Grain	2.077866947413272*	.106579999804629	.000
Rice Grain	Rice Husk	.026906088542408	.106579999804629	.802
	Rice Straw	-.145639273385904	.106579999804629	.177
	Soil	-2.077866947413272*	.106579999804629	.000

*. The mean difference is significant at the 0.05 level

7. Mn

	Sum of Squares	Df	Mean Square	F	Sig.	F Crit
Between Groups	5090869.204	2	2545434.602	34.698	.000	3.455
Within Groups	3081076.238	42	73358.958			
Total	8171945.442	44				

(I) Sample	(J) Sample	Mean Difference (I-J)	Std. Error	Sig.
Rice Straw	Soil	-126.367341338137300	98.899921168787770	.208
	Rice Grain	641.876888191776400*	98.899921168787770	.000
Soil	Rice Straw	126.367341338137300	98.899921168787770	.208
	Rice Grain	768.244229529913700*	98.899921168787770	.000
Rice Grain	Rice Straw	-641.876888191776400*	98.899921168787770	.000
	Soil	-768.244229529913700*	98.899921168787770	.000

*. The mean difference is significant at the 0.05 level

8. Se

	Sum of Squares	Df	Mean Square	F	Sig.	F Crit
Between Groups	423.143	3	141.048	181.478	.000	2.77
Within Groups	43.524	56	.777			
Total	466.667	59				

(I) Sample 1	(J) Sample 1	Mean Difference (I-J)	Std. Error	Sig.
Rice Husk	Rice Straw	-.141045891034593	.321914520121811	.663
	Soil	-6.148959812787596*	.321914520121811	.000
	Rice Grain	.084454192030023	.321914520121811	.794
Rice Straw	Rice Husk	.141045891034593	.321914520121811	.663
	Soil	-6.007913921753003*	.321914520121811	.000
	Rice Grain	.225500083064616	.321914520121811	.487
Soil	Rice Husk	6.148959812787596*	.321914520121811	.000
	Rice Straw	6.007913921753003*	.321914520121811	.000
	Rice Grain	6.233414004817618*	.321914520121811	.000
Rice Grain	Rice Husk	-.084454192030023	.321914520121811	.794
	Rice Straw	-.225500083064616	.321914520121811	.487
	Soil	-6.233414004817618*	.321914520121811	.000

*The mean difference is significant at the 0.05 level

(I) Sample	(J) Sample	Mean Difference (I-J)	Std. Error	Sig.
NPK	DAP	-8.122758841697438*	.073075964017032	.000
	MOP	.026936318005998	.073075964017032	.719
	Mavuno Plant	-.222202530803111*	.073075964017032	.011
	Baraka Plant	-3.302673691432063*	.073075964017032	.000
	SA	.033669345471956	.073075964017032	.654
	Urea	.042086471432837	.073075964017032	.576
	CAN	.017678405240306	.073075964017032	.813
	Amidas	.032826875410278	.073075964017032	.662
	Mavuno Top	-.120356232467732	.073075964017032	.128
	TSP	-.497813528567163*	.073075964017032	.000
DAP	NPK	8.122758841697438*	.073075964017032	.000
	MOP	8.149695159703436*	.073075964017032	.000
	Mavuno Plant	7.900556310894327*	.073075964017032	.000
	Baraka Plant	4.820085150265375*	.073075964017032	.000
	SA	8.156428187169395*	.073075964017032	.000
	Urea	8.164845313130275*	.073075964017032	.000
	CAN	8.140437246937744*	.073075964017032	.000
	Amidas	8.155585717107716*	.073075964017032	.000
	Mavuno Top	8.002402609229707*	.073075964017032	.000
	TSP	7.624945313130275*	.073075964017032	.000
MOP	NPK	-.026936318005998	.073075964017032	.719
	DAP	-8.149695159703436*	.073075964017032	.000
	Mavuno Plant	-.249138848809109*	.073075964017032	.006
	Baraka Plant	-3.329610009438061*	.073075964017032	.000
	SA	.006733027465958	.073075964017032	.928
	Urea	.015150153426839	.073075964017032	.840
	CAN	-.009257912765692	.073075964017032	.901
	Amidas	.005890557404280	.073075964017032	.937
	Mavuno Top	-.147292550473730	.073075964017032	.069

		-.524749846573161*	.073075964017032	.000
Mavuno Plant	NPK	.222202530803111*	.073075964017032	.011
	DAP	-7.900556310894327*	.073075964017032	.000
	MOP	.249138848809109*	.073075964017032	.006
	Baraka Plant	-3.080471160628952*	.073075964017032	.000
	SA	.255871876275067*	.073075964017032	.005
	Urea	.264289002235948*	.073075964017032	.004
	CAN	.239880936043417*	.073075964017032	.007
	Amidas	.255029406213389*	.073075964017032	.005
	Mavuno Top	.101846298335380	.073075964017032	.191
	TSP	-.275610997764052*	.073075964017032	.003
Baraka Plant	NPK	3.302673691432064*	.073075964017032	.000
	DAP	-4.820085150265375*	.073075964017032	.000
	MOP	3.329610009438062*	.073075964017032	.000
	Mavuno Plant	3.080471160628953*	.073075964017032	.000
	SA	3.336343036904020*	.073075964017032	.000
	Urea	3.344760162864900*	.073075964017032	.000
	CAN	3.320352096672370*	.073075964017032	.000
	Amidas	3.335500566842342*	.073075964017032	.000
	Mavuno Top	3.182317458964332*	.073075964017032	.000
	TSP	2.804860162864900*	.073075964017032	.000
SA	NPK	-.033669345471956	.073075964017032	.654
	DAP	-8.156428187169395*	.073075964017032	.000
	MOP	-.006733027465958	.073075964017032	.928
	Mavuno Plant	-.255871876275067*	.073075964017032	.005
	Baraka Plant	-3.336343036904019*	.073075964017032	.000
	Urea	.008417125960881	.073075964017032	.910
	CAN	-.015990940231650	.073075964017032	.831
	Amidas	-.000842470061678	.073075964017032	.991
	Mavuno Top	-.154025577939688	.073075964017032	.059
	TSP	-.531482874039119*	.073075964017032	.000
Urea	NPK	-.042086471432837	.073075964017032	.576
	DAP	-8.164845313130275*	.073075964017032	.000
	MOP	-.015150153426839	.073075964017032	.840
	Mavuno Plant	-.264289002235948*	.073075964017032	.004
	Baraka Plant	-3.344760162864900*	.073075964017032	.000
	SA	-.008417125960881	.073075964017032	.910
	CAN	-.024408066192531	.073075964017032	.745
	Amidas	-.009259596022559	.073075964017032	.901
	Mavuno Top	-.162442703900568*	.073075964017032	.048
	TSP	-.539900000000000*	.073075964017032	.000
CAN	NPK	-.017678405240306	.073075964017032	.813
	DAP	-8.140437246937744*	.073075964017032	.000
	MOP	.009257912765692	.073075964017032	.901
	Mavuno Plant	-.239880936043417*	.073075964017032	.007
	Baraka Plant	-3.320352096672369*	.073075964017032	.000
	SA	.015990940231650	.073075964017032	.831
	Urea	.024408066192531	.073075964017032	.745
	Amidas	.015148470169972	.073075964017032	.840
	Mavuno Top	-.138034637708037	.073075964017032	.086
	TSP	-.515491933807469*	.073075964017032	.000
Amidas	NPK	-.032826875410278	.073075964017032	.662
	DAP	-8.155585717107716*	.073075964017032	.000
	MOP	-.005890557404280	.073075964017032	.937
	Mavuno Plant	-.255029406213389*	.073075964017032	.005
	Baraka Plant	-3.335500566842341*	.073075964017032	.000
	SA	.000842470061678	.073075964017032	.991
	Urea	.009259596022559	.073075964017032	.901
	CAN	-.015148470169972	.073075964017032	.840
	Mavuno Top	-.153183107878010	.073075964017032	.060

	TSP	-.530640403977441*	.073075964017032	.000
Mavuno Top	NPK	.120356232467732	.073075964017032	.128
	DAP	-8.002402609229707*	.073075964017032	.000
	MOP	.147292550473730	.073075964017032	.069
	Mavuno Plant	-.101846298335379	.073075964017032	.191
	Baraka Plant	-3.182317458964331*	.073075964017032	.000
	SA	.154025577939688	.073075964017032	.059
	Urea	.162442703900568*	.073075964017032	.048
	CAN	.138034637708037	.073075964017032	.086
	Amidas	.153183107878010	.073075964017032	.060
	TSP	-.377457296099432*	.073075964017032	.000
TSP	NPK	.497813528567163*	.073075964017032	.000
	DAP	-7.624945313130275*	.073075964017032	.000
	MOP	.524749846573161*	.073075964017032	.000
	Mavuno Plant	.275610997764052*	.073075964017032	.003
	Baraka Plant	-2.804860162864900*	.073075964017032	.000
	SA	.531482874039119*	.073075964017032	.000
	Urea	.539900000000000*	.073075964017032	.000
	CAN	.515491933807469*	.073075964017032	.000
	Amidas	.530640403977441*	.073075964017032	.000
	Mavuno Top	.377457296099432*	.073075964017032	.000

Appendix IV: ANOVA for Heavy Metals Amounts in Fertilizers

1. Cd

	Sum of Squares	df	Mean Square	F	Sig.	F Crit
Between Groups	127.732	10	12.773	2391.935	.000	2.85
Within Groups	.059	11	.005			
Total	127.790	21				

*The mean difference is significant at the 0.05 level

2. Cr

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	127.732	10	12.773	2391.935	.000
Within Groups	.059	11	.005		
Total	127.790	21			

(I) Sample 1	(J) Sample 1	Mean Difference (I-J)	Std. Error	Sig.
NPK	DAP	-8.122758841697438*	.073075964017032	.000
	MOP	.026936318005998	.073075964017032	.719
	Mavuno Plant	-.222202530803111*	.073075964017032	.011
	Baraka Plant	-3.302673691432063*	.073075964017032	.000
	SA	.033669345471956	.073075964017032	.654
	Urea	.042086471432837	.073075964017032	.576
	CAN	.017678405240306	.073075964017032	.813
	Amidas	.032826875410278	.073075964017032	.662
	Mavuno Top	-.120356232467732	.073075964017032	.128
	TSP	-.497813528567163*	.073075964017032	.000
DAP	NPK	8.122758841697438*	.073075964017032	.000
	MOP	8.149695159703436*	.073075964017032	.000
	Mavuno Plant	7.900556310894327*	.073075964017032	.000
	Baraka Plant	4.820085150265375*	.073075964017032	.000

	SA	8.156428187169395*	.073075964017032	.000
	Urea	8.164845313130275*	.073075964017032	.000
	CAN	8.140437246937744*	.073075964017032	.000
	Amidas	8.155585717107716*	.073075964017032	.000
	Mavuno Top	8.002402609229707*	.073075964017032	.000
	TSP	7.624945313130275*	.073075964017032	.000
MOP	NPK	-.026936318005998	.073075964017032	.719
	DAP	-8.149695159703436*	.073075964017032	.000
	Mavuno Plant	-.249138848809109*	.073075964017032	.006
	Baraka Plant	-3.329610009438061*	.073075964017032	.000
	SA	.006733027465958	.073075964017032	.928
	Urea	.015150153426839	.073075964017032	.840
	CAN	-.009257912765692	.073075964017032	.901
	Amidas	.005890557404280	.073075964017032	.937
	Mavuno Top	-.147292550473730	.073075964017032	.069
	TSP	-.524749846573161*	.073075964017032	.000
Mavuno Plant	NPK	.222202530803111*	.073075964017032	.011
	DAP	-7.900556310894327*	.073075964017032	.000
	MOP	.249138848809109*	.073075964017032	.006
	Baraka Plant	-3.080471160628952*	.073075964017032	.000
	SA	.255871876275067*	.073075964017032	.005
	Urea	.264289002235948*	.073075964017032	.004
	CAN	.239880936043417*	.073075964017032	.007
	Amidas	.255029406213389*	.073075964017032	.005
	Mavuno Top	.101846298335380	.073075964017032	.191
	TSP	-.275610997764052*	.073075964017032	.003
Baraka Plant	NPK	3.302673691432064*	.073075964017032	.000
	DAP	-4.820085150265375*	.073075964017032	.000
	MOP	3.329610009438062*	.073075964017032	.000
	Mavuno Plant	3.080471160628953*	.073075964017032	.000
	SA	3.336343036904020*	.073075964017032	.000
	Urea	3.344760162864900*	.073075964017032	.000
	CAN	3.320352096672370*	.073075964017032	.000
	Amidas	3.335500566842342*	.073075964017032	.000
	Mavuno Top	3.182317458964332*	.073075964017032	.000
	TSP	2.804860162864900*	.073075964017032	.000
SA	NPK	-.033669345471956	.073075964017032	.654
	DAP	-8.156428187169395*	.073075964017032	.000
	MOP	-.006733027465958	.073075964017032	.928
	Mavuno Plant	-.255871876275067*	.073075964017032	.005
	Baraka Plant	-3.336343036904019*	.073075964017032	.000
	Urea	.008417125960881	.073075964017032	.910
	CAN	-.015990940231650	.073075964017032	.831
	Amidas	-.000842470061678	.073075964017032	.991
	Mavuno Top	-.154025577939688	.073075964017032	.059
	TSP	-.531482874039119*	.073075964017032	.000
Urea	NPK	-.042086471432837	.073075964017032	.576
	DAP	-8.164845313130275*	.073075964017032	.000
	MOP	-.015150153426839	.073075964017032	.840
	Mavuno Plant	-.264289002235948*	.073075964017032	.004
	Baraka Plant	-3.344760162864900*	.073075964017032	.000
	SA	-.008417125960881	.073075964017032	.910
	CAN	-.024408066192531	.073075964017032	.745
	Amidas	-.009259596022559	.073075964017032	.901

