UNIVERSITY OF NAIROBI

ASSESSMENT OF THE IMPACT OF FLOODS ON AVAILABILITY OF ESSENTIAL TRACE ELEMENTS IN SOILS, SELECTED VEGETABLES AND WATER QUALITY IN BUDALANGI, BUSIA COUNTY

BY

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S56/71545/2014

A Thesis Submitted for Examination in Partial Fulfillment of the Requirements for Award of the Degree of Master of Science in Nuclear Science at the Department of Electrical and Information Engineering, Faculty of Engineering, University of Nairobi.

November 2023

DECLARATION

I declare that this dissertation/thesis is my original work and has not been submitted elsewhere for examination, award of a degree or publication. Where other people's work or my own work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi's requirements.

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DEDICATION

This thesis is dedicated to my wife, Queenter and children; Zuri and Aria, for their support throughout my studies.

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I would like to express my heartfelt gratitude to my supervisors; Dr. Geoffrey O. Okeng'o and Mr. Michael J. Mangala, for their unwavering support and guidance throughout the entire period of my thesis preparation. Their valuable insights and expertise greatly contributed to the success of this research endeavor.

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ABSTRACT

This study assessed the impact of floods on essential trace elements in vegetables, water, and soils in Budalangi, Busia County. One hundred and twenty (120) soil samples and twenty (20) vegetables samples comprising of 3 different indigenous vegetables species were collected and analyzed for Iron (Fe), Manganese (Mn), Copper (Cu), and Zinc (Zn) while twenty (20) water samples comprising of 4 different water sources were collected and analyzed for Mercury (Hg), Lead (Pb), Chromium (Cr), Arsenic (As) and Nickel (Ni) using Energy Dispersive X-ray Fluorescence (EDXRF) at the University of Nairobi. Soil pH was also analyzed. The samples were collected under varying climatic conditions; before the floods (in December, 2021) and after the floods (in July 2022). The analysis of soil pH revealed a 7.2% and 7.6% decrease in soil pH for topsoil and subsoil, respectively, indicating a dilution effect. The relative abundance of trace elements in soil decreased in the order Fe>Mn>Cu>Zn, with a 7% reduction in Fe, 4% in Mn, 2.5% in Cu, and 13% in Zn after the floods. Despite the reductions, the measured quantities remained within global limits for agricultural soils. Vegetable concentrations of Fe, Mn, and Zn met global human consumption thresholds, but Cu exceeded recommendations. The increased uptake of Cu by vegetables can be influenced by soil pH, organic matter content brought in due to flooding and also the specific characteristics of the vegetable species, all of which can contribute to variations in copper accumulation. All five elements; Hg, Pb, Cr, As and Ni were below the limits for inorganic contaminants of drinking water according to limits by the Kenya Standard - East African Standard 12: 2014 (KS EAS 12: 2014) and World Health Organization 2011 (WHO 2011) Guidelines for drinking Water Quality. These findings underscore the need for systematic ecosystem monitoring.

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LIST OF ABBREVIATIONS AND ACRONYMS

EDXRF	-	Energy Dispersive X-ray Fluorescence
FAO	-	Food and Agriculture Organization
GOK	-	Government of Kenya
IAEA	-	International Atomic Energy Agency
INST	-	Institute of Nuclear Science and Technology
KS	-	Kenya Standards
MOH	-	Ministry of Health
SAF	-	Subsoil After Floods
SBF		Subsoil Before Floods
SRM	-	Standard Reference Material
TAF	-	Topsoil After Floods
TBF	-	Topsoil Before Floods
WHO	-	World Health Organization

CHAPTER ONE: INTRODUCTION

1.1 Background

The consequences of flooding extend beyond immediate physical damage, encompassing disruptions in water quality, soil health, and agricultural productivity. Additionally, floods have been identified as exacerbating existing environmental challenges, with implications for public health, food security, and overall ecosystem resilience. Flooding, while presenting numerous challenges, also brings about both positive and negative impacts on ecosystems. On the positive side, floods contribute to soil rejuvenation by depositing nutrient-rich sediments, enhancing soil fertility, and promoting agricultural productivity in the long run (Opere, 2013). However, the negative consequences of flooding are pronounced, particularly in terms of property damage, displacement of communities, and disruptions to critical infrastructure. Floods can lead to soil erosion, nutrient leaching, and contamination of water sources, posing significant challenges to sustainable agriculture and public health (Huho & Ang'awa, 2008).

Food insecurity is directly associated to natural disasters, such as floods and droughts (Gabrysch et al., 2018). In Kenya, cases of flooding are frequently experienced, where heavy rains destroy the crops. Floods impact on the soil fertility depends entirely on the extent and severity. In developing countries, such as Kenya and other major parts of Asia, cases of flooding have been devastating due to a lack of enough resources for their management. The epidemiological studies in these areas indicate increased cases of malnutrition in children and other associated ill health and cause low crop productivity (Rodriguez-Llanes et al., 2011).

Basically, the composition of essential trace elements in the food consumed by animals directly affects their trace element levels. Human beings and plants require essential trace elements in small quantities, estimated to be less than 100mg per day (Goldhaber ,2003. In principle, the primary source of the essential nutrients is the soil and, by extension, plants on which they are grown, which finally reaches the human body through ingestion. The presence of these essential trace elements within the body facilitates numerous physiological processes and metabolic functions. A few of the well-known essential trace elements are chromium (Cr), manganese (Mn), copper (Cu), iron (Fe), selenium (Se) and zinc (Zn).

According to Sakina & Ahmed (2018), these nutrients are crucial in establishing the health of food crops, the ecosystem's food chains, the essential trace elements found in the food consumed by animals and the natural recycling of vital elements within the environment. These trace metals are involved in extensive metabolic and physiological activities. For instance, Zn acts as a cofactor in over 100 enzymes reactions, while Mn is required as a cofactor in enzymatic activities. On the other hand, Fe is complexed in haemoglobin and plays a vital part in the transportation of oxygen in livestock and human beings. Fe is also an essential metal in aiding photosynthetic activities in plants (Andresen et al., 2018). The distribution of the essential trace elements in soil is affected by multiple agents such as weathering and soil erosion, parent rocks materials, soil physical properties like infiltration rates, leaching of essential trace metals, and human activities such as excessive/prolonged agricultural activities in certain soils (Noulas et al., 2018).These variables affect the subsequent absorption of these essential trace metals by plants, thereby influencing the overall trace element distribution and availability in the soil ecosystem, by extension, in plants and animals. For that reason, understanding these trace metals' distribution in the soil can assist in addressing the challenges of soil infertility in the affected regions (Alloway, 2009a; Johnston, 2005)

The Earth's crust contains a variety of elements, each occurring at varying concentration. For example, iron (Fe) is a major element that is found in the Earth's crust and soils, typically spanning across a range of 600 to 50,000 mg kg^{-1}, with an average global concentration of 38,000 mg kg^{-1}. Iron exists in two oxidation states, Fe^{3+} and $Fe^{2+,}$ primarily as hydroxides and oxides in soils. Zinc (Zn) has concentrations spanning across a range of 60 to 100 mg kg^{-1} and exists in the Zn^{2+} oxidation state. Higher concentrations of zinc are linked with organic and calcareous soils, while lighter sandy soils tend to have lower concentrations. On the other hand, manganese (Mn) has a reported concentration spanning across a range of 20 to 9,200 mg kg^{-1} in uncontaminated soils. Manganese commonly occurs in the $Mn^{2+,}$ $Mn^{4+,}$ $Mn^{6+,}$ and Mn^{7+} oxidation states. Loamy and calcareous soils typically contain elevated quantities of manganese. In soils free from contamination, copper (Cu) concentrations range from 5 to 140 mg kg^{-1}, varying based on the composition of the parent soil material. Copper is primarily present in the Cu^{+} and Cu^{2+} oxidation states and tends to accumulate in the top layers of soil, adsorbing to oxyhydroxides of iron and manganese, clay minerals, organic matter, and carbonates (Kabata-Pendias and Pendias, 2011).

Hajar et al. (2014) have shown that the levels of trace elements' concentrations in plants and vegetables is influenced by the type of soil they are cultivated in, is specific to the plant species or variety. Several studies, including those by Hajar et al. (2014), Khan et al., (2013), and (Nayak et al., (2015), have demonstrated a direct relationship between the concentration levels of trace elements in soils and in plants.

In general, the dispersion of trace elements within the ecosystem has significant implications for the well-being of humans and plants (Bhattacharya et al., 2016). In order to assess the nutritional importance of these elements, it is essential to consider their specific health requirements, and the recommended dietary intake ranges, several studies have been conducted (Table 1.1). For example, Fe deficiency in human beings is characterized by decreased work performance, poor concentration, and decreased resistance to infections (WHO, 2004). The Food and Nutrition Board (2001), advised that the daily dietary allowance of iron (Fe) is around 15 mg/day for women between the ages of nineteen and fifty, and 10.00 mg daily for men with age 25 to 50 years. In cases, that dietary Fe intake is low, Fe reserves in the body system are depleted, leading to Fe deficiency, making human beings susceptible to various infections. The amounts of Fe in human beings is boosted through the intake of Fe fortified formulas, grain products, and infant cereals.

Kabata-Pendias and Pendias (2011) note that in unpolluted soils, the concentration of Manganese (Mn) ranges from 20 and 9200 mg $kg^{-1.}$ Loamy and calcareous soils are usually associated with higher concentrations of Mn. Soils from mafic rocks, those with high organic matter content, high Fe, and those from semi-arid and arid areas have also been related to elevated concentrations of Mn. Manganese is important in maintaining stable blood sugar in the human body system, for hypoglycemic individuals, and in lowering total cholesterol. It is also vital in the nutritional treatment of menopausal symptoms, and osteoporosis. Its addition in the diet and, by extension, to the body is essential, in cases of infertility, lack of libido in both sexes, deafness, epilepsy, and carpal tunnel syndrome. Approximately 5.0 and 2.2 mg per day are the requirements for adults and children, respectively. Its deficiency is characterized by low blood sugar, depression, fatigue, joint dislocation, gastro-intestinal disorders, infrequent menstrual cycles, asthma, and high cholesterol levels. Dried fruits and nuts, tea, and whole-grain products have high quantities of manganese (Mn) falling within the range of 20 to 23 mg kg^{-1} (Underwood, 2017). High Mn quantities in the body system can lead to colitis and liver disease, dizziness, frequent menstrual cycles, fibroid tumors, nausea, insomnia.

Manganese (Mn) plays a significant role as an activator for enzymes engaged in photosynthesis in plants (Voss, 1998). Additionally, it serves as a fundamental component in oxidation-reduction reactions, electron transport systems, and metalloproteins. Even though Mn can take place in soils and minerals in distinct forms such as Mn^{2+}, Mn^{4+}, Mn^{6+}, and Mn^{7+}, only Mn^{2+} can be absorbed by the plants (Haluschak et al., 1998).

The amount of Zinc (Zn) in the soil can be found at a range of 60 to 100 mg/kg. It exhibits an oxidation state of Zn^{2+}. A significant correlation has been shown between the soil texture and Zn concentrations. Elevated quantities of Zn are associated with organic and calcareous soils, whereas the lowest Zn amounts characterize light sandy soils. Zn tends to adsorb to clay and organic matter and, for that reason, may amass into soils (Kabata-Pendias and Pendias, 2011). Weathering of minerals discharging Zn^{2+} ions act as the primary source of Zn, which plants can absorb (Haluschak et al., 1998). Zn^{2+} are more soluble comparative to the solubility of other trace metals, where slightly acidic soils are associated with high solubility (Voss, 1998). Additionally, metals with comparable physical and chemical properties like Zn, for example, Cu and Fe, lead to extremely competitive interactions. When elements are in high concentrations, they tend to decrease the Zn absorption rate. High nitrogen and phosphorous content, strongly acidic or alkaline, free $CaCO_3$, and low organic matter is associated with Zn deficiencies in soils (Kabata-Pendias and Pendias, 2011).

Zn is important for various physiological processes in human beings, plants, and animals (Maret & Sandstead, 2006). The recommended daily Zn allowance is approximately 9.0 milligrams per day for a child that is over 1 year of age and around 13.1 milligrams per day for adults. Zn is a hugely vital metal during periods of rapid development in animals and human beings, more so during pregnancy and recovery from illness. It is for the effective functioning of the immune system of the body. Lean red meat and pork are the best dietary sources of Zn, amongst other sources such as indigenous vegetables. Its deficiency in human beings is indicated by delayed sexual maturation, growth retardation, loss of taste and alopecia (WHO, 2004).

Kabata-Pendias and Pendias (2011) point out that Copper (Cu), a micronutrient predominantly present in the earth's crust, tends to be present in low concentrations in most drinking water sources derived from groundwater. In uncontaminated soils, Cu levels vary between 5 and 140 mg/kg, based on the composition of the parent soil material. Its dominant oxidation states are Cu^{1+} and Cu^{2+}. In general, Cu, a mass in the topsoil, with the propensity to adsorb to organic matter, oxyhydroxides of Mn and Fe, carbonates, and clay minerals. Avocado, vegetables, beef, fruits, nuts, legumes, grains and shellfish are the fundamental sources of Cu in food. Cu functions as a crucial component in the protection from heart diseases, synthesis of haemoglobin while generating and blood vessels. The deficiency of copper in human beings is characterized by anaemia, and neutropenia (de Romaña et al., 2011). However, elevated concentrations of Cu within the human body can lead to health problems such as increased deaths from cancer and cardiovascular diseases (Klevay, 2000).

The surrounding environment generally influences the bioavailability of trace elements found in plants in general (Zhang et al., 2011). Numerous studies, including those conducted by Hajar et al., 2014; K. Khan et al., 2013, and Nayak et al., 2015, have established a direct correlation between the quantities of micronutrients present in soils and their uptake by plants. Consequently, plants growing in polluted areas have a tendency to accumulate higher levels of trace metals.

Table 1.1 provides information on the nutritional implications, health requirements, and acceptable dietary limits of each micronutrient.

The quality of water is subject to various different sources, significantly impacted by anthropogenic or geogenic factors (Dkhar et al., 2014). One of the primary factors influencing water quality is the presence of toxic trace metals and compounds, which differ due to variations in geographical and geological factors. Trace elements can be deposited into sources of water due to various conditions such as leaching discharge of waste due to everyday human activity. Floods are one of the disasters that results to high water discharge and affects the quality of clean water in a region (Kashin & Ivanov, 2008).

Table 1.1: Essential Trace Elements Dietary Allowance/Intake for Children and Adults (WHO, 2004).

Elements	Age Group	Recommended dietary allowance (RDA) in mg/day (ICMR, 2009)	Recommended nutrient intake (RNI) in mg/day (FAO/ WHO, 2004)	Recommended dietary allowance (RDA) in USA in mg/day
Mn	Children	-	2 - 3	-
	Adults	5.3 - 17.0	2.1 – 5.3	1.8 - 2.3
Fe	Children	9-16	-	-
	Adults	17- 21.0	9.1 - 26.0	8.0 - 18.0
Cu	Children	-	-	-
	Adults	1.35	1.5	0.09
Zn	Children	5-8	7-12	-
	Adults	10.0 - 12.0	4.2 - 14.0	11.0

In general, heavy metals are amongst the utmost persistent contaminants in water bodies due to their resistance to fragmentation in natural conditions. Elevated quantities of these elements can be discharged into the aquatic ecosystem due to the leaching from the atmospheric deposition, bedrocks, runoff from riverbanks, water drainage and discharge of industrial and urban wastewaters.

Several studies have been done on water quality for heavy metal contamination; As, Cr, Pb, Ni and Hg distributions from various water sources; groundwater, boreholes, river, lake, wells/ponds. Some of heavy metal related ailments include; brain damage, kidney dysfunctions, disorders in the cardiovascular and reproductive systems, loss of hearing, high blood pressure, gastro-intestinal ailments, development of cancers and destruction of the nervous system amongst others. Additionally, they affect various metabolic activities that are known to produce energy in the body.

1.2 Statement of the Research Problem

Flooding is highly linked to the degradation of the soils alongside the destruction of the food crops, in which the essential trace elements are removed from the soil cover. Budalangi is one of the regions in Kenya which experiences frequent cases of flooding during the rainy season. Geographically, the region is vulnerable, due to its proximity to Lake Victoria. Budalangi is defined by extensive soil erosion, the destruction of the natural vegetation, and the pollution of the wells and boreholes waters during the rainy season. Moreover, livestock and human lives, damage of rural infrastructure, and loss of personal properties, frequent aftermaths of the flooding in the region (Opere & Ogallo, 2006.) To address food insecurity resulting from such calamities, the Kenyan government sensitizes localities on the significance of growing nutrient-dense food crops, mostly short-seasonal traditional vegetables.

In developing countries, malnutrition is a big challenge that has resulted, in increases in nutrition-related illnesses, raising concerns (Welch, 2008). In Kenya, there are reported ill health cases of nutritional deficiencies in areas prone to floods such as Budalangi (GOK/MoH, 2006). The elemental concentration of the soil profiles and in the grown food crops is crucial in assessing the nutritional status of food crops (WHO, 2004).

Additionally, water is very important in humanity survival. Water is essential not only for the metabolic activities in the human system but also necessary for other related activities in individuals' life. Floods are some of the disasters that results to high water discharge and affects the quality of water in a region (Kashin & Ivanov, 2008).

In general, heavy metals are amongst the utmost persistent contaminants in water bodies due to their resistance to fragmentation in natural conditions. Elevated quantities of these elements can be discharged into the aquatic ecosystem due to the leaching from the atmospheric deposition, bedrocks, runoff from riverbanks, water drainage and discharge of industrial and urban wastewaters.

Therefore, it is important to assess the influence of the floods in Budalangi on the total available trace elements in the soils, water and vegetables growing in the specific area. Consequently, this research contributes to the ongoing nutritional studies in the country and for the evaluation of the impact caused by floods on the dietary nutritional status and on the improvement by adopting the appropriate farming methods.

1.3 Research Objectives

1.3.1 Main objective

The main objective of this research is to assess the availability of essential trace elements in soils, vegetables, and to determine the water quality in the Budalangi area of Busia County, Kenya.

1.3.2 Specific objectives

1) To assess the pH variation of agricultural soils sampled in Budalangi Constituency under varying climatic conditions; before the floods (hot and dry season) and after the floods;
2) To assess the variation of total available trace elements; Fe, Mn, Cu, and Zn in agricultural soils sampled in Budalangi Constituency under varying climatic conditions; before the floods (hot and dry season) and after the floods;
3) To assess the distribution of total available essential trace elements; Fe, Mn, Cu, and Zn in selected vegetables in Budalangi Constituency sampled under varying climatic conditions; before the floods (hot and dry season) and after the floods;
4) To assess the quality of water sources in Budalangi Constituency under varying climatic conditions; before the floods (hot and dry season) and after the floods.

1.4 Justification and significance of the study

Presently, the majority of Kenyans are experiencing acute nutrition related ailments associated with food insecurity due to a lack of enough nutrients in their diet. According to recent research studies (Hickey et al., 2012), approximately 40% of Kenya's population is categorized as experiencing food insecurity, while approximately 60% are categorized as living in poverty. The food shortage in Kenya has been attributed to drought and climate change, crop failure and prevalent flooding which has a major effect on the availability of various essential trace elements in soils and plants.

The flooding in Budalangi Division is attributed to particularly massive water flow from River Nzoia every year during the heavy rains seasons, that has resulted in the extensive destruction of farming activities and to loss of livestock.

Currently, there is a scarcity of research focusing on the availability of trace elements in soils and the crops cultivated in the Budalangi area of Busia County. Many farmers rely on information passed down the generations about the soil's status. The area is characterized by extreme poverty approximately 65.9% and food insecurity. According to Odhiambo and Mihara (2017), residents are aware and practice (42.6%) in water and soil conservation programs. However, they noted that approximately 68.5 % of farmers do not take the necessary conservations measures despite having the information (Odhiambo & Mihara, 2017).

The consequences of flooding extend far beyond immediate visible damage. There remains a noticeable gap in the existing literature regarding the baseline trace element data from instantly before the flood event to provide insight into the mobilization of the trace elements. While studies acknowledge the overall disruption to soil fertility and nutrient cycling during flooding events, there is a limited understanding of the mobilization of essential trace elements to allows comparison of pre and post flood conditions. Therefore, investigating the direct repercussions of flood-induced trace element variations in Kenya is essential for developing targeted interventions to address nutritional deficiencies and enhance food security in flood-prone regions.

This study seeks to investigate the availability of essential trace elements in soils and selected food crops as one of way assessing the extent of the impact the floods on agricultural productivity. The study's findings, particularly the analysis of trace elements (Fe, Mn, Cu, Zn) in soils, will play a pivotal role in informing and shaping effective soil management strategies. By understanding the current nutrient levels in the soil, the study enables precise nutrient management, guiding decisions on fertilizer application to optimize soil fertility for plant growth. Additionally, the data contributes to assessing the impact of floods on soil quality, informing strategies for erosion control and soil health restoration. The information aids in crop selection, aligning choices with soil characteristics, and supports sustainable agriculture. If harmful element concentrations are identified, the study facilitates the implementation of soil remediation strategies. Moreover, insights into water quality can inform water management practices, ensuring optimal conditions for the soil. In summary, the study serves as a valuable tool for developing targeted and evidence-based approaches to soil and environmental management, promoting sustainability in agriculture and human health.

1.5 Scope and Limitation of this Study

Only the edible parts of three selected vegetables species i.e., Spinach, Collard Greens and Cow Peas leaves grown in this region were selected for this study. For each soil sample location, a representative of the top soils and subsoil were sampled for elemental analysis and pH analysis.

All the samples were collected under varying climatic conditions; before the floods in December 2021and after the floods in July 2022. The region received over 300mm of rain which is above rainfall average in Western Kenya.

This study is limited to the study of soil pH, four total essential trace element content; Mn, Cu, Zn, and Fe in the sampled soils and vegetables and five selected toxic heavy metals; Hg, Cr, Ni, As and Pb pollutants in water samples from Budalangi Constituency, Busia County using EDXRF technique.

1.6 Note on publication and conferences attended

A draft scientific paper for publications is under preparation. It is entitled, “Effects of Floods on Availability of Essential Trace Elements in Agricultural Soils and Selected Vegetables grown in Budalangi, Busia County.”

The following are conferences that I have been privileged to present my research work.

1. University of Nairobi - 4th International Engineering Conference. Nairobi, Kenya. 24 - 28 October 2022
2. Machakos University - 5th International Conference. Machakos, Kenya. 14 – 16 June 2023.

3. University of Nairobi - 5th International Engineering Conference. Nairobi, Kenya. 23 - 27 October 2023.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

In this chapter, scientific literature review relevant to the current study is presented. First, the environmental impact of floods in general are discussed and presented in section 2.2. Secondly, the impact of floods in Kenya are discussed in section 2.3. Section 2.4, 2.5 and 2.6 focuses on the availability of total trace elements in plants, soils and water, respectively. Lastly, section 2.7 presents a review of the effects of trace elements in the human diet.

2.2 Environmental Impacts of Floods: Soil Fertility and Contamination of the Ecosystem

Flooding happens when heavy rainfall leads to the accumulation of storm waters. The occurrence of soil flooding is caused by the decrease in water infiltration caused by this impermeable crust forms in the lower furrow, hindering water infiltration. Waterlogging significantly impacts the rate and direction of various geochemical, biological, and chemical reactions in the soil, thereby affecting visible soil characteristics, including soil type, organic matter content, and texture. The temporary physical characteristics of paddy soil depend not solely on inherent soil properties but also on external hydrological conditions. These soil changes have adverse effects on a plant's capacity to survive in such conditions and influence the presence of nutrients in the soil (Rodríguez et al., 2016).

In tropical regions, floods of significant magnitude result in severe consequences, often triggered by hurricanes, heavy rainstorms, dam failures, and snow melts. These floods lead to a deprivation of oxygen for the soil's microorganisms, which becomes an environmental determinant factor affecting the growth of plants cultivated in flooded regions. Floods have a crucial impact on the functionality of vast natural systems, including ecosystems and biodiversity. They deposit minerals, organic matter, and vital nutrients from oceans and rivers onto the land, enriching the soil and enhancing its productivity and fertility (Ubuoh et al., 2016).