	Mavuno Top	-.162442703900568*	.073075964017032	.048
	TSP	-.539900000000000*	.073075964017032	.000
CAN	NPK	-.017678405240306	.073075964017032	.813
	DAP	-8.140437246937744*	.073075964017032	.000
	MOP	.009257912765692	.073075964017032	.901
	Mavuno Plant	-.239880936043417*	.073075964017032	.007
	Baraka Plant	-3.320352096672369*	.073075964017032	.000
	SA	.015990940231650	.073075964017032	.831
	Urea	.024408066192531	.073075964017032	.745
	Amidas	.015148470169972	.073075964017032	.840
	Mavuno Top	-.138034637708037	.073075964017032	.086
	TSP	-.515491933807469*	.073075964017032	.000
Amidas	NPK	-.032826875410278	.073075964017032	.662
	DAP	-8.155585717107716*	.073075964017032	.000
	MOP	-.005890557404280	.073075964017032	.937
	Mavuno Plant	-.255029406213389*	.073075964017032	.005
	Baraka Plant	-3.335500566842341*	.073075964017032	.000
	SA	.000842470061678	.073075964017032	.991
	Urea	.009259596022559	.073075964017032	.901
	CAN	-.015148470169972	.073075964017032	.840
	Mavuno Top	-.153183107878010	.073075964017032	.060
	TSP	-.530640403977441*	.073075964017032	.000
Mavuno Top	NPK	.120356232467732	.073075964017032	.128
	DAP	-8.002402609229707*	.073075964017032	.000
	MOP	.147292550473730	.073075964017032	.069
	Mavuno Plant	-.101846298335379	.073075964017032	.191
	Baraka Plant	-3.182317458964331*	.073075964017032	.000
	SA	.154025577939688	.073075964017032	.059
	Urea	.162442703900568*	.073075964017032	.048
	CAN	.138034637708037	.073075964017032	.086
	Amidas	.153183107878010	.073075964017032	.060
	TSP	-.377457296099432*	.073075964017032	.000
TSP	NPK	.497813528567163*	.073075964017032	.000
	DAP	-7.624945313130275*	.073075964017032	.000
	MOP	.524749846573161*	.073075964017032	.000
	Mavuno Plant	.275610997764052*	.073075964017032	.003
	Baraka Plant	-2.804860162864900*	.073075964017032	.000
	SA	.531482874039119*	.073075964017032	.000
	Urea	.539900000000000*	.073075964017032	.000
	CAN	.515491933807469*	.073075964017032	.000
	Amidas	.530640403977441*	.073075964017032	.000
	Mavuno Top	.377457296099432*	.073075964017032	.000

*. The mean difference is significant at the 0.05 level

3. Ni

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1920752.065	10	192075.207	28.175	.000
Within Groups	74988.653	11	6817.150		
Total	1995740.718	21			

(I) Sample	(J) Sample	Mean Difference (I-J)	Std. Error	Sig.
NPK	DAP	-519.100143543181500*	82.566035793584200	.000
	MOP	436.432153906748450*	82.566035793584200	.000
	Mavuno Plant	182.556824604210930*	82.566035793584200	.049
	Baraka Plant	-65.368118716866040	82.566035793584200	.445
	SA	327.896430485697900*	82.566035793584200	.002
	Urea	426.107421489072000*	82.566035793584200	.000
	CAN	436.432153906748450*	82.566035793584200	.000
	Amidas	430.286366346445050*	82.566035793584200	.000
	Mavuno Top	331.314287176385450*	82.566035793584200	.002
	TSP	-103.515796093251540	82.566035793584200	.236
DAP	NPK	519.100143543181500*	82.566035793584200	.000
	MOP	955.532297449930000*	82.566035793584200	.000
	Mavuno Plant	701.656968147392500*	82.566035793584200	.000
	Baraka Plant	453.732024826315470*	82.566035793584200	.000
	SA	846.996574028879300*	82.566035793584200	.000
	Urea	945.207565032253600*	82.566035793584200	.000
	CAN	955.532297449930000*	82.566035793584200	.000
	Amidas	949.386509889626600*	82.566035793584200	.000
	Mavuno Top	850.414430719567000*	82.566035793584200	.000
	TSP	415.584347449929960*	82.566035793584200	.000
MOP	NPK	-436.432153906748450*	82.566035793584200	.000
	DAP	-955.532297449930000*	82.566035793584200	.000
	Mavuno Plant	-253.875329302537500*	82.566035793584200	.011
	Baraka Plant	-501.800272623614500*	82.566035793584200	.000
	SA	-108.535723421050500	82.566035793584200	.215
	Urea	-10.324732417676424	82.566035793584200	.903
	CAN	.000000000000000	82.566035793584200	1.000
	Amidas	-6.145787560303400	82.566035793584200	.942
	Mavuno Top	-105.117866730363000	82.566035793584200	.229
	TSP	-539.947950000000000*	82.566035793584200	.000
Mavuno Plant	NPK	-182.556824604210930*	82.566035793584200	.049
	DAP	-701.656968147392500*	82.566035793584200	.000
	MOP	253.875329302537500*	82.566035793584200	.011
	Baraka Plant	-247.924943321077000*	82.566035793584200	.012
	SA	145.339605881487000	82.566035793584200	.106
	Urea	243.550596884861080*	82.566035793584200	.013
	CAN	253.875329302537500*	82.566035793584200	.011
	Amidas	247.729541742234100*	82.566035793584200	.012
	Mavuno Top	148.757462572174500	82.566035793584200	.099
	TSP	-286.072620697462500*	82.566035793584200	.005
Baraka Plant	NPK	65.368118716866040	82.566035793584200	.445
	DAP	-453.732024826315470*	82.566035793584200	.000
	MOP	501.800272623614500*	82.566035793584200	.000

	Mavuno Plant	247.924943321077000*	82.566035793584200	.012
	SA	393.264549202564000*	82.566035793584200	.001
	Urea	491.475540205938050*	82.566035793584200	.000
	CAN	501.800272623614500*	82.566035793584200	.000
	Amidas	495.654485063311100*	82.566035793584200	.000
	Mavuno Top	396.682405893251400*	82.566035793584200	.001
	TSP	-38.147677376385500	82.566035793584200	.653
SA	NPK	-327.896430485697900*	82.566035793584200	.002
	DAP	-846.996574028879300*	82.566035793584200	.000
	MOP	108.535723421050500	82.566035793584200	.215
	Mavuno Plant	-145.339605881487000	82.566035793584200	.106
	Baraka Plant	-393.264549202564000*	82.566035793584200	.001
	Urea	98.210991003374080	82.566035793584200	.259
	CAN	108.535723421050500	82.566035793584200	.215
	Amidas	102.389935860747100	82.566035793584200	.241
	Mavuno Top	3.417856690687501	82.566035793584200	.968
	TSP	-431.412226578949460*	82.566035793584200	.000
Urea	NPK	-426.107421489072000*	82.566035793584200	.000
	DAP	-945.207565032253600*	82.566035793584200	.000
	MOP	10.324732417676424	82.566035793584200	.903
	Mavuno Plant	-243.550596884861080*	82.566035793584200	.013
	Baraka Plant	-491.475540205938050*	82.566035793584200	.000
	SA	-98.210991003374080	82.566035793584200	.259
	CAN	10.324732417676424	82.566035793584200	.903
	Amidas	4.178944857373025	82.566035793584200	.961
	Mavuno Top	-94.793134312686580	82.566035793584200	.275
	TSP	-529.623217582323600*	82.566035793584200	.000
CAN	NPK	-436.432153906748450*	82.566035793584200	.000
	DAP	-955.532297449930000*	82.566035793584200	.000
	MOP	.000000000000000	82.566035793584200	1.000
	Mavuno Plant	-253.875329302537500*	82.566035793584200	.011
	Baraka Plant	-501.800272623614500*	82.566035793584200	.000
	SA	-108.535723421050500	82.566035793584200	.215
	Urea	-10.324732417676424	82.566035793584200	.903
	Amidas	-6.145787560303400	82.566035793584200	.942
	Mavuno Top	-105.117866730363000	82.566035793584200	.229
	TSP	-539.947950000000000*	82.566035793584200	.000
Amidas	NPK	-430.286366346445050*	82.566035793584200	.000
	DAP	-949.386509889626600*	82.566035793584200	.000
	MOP	6.145787560303400	82.566035793584200	.942
	Mavuno Plant	-247.729541742234100*	82.566035793584200	.012
	Baraka Plant	-495.654485063311100*	82.566035793584200	.000
	SA	-102.389935860747100	82.566035793584200	.241
	Urea	-4.178944857373024	82.566035793584200	.961
	CAN	6.145787560303400	82.566035793584200	.942
	Mavuno Top	-98.972079170059600	82.566035793584200	.256

	TSP	-533.802162439696600*	82.566035793584200	.000
Mavuno Top	NPK	-331.314287176385450*	82.566035793584200	.002
	DAP	-850.414430719567000*	82.566035793584200	.000
	MOP	105.117866730363000	82.566035793584200	.229
	Mavuno Plant	-148.757462572174500	82.566035793584200	.099
	Baraka Plant	-396.682405893251400*	82.566035793584200	.001
	SA	-3.417856690687500	82.566035793584200	.968
	Urea	94.793134312686580	82.566035793584200	.275
	CAN	105.117866730363000	82.566035793584200	.229
	Amidas	98.972079170059600	82.566035793584200	.256
	TSP	-434.830083269637000*	82.566035793584200	.000
TSP	NPK	103.515796093251540	82.566035793584200	.236
	DAP	-415.584347449929960*	82.566035793584200	.000
	MOP	539.947950000000000*	82.566035793584200	.000
	Mavuno Plant	286.072620697462500*	82.566035793584200	.005
	Baraka Plant	38.147677376385500	82.566035793584200	.653
	SA	431.412226578949460*	82.566035793584200	.000
	Urea	529.623217582323600*	82.566035793584200	.000
	CAN	539.947950000000000*	82.566035793584200	.000
	Amidas	533.802162439696600*	82.566035793584200	.000
	Mavuno Top	434.830083269637000*	82.566035793584200	.000

*. The mean difference is significant at the 0.05 level

4. Pb

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	5.655	10	.566	.763	.661
Within Groups	8.149	11	.741		
Total	13.805	21			

5. Zn

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	28204470.146	10	2820447.015	7.746	.001
Within Groups	4005106.727	11	364100.612		
Total	32209576.872	21			

(I) Sample	(J) Sample	Mean Difference (I-J)	Std. Error	Sig.
NPK	DAP	-577.109375323717600	603.407500389201700	.359
	MOP	.000000000000000	603.407500389201700	1.000
	Mavuno Plant	-1646.311107320395000*	603.407500389201700	.020
	Baraka Plant	-3144.738069656439600*	603.407500389201700	.000
	SA	.000000000000000	603.407500389201700	1.000
	Urea	.000000000000000	603.407500389201700	1.000
	CAN	.000000000000000	603.407500389201700	1.000
	Amidas	.000000000000000	603.407500389201700	1.000
	Mavuno Top	-26.455613755695750	603.407500389201700	.966
	TSP	-2657.678400000000000*	603.407500389201700	.001

DAP	NPK	577.109375323717600	603.407500389201700	.359
	MOP	577.109375323717600	603.407500389201700	.359
	Mavuno Plant	-1069.201731996677400	603.407500389201700	.104
	Baraka Plant	-2567.628694332722300*	603.407500389201700	.001
	SA	577.109375323717600	603.407500389201700	.359
	Urea	577.109375323717600	603.407500389201700	.359
	CAN	577.109375323717600	603.407500389201700	.359
	Amidas	577.109375323717600	603.407500389201700	.359
	Mavuno Top	550.653761568021900	603.407500389201700	.381
	TSP	-2080.569024676282400*	603.407500389201700	.005
MOP	NPK	.000000000000000	603.407500389201700	1.000
	DAP	-577.109375323717600	603.407500389201700	.359
	Mavuno Plant	-1646.311107320395000*	603.407500389201700	.020
	Baraka Plant	-3144.738069656439600*	603.407500389201700	.000
	SA	.000000000000000	603.407500389201700	1.000
	Urea	.000000000000000	603.407500389201700	1.000
	CAN	.000000000000000	603.407500389201700	1.000
	Amidas	.000000000000000	603.407500389201700	1.000
	Mavuno Top	-26.455613755695750	603.407500389201700	.966
	TSP	-2657.678400000000000*	603.407500389201700	.001
Mavuno Plant	NPK	1646.311107320395000*	603.407500389201700	.020
	DAP	1069.201731996677400	603.407500389201700	.104
	MOP	1646.311107320395000*	603.407500389201700	.020
	Baraka Plant	-1498.426962336044700*	603.407500389201700	.030
	SA	1646.311107320395000*	603.407500389201700	.020
	Urea	1646.311107320395000*	603.407500389201700	.020
	CAN	1646.311107320395000*	603.407500389201700	.020
	Amidas	1646.311107320395000*	603.407500389201700	.020
	Mavuno Top	1619.855493564699100*	603.407500389201700	.021
	TSP	-1011.367292679604800	603.407500389201700	.122
Baraka Plant	NPK	3144.738069656439600*	603.407500389201700	.000
	DAP	2567.628694332722300*	603.407500389201700	.001
	MOP	3144.738069656439600*	603.407500389201700	.000
	Mavuno Plant	1498.426962336044700*	603.407500389201700	.030
	SA	3144.738069656439600*	603.407500389201700	.000
	Urea	3144.738069656439600*	603.407500389201700	.000
	CAN	3144.738069656439600*	603.407500389201700	.000
	Amidas	3144.738069656439600*	603.407500389201700	.000
	Mavuno Top	3118.282455900744000*	603.407500389201700	.000
	TSP	487.059669656439800	603.407500389201700	.437
SA	NPK	.000000000000000	603.407500389201700	1.000
	DAP	-577.109375323717600	603.407500389201700	.359
	MOP	.000000000000000	603.407500389201700	1.000
	Mavuno Plant	-1646.311107320395000*	603.407500389201700	.020
	Baraka Plant	-3144.738069656439600*	603.407500389201700	.000
	Urea	.000000000000000	603.407500389201700	1.000
	CAN	.000000000000000	603.407500389201700	1.000
	Amidas	.000000000000000	603.407500389201700	1.000
	Mavuno Top	-26.455613755695750	603.407500389201700	.966
	TSP	-2657.678400000000000*	603.407500389201700	.001
Urea	NPK	.000000000000000	603.407500389201700	1.000
	DAP	-577.109375323717600	603.407500389201700	.359
	MOP	.000000000000000	603.407500389201700	1.000
	Mavuno Plant	-1646.311107320395000*	603.407500389201700	.020

	Baraka Plant	-3144.738069656439600*	603.407500389201700	.000
	SA	.000000000000000	603.407500389201700	1.000
	CAN	.000000000000000	603.407500389201700	1.000
	Amidas	.000000000000000	603.407500389201700	1.000
	Mavuno Top	-26.455613755695750	603.407500389201700	.966
CAN	TSP	-2657.678400000000000*	603.407500389201700	.001
	NPK	.000000000000000	603.407500389201700	1.000
	DAP	-577.109375323717600	603.407500389201700	.359
	MOP	.000000000000000	603.407500389201700	1.000
	Mavuno Plant	-1646.311107320395000*	603.407500389201700	.020
	Baraka Plant	-3144.738069656439600*	603.407500389201700	.000
	SA	.000000000000000	603.407500389201700	1.000
	Urea	.000000000000000	603.407500389201700	1.000
	Amidas	.000000000000000	603.407500389201700	1.000
	Mavuno Top	-26.455613755695750	603.407500389201700	.966
Amidas	TSP	-2657.678400000000000*	603.407500389201700	.001
	NPK	.000000000000000	603.407500389201700	1.000
	DAP	-577.109375323717600	603.407500389201700	.359
	MOP	.000000000000000	603.407500389201700	1.000
	Mavuno Plant	-1646.311107320395000*	603.407500389201700	.020
	Baraka Plant	-3144.738069656439600*	603.407500389201700	.000
	SA	.000000000000000	603.407500389201700	1.000
	Urea	.000000000000000	603.407500389201700	1.000
	CAN	.000000000000000	603.407500389201700	1.000
	Mavuno Top	-26.455613755695750	603.407500389201700	.966
	TSP	-2657.678400000000000*	603.407500389201700	.001
Mavuno Top	NPK	26.455613755695750	603.407500389201700	.966
	DAP	-550.653761568021900	603.407500389201700	.381
	MOP	26.455613755695750	603.407500389201700	.966
	Mavuno Plant	-1619.855493564699100*	603.407500389201700	.021
	Baraka Plant	-3118.282455900744000*	603.407500389201700	.000
	SA	26.455613755695750	603.407500389201700	.966
	Urea	26.455613755695750	603.407500389201700	.966
	CAN	26.455613755695750	603.407500389201700	.966
	Amidas	26.455613755695750	603.407500389201700	.966
	TSP	-2631.222786244304000*	603.407500389201700	.001
TSP	NPK	2657.678400000000000*	603.407500389201700	.001
	DAP	2080.569024676282400*	603.407500389201700	.005
	MOP	2657.678400000000000*	603.407500389201700	.001
	Mavuno Plant	1011.367292679604800	603.407500389201700	.122
	Baraka Plant	-487.059669656439800	603.407500389201700	.437
	SA	2657.678400000000000*	603.407500389201700	.001
	Urea	2657.678400000000000*	603.407500389201700	.001
	CAN	2657.678400000000000*	603.407500389201700	.001
	Amidas	2657.678400000000000*	603.407500389201700	.001
	Mavuno Top	2631.222786244304000*	603.407500389201700	.001

*. The mean difference is significant at the 0.05 level

6. As

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	276.885	10	27.689	1228.338	.000
Within Groups	.248	11	.023		
Total	277.133	21			

(I) Sample	(J) Sample	Mean Difference (I-J)	Std. Error	Sig.
NPK	DAP	3.570635785375076*	.150138087554299	.000
	MOP	11.002041500171098*	.150138087554299	.000
	Mavuno Plant	9.197701544128000*	.150138087554299	.000
	Baraka Plant	8.468502868045233*	.150138087554299	.000
	SA	11.113095136939740*	.150138087554299	.000
	Urea	11.068030895980394*	.150138087554299	.000
	CAN	10.749354402967919*	.150138087554299	.000
	Amidas	11.138848430887510*	.150138087554299	.000
	Mavuno Top	10.907081660395184*	.150138087554299	.000
	TSP	10.920645329383875*	.150138087554299	.000
DAP	NPK	-3.570635785375075*	.150138087554299	.000
	MOP	7.431405714796021*	.150138087554299	.000
	Mavuno Plant	5.627065758752925*	.150138087554299	.000
	Baraka Plant	4.897867082670158*	.150138087554299	.000
	SA	7.542459351564665*	.150138087554299	.000
	Urea	7.497395110605318*	.150138087554299	.000
	CAN	7.178718617592843*	.150138087554299	.000
	Amidas	7.568212645512435*	.150138087554299	.000
	Mavuno Top	7.336445875020108*	.150138087554299	.000
	TSP	7.350009544008800*	.150138087554299	.000
MOP	NPK	-11.002041500171098*	.150138087554299	.000
	DAP	-7.431405714796021*	.150138087554299	.000
	Mavuno Plant	-1.804339956043096*	.150138087554299	.000
	Baraka Plant	-2.533538632125863*	.150138087554299	.000
	SA	.111053636768644	.150138087554299	.475
	Urea	.065989395809297	.150138087554299	.669
	CAN	-.252687097203178	.150138087554299	.121
	Amidas	.136806930716413	.150138087554299	.382
	Mavuno Top	-.094959839775913	.150138087554299	.540
	TSP	-.081396170787221	.150138087554299	.599
Mavuno Plant	NPK	-9.197701544128000*	.150138087554299	.000
	DAP	-5.627065758752925*	.150138087554299	.000
	MOP	1.804339956043097*	.150138087554299	.000
	Baraka Plant	-.729198676082767*	.150138087554299	.001
	SA	1.915393592811741*	.150138087554299	.000
	Urea	1.870329351852393*	.150138087554299	.000
	CAN	1.551652858839919*	.150138087554299	.000
	Amidas	1.941146886759510*	.150138087554299	.000
	Mavuno Top	1.709380116267184*	.150138087554299	.000
	TSP	1.722943785255875*	.150138087554299	.000
Baraka Plant	NPK	-8.468502868045233*	.150138087554299	.000
	DAP	-4.897867082670158*	.150138087554299	.000
	MOP	2.533538632125864*	.150138087554299	.000
	Mavuno Plant	.729198676082767*	.150138087554299	.001
	SA	2.644592268894508*	.150138087554299	.000
	Urea	2.599528027935161*	.150138087554299	.000
	CAN	2.280851534922686*	.150138087554299	.000
	Amidas	2.670345562842277*	.150138087554299	.000
	Mavuno Top	2.438578792349951*	.150138087554299	.000
	TSP	2.452142461338643*	.150138087554299	.000
SA	NPK	-11.113095136939740*	.150138087554299	.000
	DAP	-7.542459351564665*	.150138087554299	.000

	MOP	-.111053636768644	.150138087554299	.475
	Mavuno Plant	-1.915393592811740*	.150138087554299	.000
	Baraka Plant	-2.644592268894508*	.150138087554299	.000
	Urea	-.045064240959347	.150138087554299	.770
	CAN	-.363740733971822*	.150138087554299	.034
	Amidas	.025753293947769	.150138087554299	.867
	Mavuno Top	-.206013476544557	.150138087554299	.197
	TSP	-.192449807555865	.150138087554299	.226
Urea	NPK	-11.068030895980394*	.150138087554299	.000
	DAP	-7.497395110605318*	.150138087554299	.000
	MOP	-.065989395809297	.150138087554299	.669
	Mavuno Plant	-1.870329351852393*	.150138087554299	.000
	Baraka Plant	-2.599528027935160*	.150138087554299	.000
	SA	.045064240959347	.150138087554299	.770
	CAN	-.318676493012474	.150138087554299	.057
	Amidas	.070817534907116	.150138087554299	.646
	Mavuno Top	-.160949235585210	.150138087554299	.307
	TSP	-.147385566596518	.150138087554299	.347
CAN	NPK	-10.749354402967919*	.150138087554299	.000
	DAP	-7.178718617592843*	.150138087554299	.000
	MOP	.252687097203178	.150138087554299	.121
	Mavuno Plant	-1.551652858839918*	.150138087554299	.000
	Baraka Plant	-2.280851534922686*	.150138087554299	.000
	SA	.363740733971822*	.150138087554299	.034
	Urea	.318676493012475	.150138087554299	.057
	Amidas	.389494027919591*	.150138087554299	.025
	Mavuno Top	.157727257427265	.150138087554299	.316
	TSP	.171290926415957	.150138087554299	.278
Amidas	NPK	-11.138848430887510*	.150138087554299	.000
	DAP	-7.568212645512435*	.150138087554299	.000
	MOP	-.136806930716413	.150138087554299	.382
	Mavuno Plant	-1.941146886759509*	.150138087554299	.000
	Baraka Plant	-2.670345562842277*	.150138087554299	.000
	SA	-.025753293947769	.150138087554299	.867
	Urea	-.070817534907116	.150138087554299	.646
	CAN	-.389494027919591*	.150138087554299	.025
	Mavuno Top	-.231766770492326	.150138087554299	.151
	TSP	-.218203101503634	.150138087554299	.174
Mavuno Top	NPK	-10.907081660395184*	.150138087554299	.000
	DAP	-7.336445875020108*	.150138087554299	.000
	MOP	.094959839775913	.150138087554299	.540
	Mavuno Plant	-1.709380116267184*	.150138087554299	.000
	Baraka Plant	-2.438578792349951*	.150138087554299	.000
	SA	.206013476544557	.150138087554299	.197
	Urea	.160949235585210	.150138087554299	.307
	CAN	-.157727257427265	.150138087554299	.316
	Amidas	.231766770492326	.150138087554299	.151
	TSP	.013563668988691	.150138087554299	.930
TSP	NPK	-10.920645329383875*	.150138087554299	.000
	DAP	-7.350009544008800*	.150138087554299	.000
	MOP	.081396170787221	.150138087554299	.599
	Mavuno Plant	-1.722943785255875*	.150138087554299	.000
	Baraka Plant	-2.452142461338642*	.150138087554299	.000
	SA	.192449807555865	.150138087554299	.226

	Urea	.147385566596518	.150138087554299	.347
	CAN	-.171290926415956	.150138087554299	.278
	Amidas	.218203101503634	.150138087554299	.174
	Mavuno Top	-.013563668988691	.150138087554299	.930

*. The mean difference is significant at the 0.05 level

7. Mn

	Sum of Squares	Df	Mean Square	F	Sig.	F Crit
Between Groups	392733.667	10	39273.367	55.549	.000	2.85
Within Groups	7777.058	11	707.005			
Total	400510.726	21				

(I) Sample	(J) Sample	Mean Difference (I-J)	Std. Error	Sig.
NPK	DAP	88.238592326776920*	26.58957105202683 7	.007
	MOP	100.960384738354950*	26.589571052026837	.003
	Mavuno Plant	-369.979337516679300*	26.589571052026837	.000
	Baraka Plant	99.067242104422060*	26.589571052026837	.003
	SA	106.044125977591530*	26.589571052026837	.002
	Urea	102.238806886303280*	26.589571052026837	.003
	CAN	97.001956551037150*	26.589571052026837	.004
	Amidas	106.764891436135230*	26.589571052026837	.002
	Mavuno Top	69.913558435666600*	26.589571052026837	.023
	TSP	21.421653776837500	26.589571052026837	.438
DAP	NPK	-88.238592326776920*	26.589571052026837	.007
	MOP	12.721792411578026	26.589571052026837	.642
	Mavuno Plant	-458.217929843456200*	26.589571052026837	.000
	Baraka Plant	10.828649777645150	26.589571052026837	.692
	SA	17.805533650814617	26.589571052026837	.517
	Urea	14.000214559526360	26.589571052026837	.609
	CAN	8.763364224260226	26.589571052026837	.748
	Amidas	18.526299109358310	26.589571052026837	.500
	Mavuno Top	-18.325033891110320	26.589571052026837	.505
	TSP	-66.816938549939420*	26.589571052026837	.029
MOP	NPK	-100.960384738354950*	26.589571052026837	.003
	DAP	-12.721792411578026	26.589571052026837	.642
	Mavuno Plant	-470.939722255034200*	26.589571052026837	.000
	Baraka Plant	-1.893142633932875	26.589571052026837	.945
	SA	5.083741239236593	26.589571052026837	.852
	Urea	1.278422147948335	26.589571052026837	.963
	CAN	-3.958428187317800	26.589571052026837	.884
	Amidas	5.804506697780283	26.589571052026837	.831
	Mavuno Top	-31.046826302688345	26.589571052026837	.268
	TSP	-79.538730961517440*	26.589571052026837	.012
Mavuno Plant	NPK	369.979337516679300*	26.589571052026837	.000
	DAP	458.217929843456200*	26.589571052026837	.000
	MOP	470.939722255034200*	26.589571052026837	.000
	Baraka Plant	469.046579621101400*	26.589571052026837	.000
	SA	476.023463494270860*	26.589571052026837	.000
	Urea	472.218144402982600*	26.589571052026837	.000
	CAN	466.981294067716500*	26.589571052026837	.000
	Amidas	476.744228952814500*	26.589571052026837	.000

	Mavuno Top	439.892895952345900*	26.589571052026837	.000
	TSP	391.400991293516800*	26.589571052026837	.000
Baraka Plant	NPK	-99.067242104422060*	26.589571052026837	.003
	DAP	-10.828649777645150	26.589571052026837	.692
	MOP	1.893142633932875	26.589571052026837	.945
	Mavuno Plant	-469.046579621101400*	26.589571052026837	.000
	SA	6.976883873169468	26.589571052026837	.798
	Urea	3.171564781881211	26.589571052026837	.907
	CAN	-2.065285553384925	26.589571052026837	.939
	Amidas	7.697649331713158	26.589571052026837	.778
	Mavuno Top	-29.153683668755470	26.589571052026837	.296
	TSP	-77.645588327584560*	26.589571052026837	.014
SA	NPK	-106.044125977591530*	26.589571052026837	.002
	DAP	-17.805533650814617	26.589571052026837	.517
	MOP	-5.083741239236593	26.589571052026837	.852
	Mavuno Plant	-476.023463494270860*	26.589571052026837	.000
	Baraka Plant	-6.976883873169468	26.589571052026837	.798
	Urea	-3.805319091288257	26.589571052026837	.889
	CAN	-9.042169426554395	26.589571052026837	.740
	Amidas	.720765458543690	26.589571052026837	.979
	Mavuno Top	-36.130567541924930	26.589571052026837	.201
	TSP	-84.622472200754030*	26.589571052026837	.009
Urea	NPK	-102.238806886303280*	26.589571052026837	.003
	DAP	-14.000214559526360	26.589571052026837	.609
	MOP	-1.278422147948335	26.589571052026837	.963
	Mavuno Plant	-472.218144402982600*	26.589571052026837	.000
	Baraka Plant	-3.171564781881210	26.589571052026837	.907
	SA	3.805319091288258	26.589571052026837	.889
	CAN	-5.236850335266135	26.589571052026837	.847
	Amidas	4.526084549831948	26.589571052026837	.868
	Mavuno Top	-32.325248450636680	26.589571052026837	.250
	TSP	-80.817153109465780*	26.589571052026837	.011
CAN	NPK	-97.001956551037150*	26.589571052026837	.004
	DAP	-8.763364224260226	26.589571052026837	.748
	MOP	3.958428187317800	26.589571052026837	.884
	Mavuno Plant	-466.981294067716500*	26.589571052026837	.000
	Baraka Plant	2.065285553384925	26.589571052026837	.939
	SA	9.042169426554395	26.589571052026837	.740
	Urea	5.236850335266135	26.589571052026837	.847
	Amidas	9.762934885098083	26.589571052026837	.720
	Mavuno Top	-27.088398115370545	26.589571052026837	.330
	TSP	-75.580302774199650*	26.589571052026837	.016
Amidas	NPK	-106.764891436135230*	26.589571052026837	.002
	DAP	-18.526299109358310	26.589571052026837	.500
	MOP	-5.804506697780283	26.589571052026837	.831
	Mavuno Plant	-476.744228952814500*	26.589571052026837	.000
	Baraka Plant	-7.697649331713158	26.589571052026837	.778
	SA	-.720765458543690	26.589571052026837	.979
	Urea	-4.526084549831948	26.589571052026837	.868
	CAN	-9.762934885098083	26.589571052026837	.720
	Mavuno Top	-36.851333000468635	26.589571052026837	.193
	TSP	-85.343237659297730*	26.589571052026837	.008
Mavuno Top	NPK	-69.913558435666600*	26.589571052026837	.023
	DAP	18.325033891110320	26.589571052026837	.505