Floods can lead to an abundant supply of nutrient-rich materials that decompose and disrupt nitrogen dynamics, thereby affecting nutrient availability and altering plant growth. One crucial indicator of soil microbial function is the activity of enzymes. Soil enzymes are significant in the decomposition of organic matter and nutrient cycling. However, soil enzymes are primarily synthesized by microorganisms present in the soil. Flooding impacts soil enzyme activities by altering oxygen levels, microbial community composition and nutrient availability (Macé et al., 2016).

Flooding is a regional phenomenon worldwide. It is the most common environmental disaster, claiming the lives of over 20,000 individuals annually and adversely affecting approximately 75 million people globally. Flooding intensifies during the winter months due to heavy rainfall. The 2013/2014 floods alone resulted in insurance companies facing losses exceeding £1 billion (Kron et al., 2019). According to Kaur et al 2020 flooding was responsible for more than 60% of the crop yield reductions in the United States of America in 2011. Further stating that added crop damage agricultural loss of soil and nutrients from waterlogging resulting from these extreme events (Kaur et al., 2020). Additional impacts of flooding include the loss of biodiversity and the deterioration of water quality, with excessive emissions of nitrous oxide and methane observed in flooded soils. If not properly addressed, long periods of flooding can lead to irreversible changes in soil quality in the subsequent years, presenting significant challenges in terms of resilience and other characteristics related to soil (Slessarev et al., 2016).

2.3 Flooding in Kenya and the Impacts

Floods, as natural disasters, inflict wide-ranging impacts on communities, ecosystems, and infrastructure. It is a global problem that affects approximately 50 to 250 million people per year, and is responsible for around 40% of natural disasters that are recorded worldwide (Ponting et al., 2021). Famine and floods are a consequence of adverse climatic events that have unfavorable impacts on almost all socio-economic activities; disruption of transport networks that negatively affects the market distribution systems and food security in general. Floods have been associated with massive loss of property, livestock and human deaths, interruption of the communication networks, destruction of infrastructure and extensive economic loss.

Kenya recorded extreme flooding cases in 2003, 1997-98, 1961, 1957-58,1951,1947, and 1937 (Huho&Ang'awa, 2008). Flooding in the country has become an annual catastrophe in the lower region of almost all the rivers draining water into Lake Victoria.

According to Kiptum et al, 2019), many parts of Kenya and other parts of Africa experience unpredictably heavy precipitation between mid-April and May. Additionally, short rainfalls occur between September and December season. The regions that are frequently vulnerable to floods calamities in Kenya are Lake Victoria Basin, which encompasses Budalangi, and Kano plains along River Nyando with flooding waters from Nandi Hills. Others are Nzoia River Basin, with flooding waters from Cherangani Hills, and the Tana River floods water originating from Mt. Kenya and Aberdares catchments (Kiptum, 2019).

Flooding in Kenya has been linked with the destruction of power lines, silting of hydropower dams and land degradation through soil erosion. Budalangi is one of the regions in Western Kenya which has recorded devastating impacts of flooding encompassing livestock and human deaths, displacement of the population and destruction of property. The region lies in the low basin of Lake Victoria, making it prone to overflows from the nearby rivers. According to Opere, (2013) low-lying regions around the mouths of natural swamps and rivers experience massive destructions that run for weeks resulting in loss of crops, among other properties. Due to poor rural infrastructure, lack of education and poverty, communities living in such regions are prone to flooding and post-flood effects.

In most developing nations, approaches to prevent land destruction have been introduced but with little success because of the absence of satisfactory technology transfer coupled with poor user adoption. Odhiambo & Mihara, (2017) conducted a study in Budalangi on the perception of water soil preservation practices among small-scale farmers. The residents are aware of water and soil conservation practices and measures, however, only 42,6 % of the population practice at least one program to maintain water and soils. Approximately 68.5 % of farmers do not take the measures despite having the information.

Huho and Ang'awa, (2008) attributed the flooding in the Budalangi region to particularly massive water flow from River Nzoia every year, that is linked to extensive destruction of farming activities plus loss of livestock. The flooding is attributed to the heavy downpour in the upper catchments from Eldoret, Elgon Downs, Kitale regions and Bungoma region's central catchments, leading to increasing waters in Yala Swamp and River Nzoia in the Lower Basin. Additionally, floods are worsened by events such as destruction of the dykes whenever the water from River Nzoia exceeds 245.70 m^3/s.

Onywere et al. (2011) used remote sensing data to demonstrate land cover transformations and their influence in Yala Swamp and Budalangi region. From the study, the land covered by swamps has been reduced, creating room for agricultural activities and settlements. Loss of the filtration ability for the sediments by the mouth of Nzoia Swamps due to the elimination of vegetation cover has led to additional growth of the delta as the Nzoia river releases water into Lake Victoria. According to Onywere et al. (2011), the availability of the sediments in the water indicates devastating farming activities coupled with the failure of the state's strategies, policies and priorities on poverty eradication and development of the socio-economy.

In February 2020, a heavy downpour was recorded in East Africa, which led to flooding plus an increase in water levels within various lakes in the region. The events happened when the COVID-19 pandemic was ravaging the global population. The flooding affected various human activities where the fishing in various lakes was interrupted (Aura et al., 2020). Most of the people lost their livelihood that resulted in deaths directly and indirectly. That is because the fluctuation of water levels in lakes such as Lake Turkana, Lake Baringo, and Lake Victoria affected fish production, which was coupled with the loss of lives through food starvation and the effects of the furious floods. According to Kiptum, (2019), flooding accounted for approximately 15% of the global deaths recorded between 1987 and 1997, with over 228,000 lives being lost in Asia. Various studies have associated diseases with flooding in Kenya (Opere, 2013). Examples of such diseases include waterborne illnesses like cholera and water-related vector-borne diseases like malaria. These studies have demonstrated the increased risk of these diseases in flood-prone areas (Ntajal et al., 2022; Opere, 2013).

According to Okaka & Odhiambo (2018), flooding is a major factor in the occurrence and spread of infectious illnesses because it provides conditions for the reproduction of vectors and pathogens. For that reason, an increase in flooding in Kenya means that the nation will encounter increased cases of infectious ailments tied to flooding. Therefore, the country needs to roll out preventive measures to mitigate the impacts of flooding in society (Okaka & Odhiambo, 2018). The same programs can be executed in the urban regions of Kenya. That is because cases of flooding have been reported in urban areas which are linked to poor urban planning (Panyako, 2018). From a scientific perspective, flooding affects the distribution of the micronutrients in the soils and plants.

This has an indirect impact on the health of humanity; hence there is a need to intensify studies on soils, water and food crops in flood-prone regions.

2.4 The Role of Micronutrients in Plant Nutrition

There has been a growing global awareness of the significance of micronutrients in the nutrition of plants, driven by increased recognition of the detrimental effects caused by both deficiencies and toxicities of these micronutrients (Welch, 2008). This increased attention is driven by a heightened recognition of the adverse outcomes linked to both the toxicity and deficiency of these essential nutrients. For optimum health of a crop and yields, a specific quantity threshold that is explicit for every trace metal and plant species is needed. In different plant species, the most prominent micronutrients are Selenium (Se), Iron (Fe), Molybdenum (Mo), Manganese (Mn), Zinc (Zn), and Copper (Cu) (Hamnér, 2016). These trace metals are necessary for plants for various enzymatic and other physiological processes. Consequently, the important trace nutrients need to be available in the soil at adequate plant amount for optimal productivity (Svečnjak et al., 2013). Other metals like Nickel (Ni), Selenium (Se), Flourine (F), and Chromium (Cr) do not have any considerable role in plant nutrition and by extension to human beings.

The concentration of micronutrients in plants is generally influenced by the content of the soil, which in turn depends heavily on the composition of the earth's crust from which it originates Svečnjak et al. (2013). According to Nayak et al. (2015), in particular soil profile, enrichment through nutrient cycling using organic manure and fertilizers can take place. In the same profiles, there is a possibility of depletion of nutrients through erosion and leaching, which affects plant nutrition.

The process of uptake of micronutrients in plants vary depending on the specific metal involved, as well as differ among different plant species (Hamnér, 2016). Element-plant interactions are influenced by factors unique to each micronutrient. As an example, the uptake of copper (Cu) in plants depends on the amount of Cu within the soil and the plant's capacity to facilitate its transfer across the interface between soil and roots (Hajar et al., 2014). Soil pH is a key factor that impact the availability of micronutrients to plants. These vital trace metals are significant in the plants' overall health and productivity.

Plants depend on essential trace elements for their growth and development (Alloway, 2009). The capacity to absorb these trace elements from the soil exhibits significant variation among different plant species. For example, certain plant species like Pinusmassonian, Castaneahenri, and Phytolaccaacinosa have been instrumental in phytoremediation efforts in polluted soils, particularly in mining areas (de Abreu et al, 2012; Zhao et al, 2012). Furthermore, different sections of plants, such as leaves, roots, and shoots, accumulate trace elements in varying quantities. For instance, Mn is primarily absorbed by plants in its divalent form (Mn^{2+}) and have a tendency to accumulate more in the stems and leaves rather than in the roots.

The trace elements are transferred from the soil to plants through various mechanisms involving absorption in diverse chemical forms and speciation. Various factors, including soil pH, plant growth stages, plant species diversity, and chemical speciation of each trace element in the soil, influence this absorption process. According to Kabata-Pendias and Pendias (2011), the movement of iron (Fe) in soil is considerably affected by factors such as soil aeration and pH, while its solubility is primarily influenced by hydrolysis and complexation. Their findings indicate that the extractable portion of Fe, accounting for 10 to 100 parts per million (ppm) of the total Fe content, is generally higher in slightly acidic sandy soils.

In some plants, manganese (Mn) is present in small traces and serves as an activator for enzymes engaged in photosynthesis, oxidation-reduction reactions, electron transport systems and metalloproteins. Although manganese can be found in soils and minerals in different forms such as Mn^{2+}, Mn^{3+}, and Mn^{4+}, only the Mn^{2+} form is capable of being absorbed by crops (Rahman et al., 2014).

Zinc is a vital micronutrient for crops, animals, and humans (McGrath & Fleming, 2007). The primary origin of Zn is the weathering of minerals, which releases Zn^{2+} ions that can be taken up by plants (Shackleton et al., 2009). Zn^{2+} exhibits higher solubility compared to other trace metals, and its solubility is often greater in slightly acidic soils (Ngure et al., 2014). Competitive interactions can occur due to the presence of metals with similar chemical and physical properties, such as Cu and Fe. When these metals are present in elevated amounts, they tend to impede the absorption of zinc (Zn).

Zinc insufficiencies in crops can be attributed to various factors, including strongly alkaline or acidic soil conditions, low organic matter content, high nitrogen and phosphorus levels, and the presence of free CaCO3 in the soil. Conversely, copper (Cu) is an important micronutrient for plants. Its availability is significantly influenced by excess nitrogen, excess phosphorus, and organic matter, which can lower its levels, as well as excessive zinc (Zn), which hinders its uptake by plants. Common dietary sources of copper (Cu) include beef, vegetables, avocado, nuts, legumes and grains (Mutune, et al., 2014). Excessive transmission of these trace elements (iron, manganese, zinc, and copper) from the soil to food crops can result in toxicity.

As previously mentioned, soil pH is significant in determining the accessibility of micronutrients in plants. The solubility and mobility of these elements are impacted by pH, which alters their ionic forms within the soil. Changes in pH can induce chemical transformations in the soil, leading to increased bioavailability of micronutrients through modifications in their chemical speciation of trace elements and their impact on chemisorption play a significant part in the transfer of these elements all the way from the soil to plants (Omwoma et al., 2010; Zhao et al., 2012).

Generally, most micronutrients are available from the soil or, if not, are related to soil correction procedures such as lime or fertilizers, which can be absorbed by the roots, to leaves amongst other parts of the crops. The components of the essential trace metals and other metals in plants replicate to some range the chemical structure of the growth media. For instance Zn is affected by chemical composition of the soils (Noulas et al., 2018). The extent to which this association happens is in variable quantities and is controlled by various determinants that affect their availability to plants. Essential trace metals are crucial in nutrition and are found in numerous food crops and foodstuff. They are transported into food constituents from the soil through environmental pollution or absorption by crops or with metal-based pesticides and fertilizers (Morgan and Connolly, 2013). The main pathway through which micronutrients get to the plant is the roots. The absorbed micronutrients are fragmented in soil solution either as complex forms or in ionic forms or as chelates but most outstandingly in solution forms (Towett et al., 2015). Those that are closer to the ground surface are taken up by the plant from aerial deposition via the leaf stomata, particularly aerosol particles and gases. Absorption processes work at a very low micronutrient amount gradient in solutions, and the rate relies on the occurrence of H^+ and other ions (Bityutskii et al., 2017). Moreover, the rate of micronutrient uptake varies with the species of the plant and the stage of development.

The processes of mineral absorption are sensitive to the soil environment, such as pH, temperature, moisture and aeration. High temperatures have a huge influence on the absorption of the elements by the plants, while the increase in pH levels affects the presence and uptake of a significant number of the essential trace metals except for Molybdenum. As per Ghosh et al. (2018) excess moisture content improves the separation of nutrients to lower horizons. Nonetheless, dry conditions prevent root action at shallow levels and reduce the breakdown and transportation of the micronutrients to different parts of the plant. In the perspective of the soil texture, finely textured soils tend to hold more micronutrients in forms that are not accessible to the plant, while course sandy soils have less ability to bind nutrients.

Root absorption of the essential trace metals can be defined as either non-metabolic or metabolic. Non-metabolic occurs when the ions such as Fe^{3+}, Cu^{2+}, and Zn^{2+} amongst others migrate from the external environment to the root endodermis, during metabolic needs energy because it occurs against the concentration gradient. The availability of ions in the soil solution is a major factor that impacts the plant's uptake of essential trace metals, which is most notably when the uptake is metabolic. When the external cation concentration of soil solution is low, metabolic uptake occurs, while at higher concentrations, the non-metabolic process predominates.

The mechanisms of absorption vary dependent on the given element. For example, Pb and Ni are absorbed via the non-metabolic process, while Cu, Zn, and Mo are absorbed metabolically. Nevertheless, the concentration of the essential trace metals can pass over a physiological barrier when the biological and structural characteristics of root cells are changed (Kabata-Pendias and Pendias, 2011).

Plant micronutrient deficiency is linked to detrimental impacts on the health of human beings through the transformation of growth, normal metabolism and physical wellbeing (Koning et al., 2008). According to Black et al., (2008) insufficient minerals and vitamins result in impaired physical and mental development in children, high death rates in women and unborn children, reduced work productivity in adults and increased illness. Children who are below the age period of 5 years are the most vulnerable, nutritional deficiencies in; Zn (51%), vitamin A (84%), and Fe (73.4%) (FAO, 2007). Indeed, expectant women are at a higher risk of Iron (60%) deficiency, Vitamin A deficiency (39%), while approximately 16% of adult males suffer from Fe deficiency, triggering anaemia. Ahmed and Mohamed, (2015) determined the occurrence of trace metals in crop products from the Egyptian market and reported that concentrations of Zinc and Copper were below the recommended levels. In a comparable study, Ida et al. (2011) determined the amounts of Fe and Zn in selected diets of school children conformed to the permissible levels of WHO.

Adequate essential trace metal supply is important to human development and growth. According to MOH, (2012), roughly 1.5 to 2.1 million children are underdeveloped hence unable to reach their full physical potential, which triggers a serious national concern. In some cases, iodine deficiency has been noted as the primary cause of mental retardation and brain damage globally. According to WHO (2002), 1.5 billion of the world wide's population resides in iodine-deficient environments.

The assessment of micronutrients in food crops is exceptionally crucial. That is because the quality of the majority of food crops relies upon the amounts and the types of minerals available in the specific food crops (Maret & Sandstead, 2006; Yagi et al., 2013). It is imperative to find the quantities of these trace metals in frequently consumed plants since their raised or decreased quantities could be detrimental to our health. For example, *Cymbopogancitratus* a flavoring agent in tea ingredients, is a good source of micronutrients like Cr, Zn, Mn, Mo, Fe, and Cu (Dkhar et al., 2014; Sigel et al., 2013. Akundabweni, (2010) reported that the concentrations of trace elements in Kenyan local vegetables are rich in those essential trace metals. However, the authors also observed that there was under-utilization and a low rate of integration of these vegetables rich in trace metals in the local diets. Consequently, they suggested that their cultivation be intensified and incorporated into diets to prevent their associated disorders.

2.5 Availability of Trace Elements on Quality of Agricultural Soils

There has been a growing emphasis on research investigating the levels of trace metals in soils aiming to assess their concentrations and distributions as well as ground and surface waters. These studies have revealed mounting evidence of bioaccumulation of these vital trace metals in plants, animals, and humans. The distribution and quantities of trace metals in soil are primarily influenced by biogeochemical cycles and exhibit significant variations based on the mineral composition and parent rock (Foti et al., 2017); Kabata-Pendias and Pendias, 2011).

In unpolluted soils, the overall elemental composition is predetermined by various factors, including the content of organic matter, the composition of parent rock, soil texture, and depth

(Alloway et al., 2005). However, human activities (including industrial waste disposal, mining operations, and other anthropogenic actions), the use of pesticides and fertilizers, as well as the application of sewage sludge, coal, and fly ash, have an impact on the concentration of micronutrients in the Earth's crust (Li et al., 2007; Ngure et al., 2014). These anthropogenic activities result in the significant release of essential trace metals, leading to their accumulation in soils.

According to Florido et al. (2011), a statistical correlation has been observed between the content of Zn ($R = 0.9$), Cu ($R = 0.7$), and Pb ($R = 0.6$) in soils and the corresponding total concentration when the soil was amended with biosolids from a wastewater treatment facility. A comparative study conducted by Yun-Guo et al., (2006) demonstrated higher elemental content in soils and crops near a mine rather than to a controlled area located at a far distance from the mine.

Various factors, including microorganisms, cation exchange capacity, pH and organic matter content, influence the bioavailability, solubility, and leaching of micronutrients to plants and groundwater (Alloway et al., 2013; Kabata-Pendias and Pendias, 2011; Zeng et al., 2011). Soil pH is crucial in the desorption of micronutrients in the soil. For example, at low pH, Fe, Zn, and Mn are more readily available, while Mo is more prevalent at elevated pH (Tohomiro et al., 2016). Soil pH has a direct correlation with the bioavailability of trace elements as it affects their chelation and solubility in the soils (Kabata-Pendias and Pendias, 2011). However, changes in pH do not significantly impact Mn in various soil types (Jahiruddin et al., 2000).

Organic matter in the soil is crucial in the solubilization and cycling of trace elements. Additionally, soil microorganisms contribute significantly to various processes such as nutrient cycling, alteration of soil structure, degradation of organic matter, and the immobilization and solubilization of trace elements (Kabata-Pendias and Pendias, 2011).

Therefore, it is essential to emphasize the implementation of effective soil management practices to address the spread and enrichment of crucial trace metals in regions experiencing micronutrient deficiencies. In order to alleviate soil deficiency issues, it is recommended to utilize organic fertilizers that contain the deficient trace elements. Additionally, preventative measures should be taken to combat soil erosion, and organic manure should be employed to minimize excessive leaching in agricultural soils. It is worth noting that farming methods play a significant part in the distribution of trace elements in agricultural soil. The use of inorganic fertilizers can interact with trace elements, and the unregulated use of such fertilizers can result in high levels of micronutrients in the agricultural soil (Alloway et al., 2005).

In regions prone to dust deposition, the deposited dust can add to the enrichment of micronutrients. Activities carried out by humans, such as the discarding of industrial waste, excavation and mining, have a significant impact on the levels of these elements. In soils, these elements exist in various forms, which are influenced by physiochemical parameters such as pH, and they often form complexes with organic and inorganic ligands (Hajar et al., 2014). The movement of microonutrients in soil is directly linked to their bioavailability and solubility for plant uptake. Soil redox conditions, the availability of other minerals and nutrient groups, and pH are the primary factors that influence the transport of essential trace metals from soils to plants. Other factors include biological activity, temperature, and water flux through the soil column. At this level, the chemistry of soil is not determined solely by one aspect but rather results from the interaction of multiple factors (Alloway, 2005).

2.6 Toxic Heavy metal Contamination in Water Sources

Not only is water needed for the metabolic activities in the human system but also necessary for other related activities in an day to day life. According to Dkhar et al. (2014), the percentage composition of the water in the human body is around 70 to 80 % by weight, with over 95 % molecules encompassing the water. Generally, H_2O is the primary component that delivers various nutrients to the body cells and it also removes the toxic materials from the body while maintaining energy production amongst other roles. Water quality varies from one source to the other which is hugely affected by human and natural factors. One of the principal determinants is the quantities of the numerous trace metals and compounds in the accessible water supplies which differ because of the variances in the geographical and geological factors (Dkhar et al., 2014). The trace metal distribution in the domestic water is fundamental in the determining the water quality suitability for drinking and other uses.

Trace elements can be deposited into sources of water due to various conditions such as leaching discharge of waste due to everyday human activity (H.M et al 1999). Floods are one of the disasters that results in high water discharge and affect the quality of water (Kashin & Ivanov, 2008).

Heavy metals, in general, are persistent contaminants in water bodies due to their resistance to degradation in natural conditions. These elements can enter the aquatic ecosystem through various pathways, including atmospheric deposition, leaching from bedrocks, runoff from riverbanks, water drainage, and the discharge of industrial and urban wastewaters. According to Khan (2011), the variability of elemental concentrations in groundwater, whether through natural processes or human interventions, often remains uncontrolled. The toxicity of these elements depends on their concentration, route of exposure, chemical forms present in the body, and their bioavailability. High concentrations of trace metals are not limited to specific water types or polluted regions; they can be found in various systems and geographical locations (T. A. Khan, 2011). Hence, it is evident that these elements enter the aquatic environment from diverse sources, both non-point and point, and can readily transition from the abiotic to the biotic structure.

Generally, the contamination of the aquatic environment with the elements is a serious worldwide challenge, due to environmental pollution from numerous human acts such as; intense metal mining and its distribution in the environment. However, other natural processes such as flooding play a big role in transporting metals from one region to another. According to Dinu et al., (2020), the bioavailability and speciation of the metals depend on the components of the water, such as the pH, competitive reactions of anions and cations and the concentration of organic substances. Dissolved organic compounds can inactivate elements in H_2O by binding them with ligands which decreases the bioavailability and toxicity of hydrobionts.

Ndwiga (2014) conducted a study on the borehole water from the Huruma Estate in Eldoret, Kenya. The study reported Cr at 17.9 µg/L while Cu was recorded at 563 µg/L and Se at 22.7 µg/L. The quantities of trace metals in the ecosystem can be transformed by various human and natural processes. For instance, Se and Mo attract modern researchers because of the ecosystem impacts of their doubled-edged presence, which can have negative effects on human wellbeing.

Kinuthia et al., (2020) did a study on the Nairobian soils and wastewater channels. From the study, the authors reported that the average amounts of the metals in wastewater varied from 0.015 to 0.0001 ppm in descending order of Pb> Cr > Ni > Hg > Cd >Ti. Pb was found to be present in amounts that are higher than the recommended range by the WHO. However, the rest of the metals under the study were found to be within the permissible range by various international health agencies.

Groundwater, a source of drinking water, is susceptible to contaminants due to its contact with plants, soils and rocks. Heavy metals contamination in the groundwater is from weathering phenomena or the nature of rocks or human activities such as intense use of fertilizers. Alqahtani et al. (2020) found fifteen elements in the domestic groundwater from the Bisha region in Saudi Arabia. The author reported that Na, Ca and Mg were found to surpass the WHO recommended ranges, while the rest of the trace metals were within limits (V, As, Cd, Zn, Cu, Ni, Co, Se, Mn, Cr). The study objectives were to evaluate environmental degradation and determine of the sources of pollutants as either anthropogenic or geogenic.