	MOP	31.046826302688345	26.589571052026837	.268
	Mavuno Plant	-439.892895952345900*	26.589571052026837	.000
	Baraka Plant	29.153683668755470	26.589571052026837	.296
	SA	36.130567541924930	26.589571052026837	.201
	Urea	32.325248450636680	26.589571052026837	.250
	CAN	27.088398115370545	26.589571052026837	.330
	Amidas	36.851333000468635	26.589571052026837	.193
	TSP	-48.491904658829090	26.589571052026837	.095
TSP	NPK	-21.421653776837500	26.589571052026837	.438
	DAP	66.816938549939420*	26.589571052026837	.029
	MOP	79.538730961517440*	26.589571052026837	.012
	Mavuno Plant	-391.400991293516800*	26.589571052026837	.000
	Baraka Plant	77.645588327584560*	26.589571052026837	.014
	SA	84.622472200754030*	26.589571052026837	.009
	Urea	80.817153109465780*	26.589571052026837	.011
	CAN	75.580302774199650*	26.589571052026837	.016
	Amidas	85.343237659297730*	26.589571052026837	.008
	Mavuno Top	48.491904658829090	26.589571052026837	.095

*. The mean difference is significant at the 0.05 level

8. Se

	Sum of Squares	Df	Mean Square	F	Sig.	F Crit
Between Groups	2137.978	10	213.798	230.075	.000	2.85
Within Groups	10.222	11	.929			
Total	2148.200	21				

(I) Sample	(J) Sample	Mean Difference (I-J)	Std. Error	Sig.
NPK	DAP	34.394920350231020*	.963978197376682	.000
	MOP	34.471859165556700*	.963978197376682	.000
	Mavuno Plant	28.316330776017880*	.963978197376682	.000
	Baraka Plant	34.394920350231020*	.963978197376682	.000
	SA	34.356450942568180*	.963978197376682	.000
	Urea	34.471859165556700*	.963978197376682	.000
	CAN	34.471859165556700*	.963978197376682	.000
	Amidas	34.471859165556700*	.963978197376682	.000
	Mavuno Top	34.471859165556700*	.963978197376682	.000
	TSP	33.701809165556700*	.963978197376682	.000
DAP	NPK	-34.394920350231020*	.963978197376682	.000
	MOP	.076938815325682	.963978197376682	.938
	Mavuno Plant	-6.078589574213138*	.963978197376682	.000
	Baraka Plant	.000000000000000	.963978197376682	1.000
	SA	-.038469407662841	.963978197376682	.969
	Urea	.076938815325682	.963978197376682	.938
	CAN	.076938815325682	.963978197376682	.938
	Amidas	.076938815325682	.963978197376682	.938
	Mavuno Top	.076938815325682	.963978197376682	.938
	TSP	-.693111184674319	.963978197376682	.487
MOP	NPK	-34.471859165556700*	.963978197376682	.000
	DAP	-.076938815325681	.963978197376682	.938
	Mavuno Plant	-6.155528389538820*	.963978197376682	.000

	Baraka Plant	-.076938815325681	.963978197376682	.938
	SA	-.115408222988522	.963978197376682	.907
	Urea	.000000000000000	.963978197376682	1.000
	CAN	.000000000000000	.963978197376682	1.000
	Amidas	.000000000000000	.963978197376682	1.000
	Mavuno Top	.000000000000000	.963978197376682	1.000
	TSP	-.770050000000000	.963978197376682	.441
Mavuno Plant	NPK	-28.316330776017880*	.963978197376682	.000
	DAP	6.078589574213138*	.963978197376682	.000
	MOP	6.155528389538820*	.963978197376682	.000
	Baraka Plant	6.078589574213138*	.963978197376682	.000
	SA	6.040120166550298*	.963978197376682	.000
	Urea	6.155528389538820*	.963978197376682	.000
	CAN	6.155528389538820*	.963978197376682	.000
	Amidas	6.155528389538820*	.963978197376682	.000
	Mavuno Top	6.155528389538820*	.963978197376682	.000
	TSP	5.385478389538820*	.963978197376682	.000
Baraka Plant	NPK	-34.394920350231020*	.963978197376682	.000
	DAP	.000000000000000	.963978197376682	1.000
	MOP	.076938815325682	.963978197376682	.938
	Mavuno Plant	-6.078589574213138*	.963978197376682	.000
	SA	-.038469407662841	.963978197376682	.969
	Urea	.076938815325682	.963978197376682	.938
	CAN	.076938815325682	.963978197376682	.938
	Amidas	.076938815325682	.963978197376682	.938
	Mavuno Top	.076938815325682	.963978197376682	.938
	TSP	-.693111184674319	.963978197376682	.487
SA	NPK	-34.356450942568180*	.963978197376682	.000
	DAP	.038469407662841	.963978197376682	.969
	MOP	.115408222988523	.963978197376682	.907
	Mavuno Plant	-6.040120166550298*	.963978197376682	.000
	Baraka Plant	.038469407662841	.963978197376682	.969
	Urea	.115408222988523	.963978197376682	.907
	CAN	.115408222988523	.963978197376682	.907
	Amidas	.115408222988523	.963978197376682	.907
	Mavuno Top	.115408222988523	.963978197376682	.907
	TSP	-.654641777011478	.963978197376682	.511
Urea	NPK	-34.471859165556700*	.963978197376682	.000
	DAP	-.076938815325681	.963978197376682	.938
	MOP	.000000000000000	.963978197376682	1.000
	Mavuno Plant	-6.155528389538820*	.963978197376682	.000
	Baraka Plant	-.076938815325681	.963978197376682	.938
	SA	-.115408222988522	.963978197376682	.907
	CAN	.000000000000000	.963978197376682	1.000
	Amidas	.000000000000000	.963978197376682	1.000
	Mavuno Top	.000000000000000	.963978197376682	1.000
	TSP	-.770050000000000	.963978197376682	.441
CAN	NPK	-34.471859165556700*	.963978197376682	.000
	DAP	-.076938815325681	.963978197376682	.938
	MOP	.000000000000000	.963978197376682	1.000

	Mavuno Plant	-6.155528389538820*	.963978197376682	.000
	Baraka Plant	-.076938815325681	.963978197376682	.938
	SA	-.115408222988522	.963978197376682	.907
	Urea	.000000000000000	.963978197376682	1.000
	Amidas	.000000000000000	.963978197376682	1.000
	Mavuno Top	.000000000000000	.963978197376682	1.000
	TSP	-.770050000000000	.963978197376682	.441
Amidas	NPK	-34.471859165556700*	.963978197376682	.000
	DAP	-.076938815325681	.963978197376682	.938
	MOP	.000000000000000	.963978197376682	1.000
	Mavuno Plant	-6.155528389538820*	.963978197376682	.000
	Baraka Plant	-.076938815325681	.963978197376682	.938
	SA	-.115408222988522	.963978197376682	.907
	Urea	.000000000000000	.963978197376682	1.000
	CAN	.000000000000000	.963978197376682	1.000
	Mavuno Top	.000000000000000	.963978197376682	1.000
	TSP	-.770050000000000	.963978197376682	.441
Mavuno Top	NPK	-34.471859165556700*	.963978197376682	.000
	DAP	-.076938815325681	.963978197376682	.938
	MOP	.000000000000000	.963978197376682	1.000
	Mavuno Plant	-6.155528389538820*	.963978197376682	.000
	Baraka Plant	-.076938815325681	.963978197376682	.938
	SA	-.115408222988522	.963978197376682	.907
	Urea	.000000000000000	.963978197376682	1.000
	CAN	.000000000000000	.963978197376682	1.000
	Amidas	.000000000000000	.963978197376682	1.000
	TSP	-.770050000000000	.963978197376682	.441
TSP	NPK	-33.701809165556700*	.963978197376682	.000
	DAP	.693111184674319	.963978197376682	.487
	MOP	.770050000000000	.963978197376682	.441
	Mavuno Plant	-5.385478389538820*	.963978197376682	.000
	Baraka Plant	.693111184674319	.963978197376682	.487
	SA	.654641777011478	.963978197376682	.511
	Urea	.770050000000000	.963978197376682	.441
	CAN	.770050000000000	.963978197376682	.441
	Amidas	.770050000000000	.963978197376682	.441
	Mavuno Top	.770050000000000	.963978197376682	.441

*. The mean difference is significant at the 0.05 level

Appendix V: ANOVA for Heavy Metals Amounts in Plants Commonly Found in Rice Farms of Mwea Irrigation Scheme

1. **Cd**

	Sum of Squares	Df	Mean Square	F	Sig.	F- Crit
Between Groups	.003	4	.001	2.691	.061	2.87
Within Groups	.006	20	.000			
Total	.010	24				

2. **Cr**

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	198.726	4	49.682	1.383	.275
Within Groups	718.428	20	35.921		
Total	917.155	24			

3. **Ni**

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4819062.218	4	1204765.554	3.801	.019
Within Groups	6339059.457	20	316952.973		
Total	11158121.675	24			

(I) Sample	(J) Sample	Mean Difference (I-J)	Std. Error	Sig.
Rice Sedge	Wandering Jew	-267.046137835364100	356.063462239319500	.462
	Cockspur Grass	-1151.232859729605300*	356.063462239319500	.004
	Nut Grass	-68.003939508572100	356.063462239319500	.850
	Water Primrose	7.237285904308010	356.063462239319500	.984
Wandering Jew	Rice Sedge	267.046137835364100	356.063462239319500	.462
	Cockspur Grass	-884.186721894241100*	356.063462239319500	.022
	Nut Grass	199.042198326792000	356.063462239319500	.582
	Water Primrose	274.283423739672100	356.063462239319500	.450
Cockspur Grass	Rice Sedge	1151.232859729605300*	356.063462239319500	.004
	Wandering Jew	884.186721894241100*	356.063462239319500	.022
	Nut Grass	1083.228920221033100*	356.063462239319500	.006
	Water Primrose	1158.470145633913300*	356.063462239319500	.004
Nut Grass	Rice Sedge	68.003939508572100	356.063462239319500	.850
	Wandering Jew	-199.042198326792000	356.063462239319500	.582
	Cockspur Grass	-1083.228920221033100*	356.063462239319500	.006
	Water Primrose	75.241225412880110	356.063462239319500	.835
Water Primrose	Rice Sedge	-7.237285904308010	356.063462239319500	.984
	Wandering Jew	-274.283423739672100	356.063462239319500	.450
	Cockspur Grass	-1158.470145633913300*	356.063462239319500	.004
	Nut Grass	-75.241225412880110	356.063462239319500	.835

*The mean difference is significant at the 0.05 level

4. **Pb**

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	26.895	4	6.724	1.563	.223
Within Groups	86.008	20	4.300		
Total	112.903	24			

5. **Zn**

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	639.290	4	159.822	5.652	.003
Within Groups	565.509	20	28.275		
Total	1204.799	24			

(I) Sample	(J) Sample	Mean Difference (I-J)	Std. Error	Sig.