Beisner et al., (2014) studied trace metals in water, fish and sediment sampled from Tavasci Marsh, Arizona. From the study, the authors reported high concentrations of As (14.8 to 161 µg/L) in water which surpassed the U.S Environmental Protection Agency limit, which stands at 10 µg/L. A high concentration of As was attributed to specific geological formations such as sandstone, an associate of the Verde Formation. 29 % of the evaluated Hg was found in the water surface with conditions that favor the production of the methylmercury (Beisner et al., 2014). In the sediments, Cu, Cd, and As were found to be above the limit required by the governing agencies. The trace metals were found to be high in fish sampled from the area, more so arsenic (As).

In a related study, M. S. Lakshmana, (2018) evaluated the pH and distribution of the trace metals in the various sources of drinking water in the Majmaah area. This study was deemed necessary in the Kingdom of Saudi Arabia, due to high demand and consumption. The safety and quality of water in the region were found to meet the WHO requirements. Elements such as Cr, Se, and F were found to have a significant correlation with other elements such as Cl, As, Cu, Zn, Pb, Ni, Cd, Mn and Hg. That was attributed to the similarities in their physio-chemical nature (M. S. Lakshmana, 2018). The study concluded that the acquaintance of the trace elements' distribution in domestic water serves as the crucial primary information for the country and region in the perspective of human health.

A comparative study on the domestic water in Eldoret, Kenya, found an increase in some of the trace metals in domestic water was linked to human activities such as municipal and industrial discharge and car-washing activities. From the study, Etyang, (2015) reported that the concentration levels of Cu ranged from 0.005 to 0.050 ppm, Mn ranged from 0.068 to 0.291 ppm while Cr varied from 0.04 to 0.23 ppm. WHO/FAO's allowed concentrations of Cr is 0.1 ppm. The domestic water from Eldoret contains high levels of Cr which is attributed to human activities plus other natural processes.

Another comparative analysis was done by Outa et al., (2020) on the availability of Pb, As, Cd and Ag, among other micro-elements in water, macrophytes, and sediment in Lake Victoria. Generally, Inland water sources are prone to contamination globally due to various natural and anthropogenic activities. Lake Victoria receives water from different sources, and some industrial discharge finds its way into the lake during cases such as floods and the normal release of wastewater by the majority of the firms. Outa et al., (2020) reported elevated Pb, As, Cd, Ag, Zn and Cr concentrations in the sediments from Kisumu City. The water from the Lake Victoria registered high concentrations of minor and major trace metals and high electrical conductivity. The study concluded that water from the Lake is not safe for domestic use and poses great dangers to the health of residents and animals living in Kisumu City and its environs. Therefore, the Kenyan researchers need to intensify studies on various water bodies to safeguard the living conditions of residents, more so in regions such as Budalangi defined by frequent flooding cases.

Lead (Pb) is considered as a toxic trace metal to human health, adversely affecting the functioning of various bodily organs such as the liver and kidneys and some of its related ailments due to Pb poisoning include long-lasting damage to the nervous system, brain damage, kidney dysfunctions, disorders in the cardiovascular and reproductive systems, loss of hearing, high blood pressure and gastro-intestinal ailments amongst others (Fashola et al., 2016; WHO, 2011). Other ailments include damage to the peripheral, hematopoietic and central nervous systems have been associated to lead (Pb) poisoning.

Arsenic occurs as a sulphide, chloride, or oxide, depending on the geological factors. This metal is the backbone of heavy metal poisoning with the ability to cause serious ailments even in small amounts (Farrow, 2015). Its presence in the human system is associated with development of cancers, destruction of the nervous system; it can also lead to various cases of diabetes, damage to a gastro-intestinal tract, more so when taken for an extensive period of time. Additionally, it can prevent various metabolic activities that are known to produce energy in the body. When taken in huge amounts it can result in a reduction in the creation of the blood cells, enlargement of the liver, collapse of the cardiovascular system, alteration in the colour of the skin and brain damage (WHO, 2011).

Chromium is an element that can occur in both trivalent and hexavalent states, more so in drinking water where the recommended limit is 0.05 ppm (Dkhar, 2011). In regulated amounts, Cr can act as an essential micronutrient with a role in regulating the glucose levels in the human body. However, in excess amounts, it can result in massive destructions of the DNA, which can lead to gene mutations. In addition, the respiratory system can be greatly damaged by the high concentrations of Cr, resulting in the development of nasal cavity cancers and detrimental effects on the livers and kidneys (Fashola et al., 2016) . In other cases, damage of the gastrointestinal tract can be observed with extensive developments of ulcers in the exposed individuals. Excess amounts of Cr can also result in reproduction toxicity which is defined by birth defects, low birth weight, and disturbed spermatogenesis.

Mercury (Hg) is not useful in the human body, and its presence in the human system can lead to ill health effects such as stunted growth in children. It also destroys the central nervous system resulting in the loss of memory loss on the exposed persons. It also prevents cell division which changes gene expression; it also destroys the nucleic acids in the body, denatures proteins and inhibits enzymes. High amounts of Hg exposure can lead to instant death and it has been defined as a carcinogenic agent by the International Agency for Research on Cancer (Fashola et al., 2016).

Table 2.1: The acceptable thresholds for heavy metal concentrations in drinking water and water ecosystems, as per the guidelines set by the World Health Organization (WHO, 2011).

Metal	Normal conc. for fresh water (mg/L)	Max conc. in drinking water (WHO) (mg/L)
Hg	<500	0.001
As	0.01	_
Cr	<2000	0.05
Ni	0.02	0.02
Pb	_	0.01

Nickel is regarded as a temperately toxic heavy metal. It can play crucial roles in the human body when taken in regulated amounts. It is known to prevent anaemia due to its ability to increase the intake of iron into the human body. It also plays a central function in helping the body in absorbing Ca, which inhibits the development of osteoporosis (WHO, 2011). However, excess intake of Ni can lead to shortness of breath, headaches and the development of nasal and lung cancers.

2.7 Dietary Nutritional Intake Requirements: Trace elements and Human Health

Micronutrients are essential nutrients required by plants, animals, and humans in small amounts, typically less than 100 mg per day. The accessibility of these indispensable micronutrients in the body system helps in several physiological and metabolic activities. Cu, Fe, Zn and Mn are recognized as essential trace metals that are very important for all living organisms. The sufficient availability of the essential trace metals in vegetables is exceptionally vital in the human diet (Mavengahama et al., 2014; Goldhaber, 2003).

A balanced diet is very imperative in the recovery from physical injuries or illness. Ideally, individuals who are properly nourished possess a robust immune system and immunity to many diseases against infections. The immune system depends on a nutritious well-balanced diet that consists of adequate levels of essential micronutrients, a vital component in improving the health of human beings (FAO, 2002). Consumption of different types of plants acts is a diverse range of food sources

In Sub-Saharan Africa and Kenya, maize is the main food crop that significant members of society largely consume. Other food crops include; cassava, finger millet, yams, sorghum, beans, collard greens (sukuma wiki), cabbage, African Spider plants (saget), African night shade (Managu). These crops supplement a significant proportion of energy required daily in the Kenyan diet (Kageliza, 2014). The cereals were found to be the principal source of Mn, Cu, and Fe, with the estimated contribution of 30 to 50 mg kg^{-1} for Zn and 20 to 30 mg kg^{-1}for Mn. The study analyzed diverse cereals to ascertain the quantities of Fe and Zn in the perspective of nutrition at 32 ± 1 mg kg^{-1}and 15 ± 1 mg kg^{-1} , respectively. The Zn content was reported at 11 ± 1 mg kg^{-1}, and Fe at 65 ± 2 mg kg^{-1} in sorghum (Hemalatha et al., 2007). In the finger millet, a concentration of 17 ± 0.3 mg kg^{-1} was reported for Zn, while 21 ± 1 mg kg^{-1} was recorded for Fe. A related similar study was conducted in Nigeria, where maize had 3 ± 0 mg kg^{-1}, 25 ± 3 mg kg^{-1}, 44 ± 2 mg kg^{-1}, for Cu, Zn, and Fe, respectively. Other elements had levels of 48 ± 3 mg kg^{-1}for Fe, 5 ± 0.1 mg kg^{-1} for Cu, 26 ± 2 mg kg^{-1} for Zn were reported in beans (Edeoguet al., 2007).

In study conducted on Kenya's rural, indigenous complementary infant flours were examined where high changeability in Mn, Zn, Cu, and Fe was reported. Cu varied from 1 ± 0 mg/kg to 6 ± 1 mg/kg, Fe varied from 30 ± 4 mg/kg to 300 ± 60 mg/kg, Mn ranged from 2 ± 0.2 mg/kg to 300 ± 10 mg/kg, and Zn ranged from 14 ± 0.3 mg/kg to 100 ± 4 mg/kg. Such differences can be linked to the differences in the soil's percentage content, which affect the amounts of essential trace metals in plants. Additionally, differences in climatic conditions play a huge role in controlling the distribution of the trace metals in the earth's crust, where the plants are grown for consumption. The flour that was analyzed by (Kageliza, 2014) was majorly obtained from green grams, cassava, finger millet, fine maize, soya, fish powder, groundnuts and milk powder in varying amounts. From the study, it was evident that the essential trace metals in different foodstuffs are totally reliant on extensive variables, which ranged from the type of plants and soils.

Research was conducted on *Amaranthuscruentus*and *Amaranthushypochondriacus*by Kipyegon, (2012) to ascertain the availability of the micronutrients in grains, stems/leaves of the two species of Amaranth. The indigenous vegetable is readily available in major parts of Kenya, and it mainly grows as weed during the rainy seasons. The analysis was done in relation to the concentration of the essential trace metals in soils around amaranth plant. Ngeno, (2012) reported the varying concentration of the essential trace metals such as Fe, Mn, Zn and Cu in two-grain amaranth species, which were sampled from distinct geographical locations and at different maturity stages. The elemental content in different parts of the plant varies according to their age and species. For instance, the amounts of Cr and Zn in the leaves of both species improved with the plants' growth from twenty-five to fifty days and then decreased from fifty to seventy-five days. However, the concentrations of Se, Mn, and Cu declined with the age of the plants. According to Mavengahama et al., (2014), wild vegetables are very essential sources of micronutrients in human diet.

A comparative analysis was done by Maina et al. (2012) on the traditional diets prominent in Eastern Kenya. The foods under the study were prepared as per the 'Kamba' traditional procedure. The samples were then dried and analyzed for the availability of essential trace metals such as Fe, Mn, Cu and Zn. For beans, Zn varied from 20 to 40 mg kg^{-1}, Cu levels ranged from 10 to 40 mg kg^{-1}, Fe was recorded at a concentration range of 250 mg kg^{-1} to 700 mg kg^{-1} while Mn varied from 30 to 100 mg kg^{-1}. For finger millet, the Fe, Mn, Zn and Cu, concentrations values were reported at a mean of 130 to 300 mg/kg, 100 to 300 mg/kg, 15 to 20 mg/kg, and 10 to 20 mg/kg, respectively for the samples from the three-sampling regions. In the decorticated maize, Fe was found to have higher concentrations values of 160 to 290 mg kg^{-1} in relation to other essential trace metals. Zn was found at a range of 40 to 70 mg kg^{-1} while Cu levels were approximately 20 mg kg^{-1} and Mn was reported at 35 to 80 mg kg^{-1}. Regional disparities in the amounts of the essential trace metals in cooked 'maize and beans mixture' (muthokoi) were realized in samples from Machakos district, depicting relatively higher concentrations. However, the samples from Mwingi district recorded very high concentrations of Fe with a maximum concentration of 1600 mg kg^{-1}. From analysis, the study concluded that finger millet could act as a good supplement of Fe and Mn while beans can act as the primary source of Fe. However, Cu was found to be the lowest in all the samples under the analysis.

However, extreme intake of essential trace elements can be harmful to the body, low levels of are linked to weakened immune system, reduced physical and mental growth, reduced reproductive performance, and decreased work productivity (M.Maina et al., 2012). For instance, a deficiency in iron (Fe) is associated with difficulties in concentration, decreased work performance, and lowered resistance to infections. Trumbo (2001) recommended a daily intake of approximately 10 mg of iron for men aged 25 to 50, and 15 mg for women aged 20 to 50. However, research conducted in developing countries indicates consistently low levels of dietary iron consumption, depleting the body's iron reserves and resulting in iron deficiency. To address this issue and improve iron levels in diets, it is recommended to fortify infant cereals, grain products, and formulas with this mineral.

Zinc (Zn) plays a crucial role in multiple metabolic and physiological activities in the human body (McGrath & Fleming, 2007). According to Kangeliza (2014), the daily recommended dietary intake of Zn is 15 mg for grown ups. For children above a certain age, the recommended intake is slightly lower at 10 mg per day. These recommended values serve as guidelines to ensure adequate zinc consumption to support normal physiological functions and overall health. It is important to note that individual zinc requirements may vary based on factors such as age, gender, physiological conditions, and specific health needs. Zinc plays a particularly important role during periods of rapid growth and development, as well as in various physiological processes like recovery from illness. It is also essential for the proper functioning of the human immune system. Good dietary sources of zinc include pork, lean red meat, and other foods. Deficiency in zinc manifests as alopecia, growth retardation, loss of taste, and delayed skeletal and sexual maturation.

Manganese (Mn) is vital for reducing total cholesterol in hypoglycemic individuals and maintaining stable blood sugar levels. It also plays a critical role in the nutritional treatment of post-partum depression, menopausal symptoms, and osteoporosis. Additionally, manganese is necessary for addressing conditions such as deafness, infertility, lack of libido, carpal tunnel syndrome, and epilepsy. The daily requirement for manganese is 2 mg for children and 5 mg for adults. Deficiency in manganese leads to symptoms like depression, low blood sugar, joint dislocation, asthma, fatigue, gastrointestinal disorders, irregular menstrual cycles, and high cholesterol levels. Whole-grain products, dried fruits, tea, and nuts are rich sources of manganese, containing approximately 20 to 23 mg kg-1. However, caution must be exercised as excessive manganese levels can cause symptoms such as frequent menstrual cycles, dizziness, fibroid tumours, insomnia, liver disease, colitis, and nausea.

Copper (Cu) is important for haemoglobin synthesis and plays a key role in important processes like hormone and blood vessel generation, as well as protection against heart diseases. Deficiency in copper is associated with bone abnormalities, neutropenia, and anaemia (de Romaña et al., 2011). It is worth noting that excessive copper accumulation in the body can have adverse health effects. High levels of copper have been associated with conditions such as cardiovascular disease and an increased risk of cancer mortality (Klevay, 2000). Deficiencies in vitamin A, zinc, and iron are significant contributors to mortality in developing countries. Unfortunately, affected populations are often unaware of these deficiencies due to the absence of clinical symptoms, giving rise to the term "hidden hunger" (Maziya-Dixon et al., 2010). Sub-Saharan Africa, for example, has been linked to high plant-based food intake relative to animal-based products, which contributes to the deficiencies of zinc, iron, and vitamin A.

In summary of the literature review, various studies have shown that floods are known to lead to depletion of nutrients through soil erosion, leaching, and deprivation of oxygen for the soil's microorganisms, which becomes an environmental determinant factor affecting the growth of plants cultivated in flooded regions. Floods can also lead to an abundant supply of nutrient-rich materials that decompose and disrupt nitrogen dynamics, thereby affecting nutrient availability and altering plant growth. In plants, trace elements have a vital role as activators for various enzymes involved in essential processes such as photosynthesis, electron transport systems, oxidation-reduction reactions, and the functioning of metalloproteinase. These elements, even though required in trace amounts, are crucial for the proper functioning of these enzymatic and metabolic processes. The significance of micronutrients in plant nutrition has garnered global attention, driven by an increased awareness of the detrimental effects associated with both micronutrient toxicity and deficiency. The concentration of micronutrients in plants is generally influenced by the content of the soil. Floods are also known to alter the pH of soil. Soil pH plays a crucial part in determining the accessibility of trace elements for plants. The mobility and solubility of trace elements are significantly influenced by soil pH, which alters their ionic forms within the soil. Changes in pH can induce chemical transformations in the soil, leading to increased bioavailability of micronutrients through modifications in their chemical speciation and influencing chemisorption. For instance, Zinc (Zn) is a vital micronutrient for crops, animals, and humans; its solubility in soil is a crucial factor influencing the availability of nutrients to plants. Zinc’s availability for plant uptake is often greater in slightly acidic soils.

Plant micronutrient deficiency and toxicity is linked to detrimental impacts on the health of human beings through the transformation of growth, normal metabolism and physical wellbeing. Insufficient minerals and vitamins result in impaired physical and mental development in children, high death rates in women and unborn children, reduced work productivity in adults and increased illness. In Kenya, the main food crops include; maize, cassava, finger millet, yams, sorghum, beans, collard greens (sukuma wiki), cabbage, African Spider plants (saget), African night shade (Managu). These crops supplement a significant proportion of energy required daily in the Kenyan diet. For instance, a deficiency in iron (Fe) is associated with difficulties in concentration, decreased work performance, and lowered resistance to infections. Research conducted in developing countries indicate consistently low levels of dietary iron consumption, depleting the body's iron reserves and resulting in iron deficiency. The aftermath of floods often reveals increased soil acidity levels, further influencing nutrient availability. The depth of soil plays a pivotal role in influencing nutrient availability to plants, thereby influencing overall soil fertility. Importantly, these disruptions have cascading effects on trace elements like iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn) within crops (Jennewein et al., 2020).

Additional impacts of flooding include the loss of biodiversity and the deterioration of water quality. Water quality varies from one source to the other which is hugely affected by human and natural factors. The trace metal distribution in the domestic water is fundamental in the determining the water quality suitability for drinking and other uses.

According to various studies many parts of Kenya and other parts of Africa experience unpredictably heavy precipitation between mid-April and May which is the study period of this research. Therefore, the need for more research on the elemental concentrations of trace metals in soils and plants, as well as domestic water sources is deemed necessary to determine their impact and risks to both crop quality and human health. If not properly addressed, long periods of flooding can lead to irreversible changes in soil quality, plant nutrition and water quality in the subsequent years, presenting significant challenges to the region.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Introduction

The study area is prone to frequent flooding associated with extensive soil degradation, food crop destruction, loss of the property, livestock and human beings. The study area chosen for this research was Busia County because the region lies in the basin of Lake Victoria. The primary objective of this study is to assess the impact of the frequent flooding in Budalangi, Busia County on the levels of Mn, Cu Fe, and Zn in the selected vegetables and in the soils on which they are grown.

In this section, the description of the study area is given, sample preparation, sampling procedures, quality control procedures and analysis are outlined. Soil pH, four total essential trace element content; Mn, Cu, Zn, and Fe in the sampled soils and vegetables and five selected toxic heavy metals pollutants in water samples; Hg, Pb, Cr, Ni, and As were examined from the study region and analyzed using EDXRF technique at the Institute of Nuclear Science and Technology, University of Nairobi.

The chapter is concluded with the description of the method used for data analyses. Sampling of the selected media was done randomly in selected farms within Budalangi Constituency.

3.2 Description of The Study Area

Budalangi Constituency is located in the Western Kenya, in the former Busia District, Busia County with an approximate area of 188 km^2. The Constituency encompasses Bunyala Central, Bunyala North, Bunyala East, Bunyala South, Khajula and Bunyala West locations respectively. The region is among the less densely populated areas in Busia County, with an estimated 54.4 people per km2. A study conducted by Dr. Jela Nakhabi Phoebe (2016) estimated the proportion of malnourishment in the region is approximately 17.3 % for children under the age of five (Jela, 2016). The area is prone to floods, with the main economic activities is fishing and small-scale farming. The area has great potential for occasional irrigation farming activities. The long rains take place during the months of March to May period, which is the also the flooding period. Hence, the sampling was done in December 2021 (before floods) and in July 2022 (after floods). Due to frequent flooding occurrences in the area, farming activities have been limited to higher grounds with minimal crop activities in the flood plain areas of Budalangi. Sorghum, maize, beans and potatoes are some of common crops planted during the period when there are short rains, between October and December. The most common vegetables grown include the following; cabbage, collard green, cowpeas, and spinach. Vegetables are planted throughout the year. Other features in the area include; dykes built along the River Nzoia to minimize the effects of floodings. It is also reported, that due to the introduction of dykes, incidents of malaria, bilharzia and other water borne diseases have reduced.

Figure 3.1 below shows the area of study and the locations where the sampling was done.

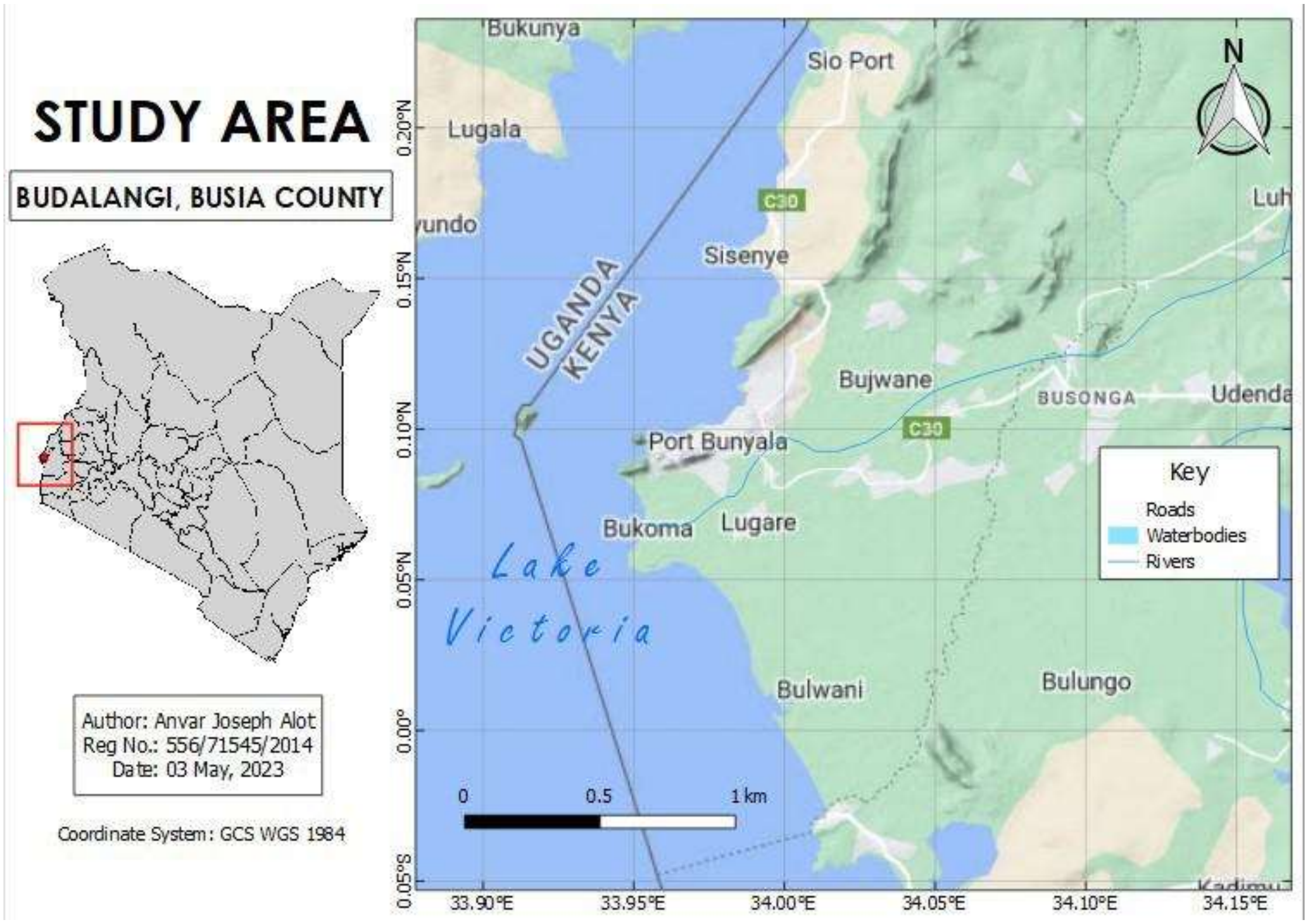


Figure 3. 1: Area of Study and Sampling Sites, Budalangi.