Rice Sedge	Wandering Jew	-5.7960000	3.3630618	.100
	Cockspur Grass	-.9036800	3.3630618	.791
	Nut Grass	9.2377600*	3.3630618	.012
	Water Primrose	4.1205600	3.3630618	.235
Wandering Jew	Rice Sedge	5.7960000	3.3630618	.100
	Cockspur Grass	4.8923200	3.3630618	.161
	Nut Grass	15.0337600*	3.3630618	.000
	Water Primrose	9.9165600*	3.3630618	.008
Cockspur Grass	Rice Sedge	.9036800	3.3630618	.791
	Wandering Jew	-4.8923200	3.3630618	.161
	Nut Grass	10.1414400*	3.3630618	.007
	Water Primrose	5.0242400	3.3630618	.151
Nut Grass	Rice Sedge	-9.2377600*	3.3630618	.012
	Wandering Jew	-15.0337600*	3.3630618	.000
	Cockspur Grass	-10.1414400*	3.3630618	.007
	Water Primrose	-5.1172000	3.3630618	.144
Water Primrose	Rice Sedge	-4.1205600	3.3630618	.235
	Wandering Jew	-9.9165600*	3.3630618	.008
	Cockspur Grass	-5.0242400	3.3630618	.151
	Nut Grass	5.1172000	3.3630618	.144

*The mean difference is significant at the 0.05 level

6. **As**

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	.001	4	.000	.597	.669
Within Groups	.008	20	.000		
Total	.009	24			

7. **Mn**

	Sum of Squares	Df	Mean Square	F	Sig.	F Crit
Between Groups	1963187.837	4	490796.959	47.857	.000	2.87
Within Groups	205108.323	20	10255.416			
Total	2168296.160	24				

(I) Sample 3	(J) Sample 3	Mean Difference (I-J)	Std. Error	Sig.
Rice Sedge	Wandering Jew	-155.0909400*	64.0481574	.025
	Cockspur Grass	-131.4770200	64.0481574	.053
	Nut Grass	159.6041200*	64.0481574	.022
	Water Primrose	-673.8611200*	64.0481574	.000
Wandering Jew	Rice Sedge	155.0909400*	64.0481574	.025
	Cockspur Grass	23.6139200	64.0481574	.716
	Nut Grass	314.6950600*	64.0481574	.000
	Water Primrose	-518.7701800*	64.0481574	.000
Cockspur Grass	Rice Sedge	131.4770200	64.0481574	.053
	Wandering Jew	-23.6139200	64.0481574	.716
	Nut Grass	291.0811400*	64.0481574	.000
	Water Primrose	-542.3841000*	64.0481574	.000
Nut Grass	Rice Sedge	-159.6041200*	64.0481574	.022
	Wandering Jew	-314.6950600*	64.0481574	.000

	Cockspur Grass	-291.0811400*	64.0481574	.000
	Water Primrose	-833.4652400*	64.0481574	.000
Water Primrose	Rice Sedge	673.8611200*	64.0481574	.000
	Wandering Jew	518.7701800*	64.0481574	.000
	Cockspur Grass	542.3841000*	64.0481574	.000
	Nut Grass	833.4652400*	64.0481574	.000

*The mean difference is significant at the 0.05 level

8. Se

	Sum of Squares	df	Mean Square	F	Sig.	F Crit
Between Groups	.104	4	.026	.954	.454	2.87
Within Groups	.548	20	.027			
Total	.652	24				

Appendix VI: The t-test for Heavy Metals Amounts in Sediment from Rivers Thiba and Nyamindi during Rainy Season

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Inter of Diff	
		F	Sig.	T	Df	Sig. (2-tailed)	Mean Diff	Std. Error Diff	Lower	Upper
Cd	Equal var. assumed	1.118	.311	.263	12	.797	.0110	.0418	-.0802	.1023
	Equal var. not assumed			.276	11.998	.787	.0110	.0399	-.0759	.0980
Cr	Equal var. assumed	1.726	.214	-.196	12	.848	-.8002	4.090	-9.713	8.113
	Equal var. not assumed			-.183	7.95	.859	-.8002	4.372	-10.89	9.294
Ni	Equal var. assumed	.800	.389	-.45	12	.664	-5.299	11.88	-31.19	20.59
	Equal var. not assumed			-.43	9.1	.678	-5.299	12.36	-33.21	22.62
Pb	Equal var. assumed	3.585	.083	-.354	12	.729	-.3475	.9809	-2.484	1.789
	Equal var. not assumed			-.380	11.64	.711	-.3475	.9136	-2.345	1.650
Zn	Equal var. assumed	4.112	.065	.210	12	.837	.7327	3.4923	-6.876	8.3420
	Equal var. not assumed			.192	7.136	.853	.7327	3.8091	-8.239	9.7054
As	Equal var. assumed	.606	.451	-1.404	12	.186	-.1575	.1122	-.4021	.0870
	Equal var. not assumed			-1.464	11.988	.169	-.1575	.1076	-.3920	.0769
Mn	Equal var. assumed	2.324	.153	-.095	12	.926	-25.89	271.3	-617.1	565.3
	Equal var. not assumed			-.085	6.159	.935	-25.89	304.4	-766.2	714.4

Se	Equal var. assumed	.357	.561	-.566	12	.582	-.3307	.5841	-1.603	.9420
	Equal var. not assumed			-.563	10.649	.585	-.3307	.5880	-1.630	.9687

T-critical value: 2.179 at 0.05 level

Appendix VII: The t-test for Heavy Metals Amounts in Sediment from Rivers Thiba and Nyamindi during Dry Season

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Conf Inter of Diff	
		F	Sig.	T	Df	Sig. (2-tailed)	Mean Diff	Std. Error Diff	Lower	Upper
Cd	Equal var. assumed	.103	.754	.712	12	.490	.0099	.0139	-.0204	.0402
	Equal var. not assumed			.729	11.7	.480	.0099	.0135	-.0197	.0396
Cr	Equal var. assumed	3.502	.086	1.061	12	.309	5.526	5.207	-5.819	16.87
	Equal var. not assumed			1.198	9.090	.261	5.526	4.613	-4.894	15.94
Ni	Equal var. assumed	17.793	.001	-1.6	12	.139	-177.7	112.198	-422.1	66.80
	Equal var. not assumed			-1.8	7.7	.107	-177.7	97.254	-403.5	48.17
Pb	Equal var. assumed	71.311	.000	1.736	12	.108	3.6122	2.0808	-.92149	8.1459
	Equal var. not assumed			2.025	7.018	.082	3.6122	1.7840	-.6043	7.8287
Zn	Equal var. assumed	.923	.356	-1.345	12	.204	-16.09	11.970	-42.17	9.983
	Equal var. not assumed			-1.342	10.85	.207	-16.09	11.991	-42.53	10.337
As	Equal var. assumed	.035	.855	-.784	12	.448	-.1778	.2268	-.6720	.3164
	Equal var. not assumed			-.779	10.666	.453	-.1778	.2282	-.6821	.3264
Mn	Equal var. assumed	2.317	.154	.540	12	.599	51.17	94.80	-155.3	257.7
	Equal var. not assumed			.480	6.1	.648	51.17	106.67	-209.1	311.4
Se	Equal var. assumed	1.552	.237	-.495	12	.629	-.3575	.7221	-1.931	1.2158
	Equal var. not assumed			-.531	11.666	.605	-.3575	.6732	-1.829	1.1139

T-critical value: 2.179 at 0.05 level

Appendix VIII: The t-test for Heavy Metals Amounts in Water from Rivers Thiba and Nyamindi during Rainy Season

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Conf Inter of Diff	
		F	Sig.	T	Df	Sig. (2-tailed)	Mean Diff	Std. Error Diff	Lower	Upper
Cd	Equal var. assumed	4.3	.06	1.4	12	.19	.00009	.00007	-.00005	.0002
	Equal var. not assumed			1.5	10.3	.16	.00009	.00006	-.00004	.0002
Cr	Equal var. assumed	4.257	.061	1.38	12	.194	.0001	.0001	-.0001	.0002
	Equal var. not assumed			1.52	10.3	.158	.0001	.0001	-.0000	.0002
Ni	Equal var. assumed	5.879	.032	1.449	12	.173	.7204	.4972	-.3628	1.803
	Equal var. not assumed			1.658	8.233	.135	.7204	.4346	-.2769	1.717
Pb	Equal var. assumed	8.200	.014	-1.153	12	.271	-1.034	.8973	-2.989	.9204
	Equal var. not assumed			-.985	5.003	.370	-1.034	1.0507	-3.735	1.6659
Zn	Equal var. assumed	8.571	.013	-1.17	12	.264	-.0016	.00137	-.0046	.0013
	Equal var. not assumed			-1.00	5.00	.363	-.0016	.00161	-.0057	.0025
As	Equal var. assumed	9.654	.009	1.922	12	.079	.0018	.0009	-.00024	.0039
	Equal var. not assumed			2.227	7.399	.059	.0018	.0008	-.00009	.0037
Mn	Equal var. assumed	11.231	.006	1.977	12	.071	1.1591	.5862	-.1181	2.4365
	Equal var. not assumed			2.293	7.364	.054	1.1591	.5055	-.0242	2.3426
Se	Equal var. assumed	1.992	.184	-.348	12	.734	-.0018	.0051	-.0130	.0094
	Equal var. not assumed			-.311	6.23	.766	-.0017	.0057	-.0157	.0121

T-critical value: 2.179 at 0.05 level

Appendix IX: The t-test for Heavy Metals Amounts in Water from Rivers Thiba and Nyamindi during Dry Season

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Conf Inter of Diff	
	F	Sig.	T	Df	Sig. (2-tailed)	Mean Diff.	Std. Error Diff	Lower	Upper

Cd	Equal var. assumed	.074	.791	.092	11	.928	.0001	.0014	-.0029	.0032
	Equal var. not assumed			.094	10.98	.927	.0001	.0013	-.0029	.0031
Cr	Equal var. assumed	25.496	.000	-1.644	11	.128	-.0004	.00026	-.0010	.00015
	Equal var. not assumed			-1.511	5.000	.191	-.0004	.00029	-.0012	.00031
Ni	Equal var. assumed	7.404	.020	-1.088	11	.300	-.0148	.0136	-.0448	.0151
	Equal var. not assumed			-1.000	5.000	.363	-.0148	.0148	-.0529	.0232
Pb	Equal var. assumed	4.945	.048	-1.243	11	.240	-.0125	.0101	-.0348	.0096
	Equal var. not assumed			-1.146	5.183	.302	-.0125	.0109	-.0404	.0153
As	Equal var. assumed	.085	.776	-.145	11	.887	-.0000	.00003	-.0001	.0001
	Equal var. not assumed			-.145	10.48	.888	-.0000	.00003	-.0001	.0001
Mn	Equal var. assumed	.366	.558	-.650	11	.529	-.0008	.0013	-.0037	.0020
	Equal var. not assumed			-.656	10.96	.525	-.0008	.0012	-.0036	.0019
Se	Equal var. assumed	7.404	.020	-1.088	11	.300	-.00003	.00003	-.0001	.00003
	Equal var. not assumed			-1.000	5.000	.363	-.00003	.00003	-.0001	.00005

T-critical value: 2.201 at 0.05 level

Appendix X: ANOVA for Heavy Metals Amounts in Soils from the Five Main Rice Growing Sections of Mwea Irrigation Scheme

1. Cadmium

	Sum of Squares	Df	Mean Square	F	Sig.	F Crit
Between Groups	.001	4	.000	.272	.890	3.478
Within Groups	.006	10	.001			
Total	.006	14				

2. Chromium

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	283.892	4	70.973	2.723	.091
Within Groups	260.688	10	26.069		
Total	544.580	14			

3. Nickel

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	1064.840	4	266.210	3.149	.064
Within Groups	845.492	10	84.549		
Total	1910.332	14			

4. Lead

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	53.570	4	13.393	26.186	.000
Within Groups	5.114	10	.511		
Total	58.685	14			

(I) Sample	(J) Sample	Mean Difference (I-J)	Std. Error	Sig.
T	K	-2.128673882610766*	.583919646736833	.004
	W	-2.091744841809198*	.583919646736833	.005
	H	-5.719303091365749*	.583919646736833	.000
	M	-3.568439275938532*	.583919646736833	.000
K	T	2.128673882610766*	.583919646736833	.004
	W	.036929040801567	.583919646736833	.951
	H	-3.590629208754983*	.583919646736833	.000
	M	-1.439765393327766*	.583919646736833	.033
W	T	2.091744841809199*	.583919646736833	.005
	K	-.036929040801567	.583919646736833	.951
	H	-3.627558249556550*	.583919646736833	.000
	M	-1.476694434129333*	.583919646736833	.030
H	T	5.719303091365749*	.583919646736833	.000
	K	3.590629208754983*	.583919646736833	.000
	W	3.627558249556550*	.583919646736833	.000
	M	2.150863815427217*	.583919646736833	.004
M	T	3.568439275938532*	.583919646736833	.000
	K	1.439765393327766*	.583919646736833	.033
	W	1.476694434129334*	.583919646736833	.030
	H	-2.150863815427216*	.583919646736833	.004

5. Zinc

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	45.429	4	11.357	.411	.797
Within Groups	276.255	10	27.625		
Total	321.684	14			

6. Arsenic

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	4.284	4	1.071	40.853	.000
Within Groups	.262	10	.026		
Total	4.546	14			

(I) Sample	(J) Sample	Mean Difference (I-J)	Std. Error	Sig.
T	K	.170538195073708	.132199072836194	.226
	W	-.049913246139822	.132199072836194	.714
	H	-1.268689220470171*	.132199072836194	.000
	M	-.668295460244455*	.132199072836194	.000
K	T	-.170538195073708	.132199072836194	.226
	W	-.220451441213530	.132199072836194	.126
	H	-1.439227415543879*	.132199072836194	.000
	M	-.838833655318163*	.132199072836194	.000
W	T	.049913246139822	.132199072836194	.714
	K	.220451441213530	.132199072836194	.126
	H	-1.218775974330349*	.132199072836194	.000
	M	-.618382214104633*	.132199072836194	.001
H	T	1.268689220470172*	.132199072836194	.000
	K	1.439227415543880*	.132199072836194	.000
	W	1.218775974330350*	.132199072836194	.000
	M	.600393760225716*	.132199072836194	.001
M	T	.668295460244455*	.132199072836194	.000
	K	.838833655318164*	.132199072836194	.000
	W	.618382214104633*	.132199072836194	.001
	H	-.600393760225716*	.132199072836194	.001

*. The mean difference is significant at the 0.05 level.