3.3 Field Sampling Procedures

3.3.1 General statement on sampling procedure

The selection of a random sampling process for this study was deliberate and methodologically rigorous, aiming to ensure a representative and unbiased collection of soil, water, and vegetable samples from Budalangi, Busia County. The decision to employ random sampling was driven by the need to capture the heterogeneity of the study area, as flood impacts can exhibit spatial variability. The sampling points were chosen without predetermined patterns or preferences, contributing to a more accurate reflection of the overall conditions in the study area. The sampling procedure shares fundamental principles with the International Atomic Energy Agency (IAEA) environmental sampling procedures that often provide robust protocols for nuclear-related analyses, enhance the credibility of the findings, emphasizing representativeness, minimization of bias, data comparability, and reliability of findings.

3.3.2 Soil Sampling and Pretreatment

A total number of a hundred and twenty (120) soil samples were randomly collected; sixty (60) before the flooding season in December, 2021 and sixty (60) after the flooding season in July, 2022, from thirty (30) farms located along the river Nzoia and high grounds of the Budalangi basin, over approximate area 100-120 Km^2. The one hundred and twenty (120) soil samples each weighing approximately 1/2 kg were obtained from a depth of 0 - 10 cm for topsoil and at 10 – 50 cm for the subsoils, each using an Auger, for respective sampling period. The soil samples were mixed homogeneously using a trowel in a bucket to obtain a representative sample (Fig 3.2).

The topsoil is the layer where a significant accumulation of nutrients occurs, making it crucial for agriculture. Generally, deeper topsoil is considered more favorable for agricultural purposes. Shallow topsoil is typically less than 10 cm in depth, while deep topsoil refers to depths greater than 10 cm.

The geographic coordinates of each sampled site were documented during both sampling periods using a Global Positioning System (GPS) device. The soil samples were labelled with the initials TS and SS to represent Topsoil and Subsoil, respectively, followed with a 3-digit numeral code to represent the sampling point, TS-001 Topsoil sample from site one. The second set of soil samples were collected after the flooding season, were distinguished from the previously sampled soil samples with letter B. For example, TS-001B is a Topsoil sample from site one after the floods (Figure 3.2 and 3.3 and Table 3.1).

The labeled soil samples were carefully placed into polyethylene bags and securely transported to the laboratories of the Institute of Nuclear Science & Technology for subsequent analysis of trace metals.

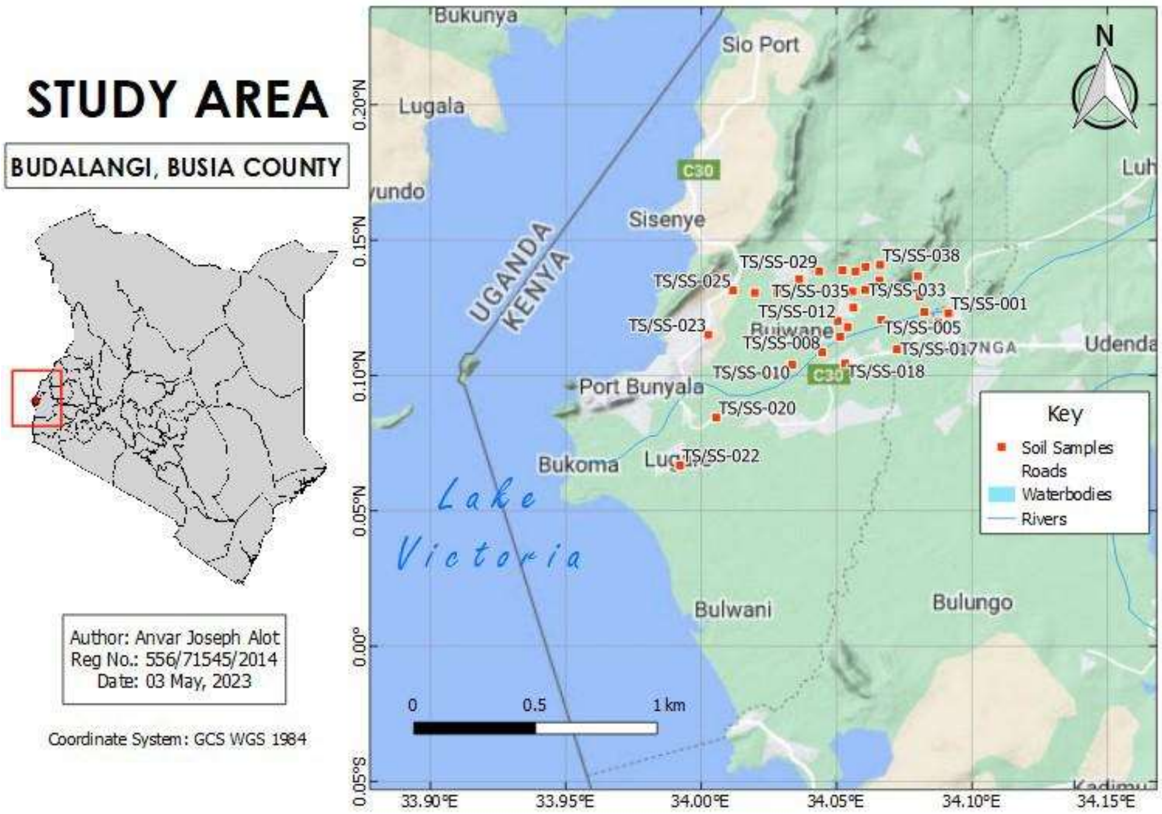


Figure 3. 2: Soil sampling sites - Budalangi

Figure 3. 3: Soil Sampling

Table 3. 1: GPS Locations of Soil Sampling Points

Sample Code	Northings	Eastings	Elevation (M)	Location Name
TS/SS-001	0.12294	34.09151	1128	Rwambua Sub- location
TS/SS-003	0.12334	34.08265	1138	Rwambua Sub- location
TS/SS-005	0.12046	34.0667	1137	Rwambua Sub- location
TS/SS-006	0.11779	34.05424	1137	Mudembi Sub- location
TS/SS-007	0.11417	34.05142	1138	Mudembi Sub- location
TS/SS-008	0.10842	34.04484	1138	Mudembi Sub- location
TS/SS-010	0.10382	34.03366	1135	Mudembi Sub- location
TS/SS-012	0.12005	34.0506	1137	Mudembi Sub- location
TS/SS-013	0.12497	34.05639	1138	Mudembi Sub- location
TS/SS-014	0.11959	34.08773	1144	Usonga
TS/SS-017	0.10955	34.07245	1144	Magombe East
TS/SS-018	0.10429	34.05325	1143	Magombe Central
TS/SS-020	0.08428	34.00556	1140	Lugale
TS/SS-022	0.06663	33.9922	1140	Ndekwe
TS/SS-023	0.11497	34.00262	1141	Bulemia
TS/SS-025	0.13131	34.01178	1153	Mundere
TS/SS-026	0.1305	34.01984	1144	Bujonjori Sub location

Sample Code	Northings	Eastings	Elevation (M)	Location Name
TS/SS-027	0.13052	34.02819	1146	Budalangi HQ
TS/SS-028	0.13554	34.03628	1158	Makina Sub-location
TS/SS-029	0.13843	34.04374	1146	Namunye, Masabha Sublocation
TS/SS-030	0.13881	34.05235	1145	Namunye, Masabha Sublocation
TS/SS-031	0.13838	34.05708	1145	Mumoni Village, Mudembi Sub location
TS/SS-032	0.13503	34.06602	1161	Naera Village, Model High School, Rwambwa
TS/SS-033	0.13137	34.06071	1147	Naera B Village, Rwambwa
TS/SS-034	0.13161	34.06071	1146	Mumoni Village, Mudembi Sub location
TS/SS-035	0.13103	34.05598	1145	Mumoni Village, Mudembi Sub location
TS/SS-037	0.14009	34.06091	1153	Naera B Village, Rwambwa, Next to Quarry
TS/SS-038	0.14081	34.06623	1174	Naera A Village, Rwambwa
TS/SS-040	0.13667	34.08014	1146	Ebukhwaya, Namalo Girls
TS/SS-041	0.1291	34.08089	1143	Bukhoba Village, Rwambua Sublocation

3.3.3 Vegetable sampling

A total number of twenty (20) vegetable samples were randomly collected; ten (10) before the flooding season in December, 2021 and ten (10) after the flooding season in July, 2022, from 10 ten (10) farms located along the river Nzoia and high grounds of the Budalangi basin, over an approximate area of 50 – 70 Km^2. The sampled vegetable leaves were; Sukuma wiki (Collard greens), Kunde (Cow pea leaves) and Spinach (Mchicha) by cutting using a knife. The samples were thoroughly cleaned with running tap water free from the impurities. For each species, a max of 6 samples were collected (Table 3.2).

The geographic coordinates of each sampled site were documented during both sampling periods using a Global Positioning System (GPS) device. The vegetable samples were labeled with the initials S, K and SP to represent the species; Sukuma wiki (Collard greens), Kunde (Cow pea leaves) and Spinach (Mchicha), respectively followed with a 3-digit numeral code to represent the sampling point, S-001 Sukuma wiki (Collard Green) sample from site one. The second set of vegetable samples collected after the flooding season, were distinguished from the previously sampled soil samples with letter B. For example, S-001B is a Sukuma Wiki (Collard greens) sample from site one after the floods (Figure 3.4 and Table 3.2).

The samples were then packaged in polyethene bags and transported to the Institute of Nuclear Science & Technology laboratories for analysis.

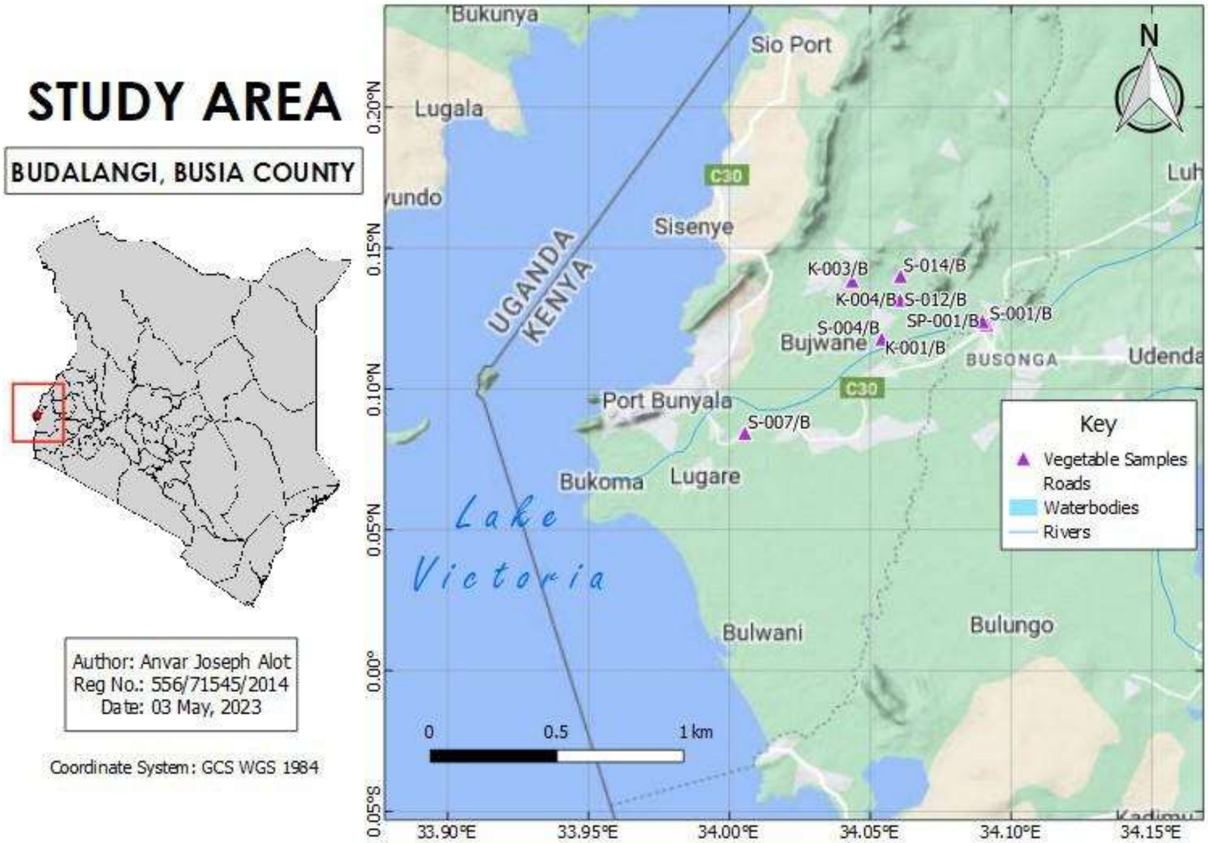


Figure 3. 4: Vegetable sampling sites, Budalangi

Figure 3. 5: Vegetable sampling

Table 3.2: GPS location readings at vegetable sampling points

Sample Code	Northings	Eastings	Elevation (m)	Location
S-001/B	0.12294	34.09152	1128	Rwambua Sub-location
SP-001/B	0.12403	34.09006	1137	Rwambua Sub-location
K-001/B	0.11779	34.05424	1137	Mudembi Sub-location
S-004/B	0.11779	34.05424	1137	Mudembi Sub-location
S-007/B	0.08428	34.00556	1140	Lugale Division, Kajula Location
S-010/B	0.13843	34.04374	1146	Namunye, Masabha Sublocation
K-003/B	0.13843	34.04374	1146	Namunye, Masabha Sublocation
K-004/B	0.13161	34.0607	1146	Mumoni Village, Mudembi Sublocation
S-012/B	0.13161	34.0607	1146	Mumoni Village, Mudembi Sublocation
S-014/B	0.14009	34.06091	1145	Mumoni Village, Mudembi Sublocation