7. Manganese

	Sum of Squares	Df	Mean Square	F	Sig.	F Crit
Between Groups	1439847.806	4	359961.952	4.510	.024	3.478
Within Groups	798188.000	10	79818.800			
Total	2238035.806	14				

(I) Sample	(J) Sample	Mean Difference (I-J)	Std. Error	Sig.
T	K	48.534847475927560	230.678419674217400	.838
	W	54.786016083798245	230.678419674217400	.817
	H	-761.818082537599700*	230.678419674217400	.008
	M	-221.960873781492300	230.678419674217400	.359
K	T	-48.534847475927560	230.678419674217400	.838
	W	6.251168607870682	230.678419674217400	.979
	H	-810.352930013527300*	230.678419674217400	.006
	M	-270.495721257419860	230.678419674217400	.268
W	T	-54.786016083798245	230.678419674217400	.817
	K	-6.251168607870682	230.678419674217400	.979

	H	-816.604098621398100*	230.678419674217400	.005
	M	-276.746889865290540	230.678419674217400	.258
H	T	761.818082537599700*	230.678419674217400	.008
	K	810.352930013527300*	230.678419674217400	.006
	W	816.604098621398100*	230.678419674217400	.005
	M	539.857208756107400*	230.678419674217400	.041
M	T	221.960873781492300	230.678419674217400	.359
	K	270.495721257419860	230.678419674217400	.268
	W	276.746889865290540	230.678419674217400	.258
	H	-539.857208756107400*	230.678419674217400	.041

8. Selenium

	Sum of Squares	Df	Mean Square	F	Sig.	F Crit
Between Groups	34.322	4	8.581	9.803	.002	3.478
Within Groups	8.753	10	.875			
Total	43.076	14				

(I) Sample	(J) Sample	Mean Difference (I-J)	Std. Error	Sig.
T	K	.000063000580316	.763908733982566	1.000
	W	.031531790454762	.763908733982566	.968
	H	-3.465126418977804*	.763908733982566	.001
	M	-2.583181294949003*	.763908733982566	.007
K	T	-.000063000580316	.763908733982566	1.000
	W	.031468789874446	.763908733982566	.968
	H	-3.465189419558120*	.763908733982566	.001
	M	-2.583244295529320*	.763908733982566	.007
W	T	-.031531790454762	.763908733982566	.968
	K	-.031468789874446	.763908733982566	.968
	H	-3.496658209432566*	.763908733982566	.001
	M	-2.614713085403766*	.763908733982566	.007
H	T	3.465126418977804*	.763908733982566	.001
	K	3.465189419558121*	.763908733982566	.001
	W	3.496658209432567*	.763908733982566	.001
	M	.881945124028801	.763908733982566	.275
M	T	2.583181294949004*	.763908733982566	.007
	K	2.583244295529320*	.763908733982566	.007
	W	2.614713085403766*	.763908733982566	.007
	H	-.881945124028800	.763908733982566	.275

Appendix XI: Two-Way ANOVA for Heavy Metals Amounts in Sediment from Rivers Thiba and Nyamindi During Rainy and Dry Seasons

1. Cd

Tests of Between-Subjects Effects

Dependent Variable: amount of Cd

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.007[a]	3	.002	.694	.565
Intercept	.170	1	.170	51.003	.000
Season	.006	1	.006	1.809	.191
River	.001	1	.001	.225	.640
Season * River	2.106E-6	1	2.106E-6	.001	.980
Error	.080	24	.003		
Total	.264	28			
Corrected Total	.087	27			

a. R Squared = .080 (Adjusted R Squared = -.035)

2. Cr

Tests of Between-Subjects Effects

Dependent Variable: amount of Cr

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	125.095[a]	3	41.698	.555	.650
Intercept	46787.669	1	46787.669	622.341	.000
Season	9.215	1	9.215	.123	.729
River	38.297	1	38.297	.509	.482
Season * River	68.626	1	68.626	.913	.349
Error	1804.322	24	75.180		
Total	50083.049	28			
Corrected Total	1929.417	27			

a. R Squared = .065 (Adjusted R Squared = -.052)

3. Ni

Tests of Between-Subjects Effects

Dependent Variable: amount of Ni

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1060552.274[a]	3	353517.425	16.200	.000
Intercept	2145670.219	1	2145670.219	98.323	.000
Season	996119.660	1	996119.660	45.646	.000
River	57384.294	1	57384.294	2.630	.118
Season * River	50928.251	1	50928.251	2.334	.140
Error	523741.815	24	21822.576		
Total	3673516.706	28			
Corrected Total	1584294.088	27			

a. R Squared = .669 (Adjusted R Squared = .628)

4. Pb

Tests of Between-Subjects Effects

Dependent Variable: amount of Pb

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	504.834[a]	3	168.278	18.548	.000
Intercept	1115.574	1	1115.574	122.965	.000

Season	482.284	1	482.284	53.160	.000
River	18.272	1	18.272	2.014	.169
Season * River	26.879	1	26.879	2.963	.098
Error	217.736	24	9.072		
Total	1903.407	28			
Corrected Total	722.570	27			

a. R Squared = .699 (Adjusted R Squared = .661)

5. Zn

Tests of Between-Subjects Effects

Dependent Variable: amount of Zn

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	5014.301[a]	3	1671.434	6.271	.003
Intercept	82770.465	1	82770.465	310.530	.000
Season	4449.966	1	4449.966	16.695	.000
River	404.681	1	404.681	1.518	.230
Season * River	485.567	1	485.567	1.822	.190
Error	6397.105	24	266.546		
Total	94226.654	28			
Corrected Total	11411.406	27			

a. R Squared = .439 (Adjusted R Squared = .369)

6. As

Tests of Between-Subjects Effects

Dependent Variable: amount of As

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.263[a]	3	.754	6.870	.002
Intercept	192.603	1	192.603	1754.121	.000
Season	2.038	1	2.038	18.562	.000
River	.193	1	.193	1.756	.198
Season * River	.001	1	.001	.006	.937
Error	2.635	24	.110		
Total	199.741	28			
Corrected Total	4.898	27			

a. R Squared = .462 (Adjusted R Squared = .395)

7. Mn

Tests of Between-Subjects Effects

Dependent Variable: amount of Mn

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	11465.576[a]	3	3821.859	.027	.994
Intercept	83059122.916	1	83059122.916	586.460	.000
Season	.745	1	.745	.000	.998
River	1095.454	1	1095.454	.008	.931
Season * River	10182.625	1	10182.625	.072	.791

Error	3399072.515	24	141628.021		
Total	88288060.942	28			
Corrected Total	3410538.092	27			

a. R Squared = .003 (Adjusted R Squared = -.121)

8. Se

Tests of Between-Subjects Effects

Dependent Variable: amount of Se

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4.949[a]	3	1.650	1.115	.362
Intercept	982.406	1	982.406	664.281	.000
Season	4.071	1	4.071	2.753	.110
River	.812	1	.812	.549	.466
Season * River	.001	1	.001	.001	.977
Error	35.494	24	1.479		
Total	1035.094	28			
Corrected Total	40.443	27			

a. R Squared = .122 (Adjusted R Squared = .013)

Appendix XII: Two-Way ANOVA for Heavy Metals Amounts in Water from Rivers Thiba and Nyamindi During Rainy and Dry Seasons

1. Cd

Tests of Between-Subjects Effects

Dependent Variable: concentration of Cd

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	5.388E-6[a]	3	1.796E-6	.583	.632
Intercept	7.574E-6	1	7.574E-6	2.458	.131
Season	5.255E-6	1	5.255E-6	1.705	.205
River	8.489E-8	1	8.489E-8	.028	.870
Season * River	2.020E-9	1	2.020E-9	.001	.980
Error	7.088E-5	23	3.082E-6		
Total	8.365E-5	27			
Corrected Total	7.626E-5	26			

a. R Squared = .071 (Adjusted R Squared = -.051)

2. Cr

Tests of Between-Subjects Effects

Dependent Variable: concentration of Cr

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	.027[a]	3	.009	5.263	.007
Intercept	.014	1	.014	7.947	.010
Season	.013	1	.013	7.791	.010
River	.005	1	.005	3.056	.094
Season * River	.005	1	.005	3.154	.089
Error	.039	23	.002		

Total	.084	27			
Corrected Total	.066	26			

a. R Squared = .407 (Adjusted R Squared = .330)

3. Ni

Tests of Between-Subjects Effects

Dependent Variable: concentration of Ni

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	4.200[a]	3	1.400	3.164	.044
Intercept	2.101	1	2.101	4.747	.040
Season	1.991	1	1.991	4.500	.045
River	.828	1	.828	1.872	.185
Season * River	.899	1	.899	2.032	.167
Error	10.178	23	.443		
Total	17.099	27			
Corrected Total	14.378	26			

a. R Squared = .292 (Adjusted R Squared = .200)

4. Pb

Tests of Between-Subjects Effects

Dependent Variable: concentration of Pb

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	5.164[a]	3	1.721	1.196	.334
Intercept	2.135	1	2.135	1.483	.236
Season	1.957	1	1.957	1.359	.256
River	1.830	1	1.830	1.271	.271
Season * River	1.743	1	1.743	1.211	.283
Error	33.113	23	1.440		
Total	40.028	27			
Corrected Total	38.277	26			

a. R Squared = .135 (Adjusted R Squared = .022)

5. Zn

Tests of Between-Subjects Effects

Dependent Variable: concentration of Zn

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	.000[a]	3	.000	.	.
Intercept	.000	1	.000	.	.
Season	.000	1	.000	.	.
River	.000	1	.000	.	.
Season * River	.000	1	.000	.	.
Error	.000	23	.000		
Total	.000	27			
Corrected Total	.000	26			

a. R Squared = . (Adjusted R Squared = .)

6. As

Tests of Between-Subjects Effects

Dependent Variable: concentration of As

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	2.119E-5[a]	3	7.064E-6	4.333	.015
Intercept	8.904E-6	1	8.904E-6	5.462	.029
Season	7.635E-6	1	7.635E-6	4.684	.041
River	5.531E-6	1	5.531E-6	3.393	.078
Season * River	5.582E-6	1	5.582E-6	3.424	.077
Error	3.749E-5	23	1.630E-6		
Total	7.066E-5	27			
Corrected Total	5.869E-5	26			

a. R Squared = .361 (Adjusted R Squared = .278)

7. Mn

Tests of Between-Subjects Effects

Dependent Variable: concentration of Mn

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	8.766[a]	3	2.922	4.755	.010
Intercept	3.471	1	3.471	5.649	.026
Season	3.327	1	3.327	5.415	.029
River	2.211	1	2.211	3.598	.070
Season * River	2.217	1	2.217	3.608	.070
Error	14.133	23	.614		
Total	27.594	27			
Corrected Total	22.900	26			

a. R Squared = .383 (Adjusted R Squared = .302)

8. Se

Tests of Between-Subjects Effects

Dependent Variable: concentration of Se

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	7.461E-5[a]	3	2.487E-5	2.815	.062
Intercept	2.256E-5	1	2.256E-5	2.553	.124
Season	2.178E-5	1	2.178E-5	2.465	.130
River	2.178E-5	1	2.178E-5	2.465	.130
Season * River	2.256E-5	1	2.256E-5	2.553	.124
Error	.000	23	8.835E-6		
Total	.000	27			
Corrected Total	.000	26			

a. R Squared = .269 (Adjusted R Squared = .173)

Appendix XIII: The t-test Results for Heavy Metals Amounts in Sediment and Water During Rainy Seasons

a. River Thiba: Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	T	Df	Sig. (2-tailed)	Mean Diff	Std. Error Diff	95% Conf Inter of Diff Lower	Upper
Cd	Equal var. assumed	18.087	.001	3.232	14	.006	.0990	.0306	.0333	.1647
	Equal var. not assumed			3.232	7.000	.014	.099	.0306	.0265	.1714
Cr	Equal var. assumed	27.468	.000	19.14	14	.000	40.248	2.103	35.73	44.75
	Equal var. not assumed			19.13	7.002	.000	40.24	2.103	35.27	45.22
Ni	Equal var. assumed	8.330	.012	12.46	14	.000	85.55	6.868	70.82	100.2
	Equal var. not assumed			12.46	7.052	.000	85.55	6.868	69.34	101.7
Pb	Equal var. assumed	32.727	.000	13.846	14	.000	10.36	.7483	8.755	11.96
	Equal var. not assumed			13.85	7.007	.000	10.36	.7483	8.591	12.12
Zn	Equal var. assumed	25.829	.000	26.61	14	.000	42.56	1.599	39.13	45.99
	Equal var. not assumed			26.612	7.000	.000	42.56	1.599	38.78	46.34
As	Equal var. assumed	16.353	.001	28.326	14	.000	2.296	.0810	2.122	2.470
	Equal var. not assumed			28.326	7.001	.000	2.296	.0810	2.104	2.488
Mn	Equal var. assumed	15.662	.001	17.647	14	.000	1726	97.81	1516	1935
	Equal var. not assumed			17.647	7.000	.000	1726	97.81	1494	1957
Se	Equal var. assumed	14.263	.002	14.462	14	.000	5.430	.3754	4.625	6.235
	Equal var. not assumed			14.462	7.000	.000	5.430	.3754	4.542	6.318

T-critical value: 2.145 at 0.05 level

b. River Nyamindi: Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Diff	Std. Error Diff	95% Conf Inter of the Diff Lower	Upper
Cd	Equal var. assumed	7.278	.022	3.443	10	.006	.0881	.0255	.0310	.1451

	Equal var. not assumed			3.443	5.000	.018	.0881	.0255	.0223	.1538
Cr	Equal var. assumed	16.336	.002	10.723	10	.000	41.10	3.833	32.56	49.64
	Equal var. not assumed			10.723	5.000	.000	41.10	3.833	31.25	50.95
Ni	Equal var. assumed	14.366	.004	8.894	10	.000	91.57	10.29	68.63	114.5
	Equal var. not assumed			8.894	5.001	.000	91.57	10.29	65.11	118.0
Pb	Equal var. assumed	1.046	.331	8.239	10	.000	9.671	1.173	7.056	12.28
	Equal var. not assumed			8.239	7.348	.000	9.671	1.173	6.922	12.42
Zn	Equal var. assumed	20.459	.001	12.099	10	.000	41.82	3.457	34.12	49.53
	Equal var. not assumed			12.099	5.000	.000	41.82	3.457	32.94	50.71
As	Equal var. assumed	11.628	.007	34.698	10	.000	2.455	.0707	2.298	2.613
	Equal var. not assumed			34.698	5.000	.000	2.455	.0707	2.273	2.637
Mn	Equal var. assumed	6.361	.030	6.081	10	.000	1753	288.3	1110	2395
	Equal var. not assumed			6.081	5.000	.002	1753	288.3	1012	2494
Se	Equal var. assumed	67.676	.000	12.738	10	.000	5.764	.4525	4.756	6.773
	Equal var. not assumed			12.738	5.000	.000	5.764	.4525	4.601	6.928

T-critical value: 2.228 at 0.05 level

Appendix XIV: The t-test Results for Heavy Metals Amounts in Sediment and Water During Dry Season

a. **River Thiba: Independent Samples Test**

	Levene's Test for Equality of Variances	t-test for Equality of Means

		F	Sig.	T	df	Sig. (2-tailed)	Mean Diff	Std. Error Diff	95% Conf Inter of Diff Lower	Upper
Cd	Equal var. assumed	7.520	.017	-6.521	13	.000	-.0678	.0104	-.0903	-.0453
	Equal var. not assumed			-6.995	7.163	.000	-.0678	.0097	-.0907	-.0450
Cr	Equal var. assumed	9.974	.008	-9.701	13	.000	-44.64	4.601	-54.58	-34.70
	Equal var. not assumed			-10.421	7.000	.000	-44.64	4.284	-54.77	-34.51
Ni	Equal var. assumed	32.278	.000	-3.742	13	.002	-381.4	101.9	-601.6	-161.1
	Equal var. not assumed			-4.019	7.000	.005	-381.4	94.90	-605.8	-157.0
Pb	Equal var. assumed	88.787	.000	-2.080	13	.058	-3.984	1.915	-8.122	.1530
	Equal var. not assumed			-2.235	7.000	.061	-3.984	1.782	-8.200	.2315
Zn	Equal var. assumed	85.087	.000	-7.116	13	.000	-59.62	8.378	-77.72	-41.52
	Equal var. not assumed			-7.644	7.000	.000	-59.62	7.800	-78.06	-41.17
As	Equal var. assumed	20.990	.001	-18.072	13	.000	-2.833	.1567	-3.172	-2.494
	Equal var. not assumed			-19.413	7.000	.000	-2.833	.1459	-3.178	-2.488
Mn	Equal var. assumed	12.800	.003	-49.759	13	.000	-1765	35.48	-1842	-1688
	Equal var. not assumed			-53.450	7.000	.000	-1765	33.03	-1843	-1687
Se	Equal var. assumed	16.227	.001	-10.485	13	.000	-6.191	.5905	-7.466	-4.915
	Equal var. not assumed			-11.262	7.000	.000	-6.191	.5497	-7.491	-4.891

T-critical value: 2.160 at 0.05 level

b. River Nyamindi: Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Diff	Std. Error Diff	95% Conf Inter of Diff Lower	Upper
Cd	Equal var. assumed	7.083	.024	-6.042	10	.000	-.0581	.0096	-.0795	-.0366
	Equal var. not assumed			-6.042	5.091	.002	-.0581	.0096	-.0826	-.0335

Cr	Equal var. assumed	6.948	.025	-22.844	10	.000	-39.11	1.712	-42.93	-35.30
	Equal var. not assumed			-22.844	5.000	.000	-39.11	1.712	-43.51	-34.71
Ni	Equal var. assumed	12.471	.005	-26.312	10	.000	-559.0	21.24	-606.4	-511.7
	Equal var. not assumed			-26.312	5.000	.000	-559.0	21.24	-613.6	-504.4
Pb	Equal var. assumed	7.605	.020	-5.616	10	.000	-.3597	.0640	-.5024	-.2170
	Equal var. not assumed			-5.616	5.297	.002	-.3597	.0640	-.5216	-.1978
Zn	Equal var. assumed	4.595	.058	-8.314	10	.000	-75.71	9.106	-96.01	-55.42
	Equal var. not assumed			-8.314	5.000	.000	-75.71	9.1069	-99.12	-52.30
As	Equal var. assumed	9.546	.011	-17.161	10	.000	-3.011	.1754	-3.402	-2.620
	Equal var. not assumed			-17.161	5.000	.000	-3.011	.1754	-3.462	-2.560
Mn	Equal var. assumed	5.939	.035	-16.902	10	.000	-1714	101.4	-1940	-1488
	Equal var. not assumed			-16.902	5.000	.000	-1714	101.4	-1975	-1453
Se	Equal var. assumed	23.801	.001	-16.852	10	.000	-6.548	.3885	-7.414	-5.682
	Equal var. not assumed			-16.852	5.000	.000	-6.548	.3885	-7.547	-5.549

T-critical value: 2.228 at 0.05 level

Appendix XV: The t-test Results for Heavy Metals Amounts in Paddy Water and Adjacent River Water

a. **During Dry Season: Independent Samples Test**

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-	Mean Diff		95% Conf Inter of Diff	

						tailed)		Std. Error Diff	Lower	Upper
Cd	Equal var. assumed	9.578	.054	.796	3	.484	.0037	.0046	-.0111	.0186
	Equal var. not assumed			1.027	2.000	.412	.0037	.0036	-.0119	.0193
Cr	Equal var. assumed	3.263	.169	6.250	3	.008	.4384	.0701	.2152	.6617
	Equal var. not assumed			8.069	2.000	.015	.4384	.0543	.2046	.6722
Ni	Equal var. assumed	9.134	.057	4.158	3	.025	5.226	1.256	1.226	9.225
	Equal var. not assumed			5.368	2.000	.033	5.226	.9735	1.037	9.414
Pb	Equal var. assumed	32.807	.011	-1.144	3	.336	-.0045	.0039	-.0171	.0080
	Equal var. not assumed			-.899	1.119	.521	-.0045	.0050	-.0545	.0454
Zn	Equal var. assumed	6.498	.084	1.056	3	.369	.1588	.1504	-.3199	.6376
	Equal var. not assumed			1.363	2.000	.306	.1588	.1165	-.3425	.6602
As	Equal var. assumed	9.458	.054	2.913	3	.062	.0079	.0027	-.0007	.0166
	Equal var. not assumed			3.761	2.000	.064	.0079	.0021	-.0011	.0170
Mn	Equal var. assumed	4.987	.112	5.346	3	.013	1.818	.3402	.7360	2.901
	Equal var. not assumed			6.901	2.000	.020	1.818	.2635	.6848	2.952
Se	Equal var. assumed	3.038	.180	2.144	3	.121	.0230	.0107	-.0111	.0573
	Equal var. not assumed			2.768	2.000	.109	.0230	.0083	-.0127	.0589

T-critical value: 3.182 at 0.05 level

b. During Wet Season: Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Diff	Std. Error Diff	95% Conf Inter of Diff Lower	Upper
Cd	Equal var. assumed	8.994	.058	.742	3	.512	.0034	.0046	-.0114	.0184
	Equal var. not assumed			.958	2.007	.439	.0034	.0036	-.0121	.0190
Cr	Equal var. assumed	2.124	.241	4.658	3	.019	.3297	.0707	.1044	.5550
	Equal var. not assumed			5.909	2.211	.022	.3297	.0558	.1103	.5491
Ni	Equal var. assumed	.265	.642	2.045	3	.133	3.046	1.490	-1.695	7.788
	Equal var. not assumed			2.102	2.481	.145	3.046	1.449	-2.163	8.256
Pb	Equal var. assumed	16.121	.028	-2.687	3	.075	-.0088	.0032	-.0192	.0016
	Equal var. not assumed			-2.166	1.189	.243	-.0088	.0040	-.0446	.0270
Zn	Equal var. assumed	6.498	.084	1.056	3	.369	.1588	.1504	-.3199	.6376
	Equal var. not assumed			1.363	2.000	.306	.1588	.1165	-.3425	.6602
As	Equal var. assumed	1.365	.327	1.227	3	.307	.0037	.0030	-.0059	.0133
	Equal var. not assumed			1.353	2.931	.271	.0037	.0027	-.0051	.0125
Mn	Equal var. assumed	12.100	.040	-.762	3	.501	-.5511	.7228	-2.851	1.749
	Equal var. not assumed			-.616	1.193	.635	-.5511	.8953	-8.376	7.274
Se	Equal var. assumed	.289	.628	1.356	3	.268	.0161	.0119	-.0217	.0541
	Equal var. not assumed			1.494	2.929	.234	.0161	.0108	-.0187	.0510

T-critical value: 3.182 at 0.05 level

Appendix XVI: The t-test Results for Heavy Metals Amounts in Paddy Soils from the Five Main Rice Growing Sections and Control Soil Samples

a. Comparison of the Heavy Metals in Soil from Tebere Section and Control

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Diff	Std. Error Diff	95% Conf Inter of Diff Lower	Upper
Cd	Equal var. assumed	3.600	.131	2.335	4	.080	.0270	.0115	-.00511	.0591
	Equal var. not assumed			2.335	2.010	.144	.0270	.0115	-.0225	.0766
Cr	Equal var. assumed	9.105	.039	1.203	4	.295	6.186	5.141	-8.088	20.46
	Equal var. not assumed			1.203	2.163	.344	6.186	5.141	-14.40	26.78
Ni	Equal var. assumed	1.328	.313	.836	4	.450	5.947	7.112	-13.80	25.69
	Equal var. not assumed			.836	2.774	.469	5.947	7.112	-17.76	29.66
Pb	Equal var. assumed	5.126	.086	-2.068	4	.107	-3.836	1.854	-8.986	1.313
	Equal var. not assumed			-2.068	2.353	.155	-3.836	1.854	-10.77	3.100
Zn	Equal var. assumed	.553	.498	-1.068	4	.346	-6.483	6.069	-23.33	10.36
	Equal var. not assumed			-1.068	3.705	.350	-6.483	6.069	-23.87	10.91
As	Equal var. assumed	5.094	.087	-1.158	4	.311	-.5213	.4503	-1.771	.7291
	Equal var. not assumed			-1.158	2.082	.363	-.5213	.4503	-2.387	1.344
Mn	Equal var. assumed	.127	.740	.197	4	.853	49.53	251.2	-648.0	747.1
	Equal var. not assumed			.197	3.976	.853	49.53	251.2	-649.7	748.7
Se	Equal var. assumed	3.331	.142	-1.494	4	.210	-1.543	1.033	-4.412	1.325

	Equal var. not assumed			-1.494	2.863	.236	-1.543	1.033	-4.922	1.835

T-critical value: 2.776 at 0.05 level

b. Comparison of the Heavy Metals in Soil from Karaba Section and Control

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
						Sig. (2-tailed)	Mean Diff	Std. Error Diff	95% Conf Inter of Diff	
		F	Sig.	t	df				Lower	Upper
Cd	Equal var. assumed	5.892	.072	.683	4	.532	.0143	.0210	-.0439	.0726
	Equal var. not assumed			.683	2.003	.565	.0143	.0210	-.0758	.1045
Cr	Equal var. assumed	3.461	.136	1.743	4	.156	4.252	2.439	-2.520	11.02
	Equal var. not assumed			1.743	2.809	.186	4.252	2.439	-3.817	12.32
Ni	Equal var. assumed	.684	.455	3.633	4	.022	18.61	5.123	4.387	32.83
	Equal var. not assumed			3.633	3.554	.027	18.61	5.123	3.654	33.57
Pb	Equal var. assumed	8.172	.046	-.951	4	.395	-1.707	1.795	-6.693	3.278
	Equal var. not assumed			-.951	2.083	.439	-1.707	1.795	-9.148	5.733
Zn	Equal var. assumed	.005	.949	-.520	4	.631	-2.594	4.990	-16.44	11.26
	Equal var. not assumed			-.520	3.985	.631	-2.594	4.990	-16.47	11.28
As	Equal var. assumed	4.551	.100	-1.526	4	.202	-.6918	.4532	-1.950	.5665
	Equal var. not assumed			-1.526	2.135	.259	-.6918	.4532	-2.528	1.145
Mn	Equal var. assumed	.002	.964	.004	4	.997	.9982	227.9	-631.7	633.7
	Equal var. not assumed			.004	3.942	.997	.9982	227.9	-635.4	637.4
Se	Equal var. assumed	.397	.563	-1.294	4	.265	-1.543	1.19	-4.854	1.767
	Equal var. not assumed			-1.294	3.809	.268	-1.543	1.192	-4.921	1.833

T-critical value: 2.776 at 0.05 level

c. **Comparison of the Heavy Metals in Soil from Wamumu Section and Control**

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	Df	Sig. (2-tailed)	Mean Diff	Std. Error Diff	95% Conf Inter of Diff Lower	Upper
Cd	Equal var. assumed	9.238	.038	3.540	4	.024	.0096	.0027	.0020	.0172
	Equal var. not assumed			3.540	2.188	.062	.0096	.0027	-.0011	.0205
Cr	Equal var. assumed	4.179	.110	1.605	4	.184	5.331	3.322	-3.891	14.55
	Equal var. not assumed			1.605	2.411	.228	5.331	3.322	-6.862	17.52
Ni	Equal var. assumed	5.023	.088	2.544	4	.064	21.48	8.444	-1.959	44.93
	Equal var. not assumed			2.544	2.530	.100	21.48	8.444	-8.445	51.41
Pb	Equal var. assumed	7.235	.055	-.965	4	.389	-1.744	1.808	-6.765	3.276
	Equal var. not assumed			-.965	2.140	.431	-1.744	1.808	-9.058	5.568
Zn	Equal var. assumed	.196	.681	-1.480	4	.213	-6.934	4.686	-19.94	6.077
	Equal var. not assumed			-1.480	3.840	.216	-6.934	4.686	-20.16	6.294
As	Equal var. assumed	4.594	.099	-1.041	4	.357	-.4714	.4530	-1.729	.7865
	Equal var. not assumed			-1.041	2.131	.402	-.4714	.4530	-2.310	1.367
Mn	Equal var. assumed	.675	.457	-.027	4	.980	-5.252	198.2	-555.5	545.0
	Equal var. not assumed			-.027	3.246	.980	-5.252	198.2	-609.8	599.3
Se	Equal var. assumed	6.471	.064	-1.613	4	.182	-1.575	.9765	-4.286	1.136
	Equal var. not assumed			-1.613	2.380	.228	-1.575	.9765	-5.195	2.045

T-critical value: 2.776 at 0.05 level

d. **Comparison of the Heavy Metals in Soil from Thiba Section and Control**

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	Df	Sig. (2-tailed)	Mean Diff	Std. Error Diff	95% Conf Inter of Diff Lower	Upper

Cd	Equal var. assumed	7.884	.048	1.394	4	.236	.0190	.0136	-.0188	.0569
	Equal var. not assumed			1.394	2.007	.298	.0190	.0136	-.0395	.0775
Cr	Equal var. assumed	.072	.802	-3.106	4	.036	-3.940	1.268	-7.461	-.4181
	Equal var. not assumed			-3.106	3.687	.040	-3.940	1.268	-7.582	-.2973
Ni	Equal var. assumed	1.358	.309	3.988	4	.016	12.38	3.104	3.762	21.00
	Equal var. not assumed			3.988	2.538	.038	12.38	3.104	1.401	23.36
Pb	Equal var. assumed	5.018	.089	1.013	4	.368	1.882	1.858	-3.275	7.041
	Equal var. not assumed			1.013	2.367	.403	1.882	1.858	-5.033	8.799
Zn	Equal var. assumed	3.783	.124	-1.083	4	.340	-4.155	3.838	-14.81	6.501
	Equal var. not assumed			-1.083	2.450	.374	-4.155	3.838	-18.07	9.766
As	Equal var. assumed	3.908	.119	1.632	4	.178	.7473	.4579	-.5241	2.018
	Equal var. not assumed			1.632	2.221	.232	.7473	.4579	-1.046	2.541
Mn	Equal var. assumed	.082	.789	3.710	4	.021	811.3	218.7	204.1	1418
	Equal var. not assumed			3.710	3.820	.022	811.3	218.7	192.6	1430
Se	Equal var. assumed	2.404	.196	1.815	4	.144	1.921	1.058	-1.017	4.860
	Equal var. not assumed			1.815	3.062	.165	1.921	1.058	-1.408	5.251

T-critical value: 2.776 at 0.05 level

e. Comparison of the Heavy Metals in Soil from Mwea Section and Control

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	T	df	Sig. (2-tailed)	Mean Diff	Std. Error Diff	95% Conf Inter of Diff Lower	Upper
Cd	Equal var. assumed	14.734	.018	.774	4	.482	.0103	.0133	-.0267	.0474
	Equal var. not assumed			.774	2.008	.520	.0103	.0133	-.0469	.0676
Cr	Equal var. assumed	1.204	.334	-1.629	4	.179	-3.095	1.900	-8.371	2.180
	Equal var. not assumed			-1.629	3.389	.191	-3.095	1.900	-8.769	2.577
Ni	Equal var. assumed	.679	.456	-.328	4	.759	-1.657	5.050	-15.67	12.36
	Equal var. not assumed			-.328	3.596	.761	-1.657	5.050	-16.32	13.00
Pb	Equal var. assumed	7.409	.053	-.148	4	.889	-.2680	1.806	-5.283	4.747
	Equal var. not assumed			-.148	2.130	.895	-.2680	1.806	-7.601	7.065
Zn	Equal var. assumed	5.980	.071	-1.857	4	.137	-6.881	3.705	-17.16	3.405
	Equal var. not assumed			-1.857	2.152	.195	-6.881	3.705	-21.79	8.029
As	Equal var. assumed	3.411	.139	.318	4	.767	.1469	.4627	-1.137	1.431
	Equal var. not assumed			.318	2.308	.777	.1469	.4627	-1.610	1.904
Mn	Equal var. assumed	.380	.571	.982	4	.382	271.4	276.3	-495.8	1038
	Equal var. not assumed			.982	3.786	.384	271.4	276.3	-513.3	1056
Se	Equal var. assumed	1.206	.334	.931	4	.404	1.039	1.116	-2.060	4.139
	Equal var. not assumed			.931	3.457	.412	1.039	1.116	-2.261	4.341

T-critical value: 2.776 at 0.05 level

Appendix XVII: The t-test Results Comparing Heavy Metals Amounts in Sediment During Rainy and Dry Season

1. **River Thiba**

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	Df	Sig. (2-tailed)	Mean Diff	Std. Error Diff	95% Conf Inter of Diff Lower	Upper
Cd	Equal var. assumed	8.068	.013	.941	14	.362	.0302	.0321	-.0386	.0991
	Equal var. not assumed			.941	8.375	.373	.0302	.0321	-.0432	.1037
Cr	Equal var. assumed	2.003	.179	-.906	14	.380	-4.322	4.772	-14.55	5.913
	Equal var. not assumed			-.906	10.189	.386	-4.322	4.772	-14.92	6.284
Ni	Equal var. assumes	32.467	.000	-3.100	14	.008	-294.9	95.15	-499.0	-90.87
	Equal var. not assumed			-3.100	7.073	.017	-294.9	95.15	-519.4	-70.43
Pb	Equal var. assumed	25.560	.000	3.313	14	.005	6.406	1.933	2.259	10.55
	Equal var. not assumed			3.313	9.391	.009	6.406	1.933	2.060	10.75
Zn	Equal var. assumed	57.013	.000	-2.143	14	.050	-17.05	7.962	-34.13	.0182
	Equal var. not assumed			-2.143	7.588	.066	-17.05	7.962	-35.59	1.477
As	Equal var. assumed	3.816	.071	-3.205	14	.006	-.5350	.1669	-.8931	-.1769
	Equal var. not assumed			-3.205	10.943	.008	-.5350	.1669	-.9027	-.1673
Mn	Equal var. assumed	6.270	.025	-.370	14	.717	-38.20	103.2	-259.6	183.2
	Equal var. not assumed			-.370	8.576	.720	-38.20	103.2	-273.5	197.1
Se	Equal var. assumed	1.413	.254	-1.137	14	.274	-.7571	.6657	-2.185	.6706

	Equal var. not assumed			-1.137	12.364	.277	-.7571	.6657	-2.202	.6886

T-critical = 2.145

2. **River Nyamindi**

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Conf Inter of Diff	
		F	Sig.	t	Df	Sig. (2-tailed)	Mean Diff	Std. Error Diff	Lower	Upper
Cd	Equal var. assumed	2.438	.149	1.066	10	.311	.0291	.0273	-.0317	.0900
	Equal var. not assumed			1.066	6.373	.325	.0291	.0273	-.0367	.0950
Cr	Equal var. assumed	4.518	.059	.477	10	.643	2.004	4.198	-7.350	11.35
	Equal var. not assumed			.477	6.919	.648	2.004	4.198	-7.947	11.95
Ni	Equal var. assumed	2.630	.136	-19.793	10	.000	-467.3	23.61	-519.9	-414.7
	Equal var. not assumed			-19.793	7.225	.000	-467.3	23.61	-522.7	-411.8
Pb	Equal var. assumed	8.520	.015	19.624	10	.000	10.36	.5282	9.189	11.54
	Equal var. not assumed			19.624	5.145	.000	10.36	.5282	9.019	11.71
Zn	Equal var. assumed	1.126	.314	-3.479	10	.006	-33.88	9.741	-55.59	-12.18
	Equal var. not assumed			-3.479	6.412	.012	-33.88	9.741	-57.35	-10.42
As	Equal var. assumed	2.846	.122	-2.935	10	.015	-.5553	.1892	-.9769	-.1337
	Equal var. not assumed			-2.935	6.585	.023	-.5553	.1892	-1.008	-.1021
Mn	Equal var. assumed	2.409	.152	.127	10	.901	38.86	305.6	-642.1	719.8
	Equal var. not assumed			.127	6.219	.903	38.86	305.6	-702.6	780.3
Se	Equal var. assumed	.864	.375	-1.314	10	.218	-.7839	.5964	-2.113	.5451
	Equal var. not assumed			-1.314	9.776	.219	-.7839	.5964	-2.117	.5492

T-critical = 2.228

Appendix XVIII: The t-test Results Comparing Heavy Metals Concentration in Water During Rainy and Dry Season

1. **River Thiba**

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Conf Inter of Diff	
		F	Sig.	T	Df	Sig. (2-tailed)	Mean Diff	Std. Error Diff	Lower	Upper
Cd	Equal var. assumed	5.731	.032	-.932	13	.368	-.0009	.0009	-.0030	.0011
	Equal var. not assumed			-.868	6.034	.419	-.0009	.0010	-.0034	.0016
Cr	Equal var. assumed	22.37	.000	2.702	13	.018	.0732	.0271	.0146	.1317
	Equal var. not assumed			2.902	7.000	.023	.0732	.0252	.0135	.1328
Ni	Equal var. assumed	13.78	.003	2.046	13	.062	.9147	.4470	-.0510	1.880
	Equal var. not assumed			2.198	7.000	.064	.9147	.4161	-.0694	1.898
Pb	Equal var. assumed	12.97	.003	1.669	13	.119	.0304	.0182	-.0089	.0698
	Equal var. not assumed			1.791	7.106	.116	.0304	.0170	-.0096	.0705
As	Equal var. assumed	14.57	.002	2.278	13	.040	.0019	.0008	.0001	.0038
	Equal var. not assumed			2.447	7.008	.044	.0019	.0008	.0001	.0039
Mn	Equal var. assumed	17.31	.001	2.396	13	.032	1.284	.5360	.1264	2.442
	Equal var. not assumed			2.574	7.000	.037	1.284	.4990	.1044	2.464
Se	Equal var. assumed	22.24	.000	1.784	13	.098	.0036	.0020	-.0007	.0080

Equal var. not assumed			1.916	7.000	.097	.0036	.0019	-.0008	.0081

T-critical = 2.160

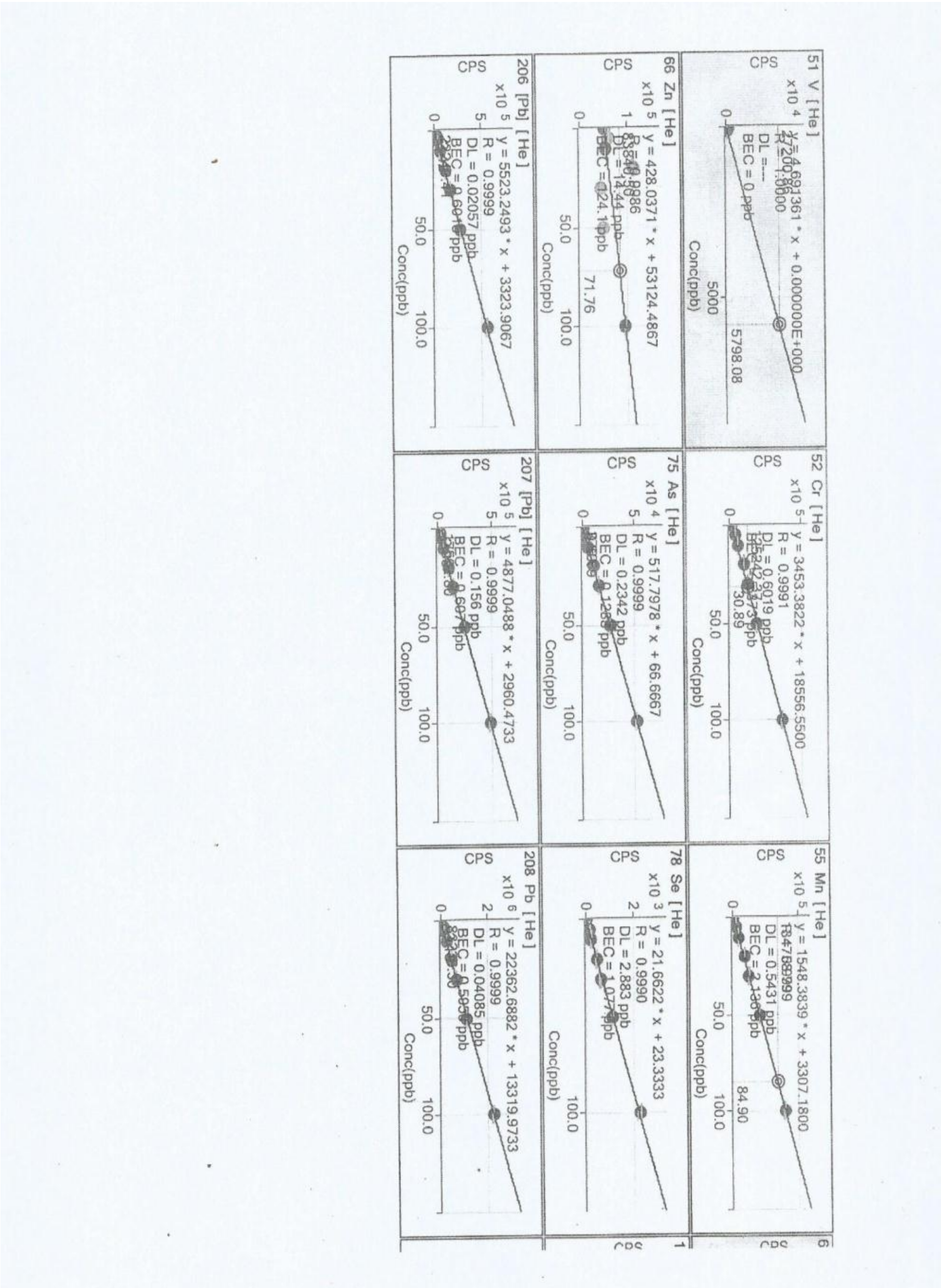
2. **River Nyamindi**

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Conf Inter of Diff	
		F	Sig.	T	df	Sig. (2-tailed)	Mean Diff	Std. Error Diff	Lower	Upper
Cd	Equal var. assumed	5.801	.037	-.954	10	.362	-.0008	.0009	-.0029	.0011
	Equal var. not assumed			-.954	5.010	.384	-.0008	.0009	-.0032	.0014
Cr	Equal var. assumed	20.121	.001	1.468	10	.173	.0162	.0110	-.0084	.0409
	Equal var. not assumed			1.468	5.007	.202	.0162	.0110	-.0122	.0447
Ni	Equal var. assumed	22.919	.001	1.421	10	.186	.1794	.1262	-.1018	.4606
	Equal var. not assumed			1.421	5.140	.213	.1794	.1262	-.1424	.5012
Pb	Equal var. assumed	6.121	.033	1.004	10	.339	1.054	1.050	-1.286	3.394
	Equal var. not assumed			1.004	5.001	.362	1.054	1.050	-1.645	3.753
As	Equal var. assumed	3.950	.075	1.129	10	.285	.0001	.0001	-.0001	.0004
	Equal var. not assumed			1.129	5.260	.308	.0001	.0001	-.0001	.0005
Mn	Equal var. assumed	5.664	.039	1.642	10	.132	.1298	.0790	-.0463	.3061
	Equal var. not assumed			1.642	5.001	.162	.1298	.07909	-.0734	.3331
Se	Equal var. assumed	6.250	.031	-1.000	10	.341	-.00003	.00003	-.0001	.00003
	Equal var. not assumed			-1.000	5.000	.363	-.00003	.00003	-.0001	.00005

T-critical = 2.228

Appendix XIX: Calibration Curves


51 V [He]
y = 4.691361 * x + 0.000000E+000
R = 1.0000
DL = ---
BEC = 0 ppb
5798.08
52 Cr [He]
y = 3453.3822 * x + 18556.5500
R = 0.9991
DL = 0.6019 ppb
30.89
55 Mn [He]
y = 1548.3839 * x + 3307.1800
DL = 0.5431 ppb
84.90
66 Zn [He]
y = 428.0371 * x + 53124.4867
DL = 14.44 ppb
BEC = 124.1 ppb
71.76
75 As [He]
y = 517.7978 * x + 66.6667
R = 0.9999
DL = 0.2342 ppb
78 Se [He]
y = 21.6622 * x + 23.3333
R = 0.9990
DL = 2.883 ppb
206 [Pb] [He]
y = 5523.2493 * x + 3323.9067
R = 0.9999
DL = 0.02057 ppb
207 [Pb] [He]
y = 4877.0488 * x + 2960.4733
R = 0.9999
DL = 0.156 ppb
208 Pb [He]
y = 22362.6882 * x + 13319.9733
R = 0.9999
DL = 0.04085 ppb
CPS
Conc(ppb)

Appendix XX: NACOSTI Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **646897**

Date of Issue: **19/August/2021**

RESEARCH LICENSE

This is to Certify that Mr.. EDWARD SILAS NJAGI of Chuka University, has been licensed to conduct research in Kirinyaga on the topic: ASSESSMENT OF HEAVY METAL POLLUTION IN MWEA IRRIGATION SCHEME AND DEVELOPMENT OF TRANSGENIC PLANT FOR PHYTOREMEDIATION OF HEAVY METAL CONTAMINATED SOILS for the period ending : 19/August/2022.

License No: **NACOSTI/P/21/12312**

646897

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document, Scan the QR Code using QR scanner application.