3.3.4 Water sampling

A total number of twenty (20), half-litre water samples were randomly collected; ten (10) before the flooding season in December, 2021 and ten (10) after the flooding season in July, 2022, from

Lake Victoria (1 sample), River Nzoia (1 sample), Boreholes (5 samples), Ponds (2 samples) and Well (1 sample) over an approximate area of 80-100 Km^2.

Prior to sampling, half-litre polyethylene (PE) bottles used for sampling were cleaned and rinsed with distilled water as to minimize any form of contamination. The PE bottles that were cleaned using nitric acid and soaked for 12 hrs in soapy water. The PE bottles were rinsed in tap water and then in distilled water (IAEA-TECDOC-950, 1997).

Approximately half-litre water samples were collected in the PE bottles by submerging them in water sources.

The geographic coordinates of each sampled site were documented during both sampling periods using a Global Positioning System (GPS) device. The water samples were labeled with the initials WS representing Water Sample followed with a 3-digit numeral code to represent the sampling point, WS-001 Water Sample from site one. Second set of water samples collected after the flooding season, were distinguished from the previously sampled water samples with letter B. For example, WS-001B is a water sample from site one after the floods (Figure 3.5, Fig 3.6 and Table 3.3).

All the samples were then carried to the INST laboratory for examination and measurement for trace element content.

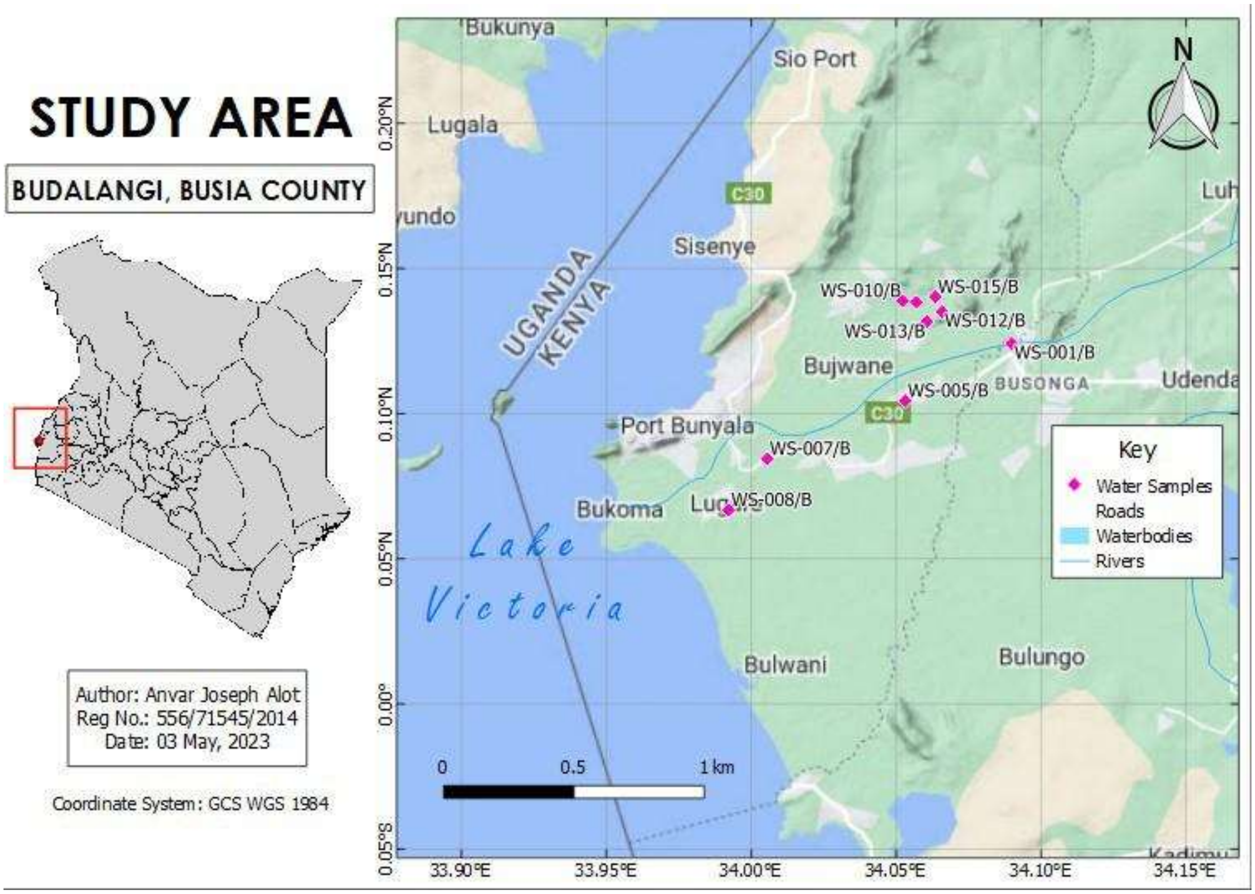


Figure 3. 6: Water sampling sites, Budalangi

Figure 3. 7: Water sampling from Well

Table 3.3: GPS location readings at water sampling points

Sample Code	Northings	Eastings	Elevation (M)	Location	Application
WS-001/B	0.12403	34.09006	1137	Rwambua Sub-location	River Nzoia, Rice irrigation
WS-005/B	0.10429	34.05325	1143	Magombe Central location	Borehole Water, Domestic use
WS-007/B	0.08428	34.00556	1140	Lugale Location	Borehole Water, Domestic use
WS-008/B	0.06663	33.9922	1140	Ndekwe	Lake Victoria, All purpose
WS-010/B	0.13881	34.05235	1145	Namunye, Masabha Sublocation	Borehole Water, Domestic use
WS-011/B	0.13838	34.05708	1145	Mumoni Village, Mudembi Sub location	Pond water, Fish rearing

Sample Code	Northings	Eastings	Elevation (M)	Location	Application
WS-012/B	0.13503	34.06602	1161	Naera Village, Model High School, Rwambwa	Borehole Water, Domestic use
WS-013/B	0.13137	34.06071	1147	Naera B Village, Rwambwa	Borehole Water, Domestic use
WS-014/B	0.13161	34.06071	1146	Mumoni Village, Mudembi Sub location	Well, Irrigation
WS-015/B	0.14019	34.06364	1156	Naera B Village, Rwambwa	Pond, Livestock

3.4 Sample Preparation Procedures

This section discusses the preparation of the soil, vegetable and water samples for pH analysis and trace element analysis with EDXRF

3.4.1 Sample Preparations for Soil pH Analysis

To determine the pH of the soil accurately, it is recommended to prepare a 1:1 soil-to-water mixture by combining dry soil samples with distilled water. The mixture should be thoroughly mixed until the soil and liquid reach a state of equilibrium, ensuring precise measurement of the soil pH.

About 10 grams each of soil sample was poured into a 500 ml beaker, followed by adding 10 ml of distilled water. The mixture was thoroughly stirred and allowed to stand for approximately for ½ hour.

The calibrated pH meter was then used to measure the pH levels after it has stabilized (Agrawal et al., 2015). For every sample, the average value from three (3) measurements of the pH values were recorded.

3.4.2 Soil Sample Preparations for Trace Element EDXRF Analysis

The soils samples were air-dried for two weeks. The dried samples materials were then crushed and sieved through a 2mm diameter sieve to exclude the large particles. Further sieving was done to achieve 75 µm particle size and to ensure sample homogeneity. Three (3) pellets each weighing approximately 0.2- 0.4 g were prepared using a hydraulic pellet press under a pressure of 5 to 8 tons for the EDXRF analyses, after dilution with cellulose material.

3.4.3 Vegetable Sample Preparations for Trace Element EDXRF Analysis

The vegetable samples were dried at room temperature for around two weeks. The sampled vegetable leaves were; Sukuma wiki (Collard greens), Kunde (Cow pea leaves) and Spinach (Mchicha).

Next, the sample was finely ground to a powder and passed through a sieve with a diameter of 2 mm. Three (3) pellets, weighing approximately 0.5-0.7 g each, were then prepared using a hydraulic pellet press. These pellets were created under a pressure of 5-8 tons and were analyzed using EDXRF without any sample dilution. Binders were not used because the samples were binding on their own, allowing a uniform and strong pellet formation.

3.4.4 Water Sample Preparations for Trace Element EDXRF Analysis

To eliminate suspended solids, approximately 500 ml of each water sample was filtered using pre filtration membrane 20-25µm (particle retention) quantitative filter papers.

For each sample, 500ml of water samples were adjusted for pH to 3.5 by adding drops annular grade Nitric acid and Ammonia solution. Then 2 ml of 1% aqueous solution of Ammonium pyrrolidinedithiocarbamate (APDC), a co-precipitation reagent, since metal chelates are particularly attractive due to their low solubility characteristics, was added to each solution.

After 40 to 60 minutes of stirring, the precipitate was filtered using a 0.4 µm nucleopore filter. membrane and analyzed for trace element content with the EDXRF.

Three (3) aliquots for each sample were prepared and analyzed for trace element content. Twenty water samples from identified sampling sites were used in this study.

3.5 Trace element Analyses with EDXRF

3.5.1 Instrumentation and EDXRF Analyses

The EDXRF instrument used comprises of a power supply, a personal computer for visualizing the data, and the electronic spectrometer modules, which consists of a solid-state detector, captures the fluorescence radiations emitted by the sample and are passed through a filter that selectively eliminates low-energy photons, ensuring only monochromatic light is transmitted (Yao et al., 2015) and finally, an X-ray tube for generating the sample excitation X-rays radiation.

The spectrometer was operated with an 80 µA current and a maximum energy of 30 KeV. It utilized an X-ray tube with a silver target and a SiLi-drift detector. The instrument produced peaks with varying intensities, corresponding to the concentrations of essential trace metals in the material under study. AXIL software was employed to analyze and quantify the spectral data, including tasks such as converting spectrum formats from CSV to SPE files and performing spectrum fitting. The calculation of element content for multiple pellets representing a specific sample followed the methodology described by Van Espen et al. (1994).

EDXRF technique used in this study utilizes the Fundamental Parameter Technique method for matrix effect corrections. Each pellet was irradiated for 500 seconds. The sample, together with the thick multielement target sample, was irradiated for 50 seconds, followed by irradiation of the multielement target sample alone for 50 seconds. These measurements are necessary for correcting the matrix effects.

The method was validated for accuracy, and detection limits using the Standard Reference Materials from the International Atomic Energy Agency (IAEA), available at the Institute of Nuclear Science & Technology Laboratories. The following Certified Reference Materials (CRM) were utilized in this study; River clay and Bowen Kale. Moreover, the reproducibility and precision of the method used was assessed by analyzing each sample in triplicates.

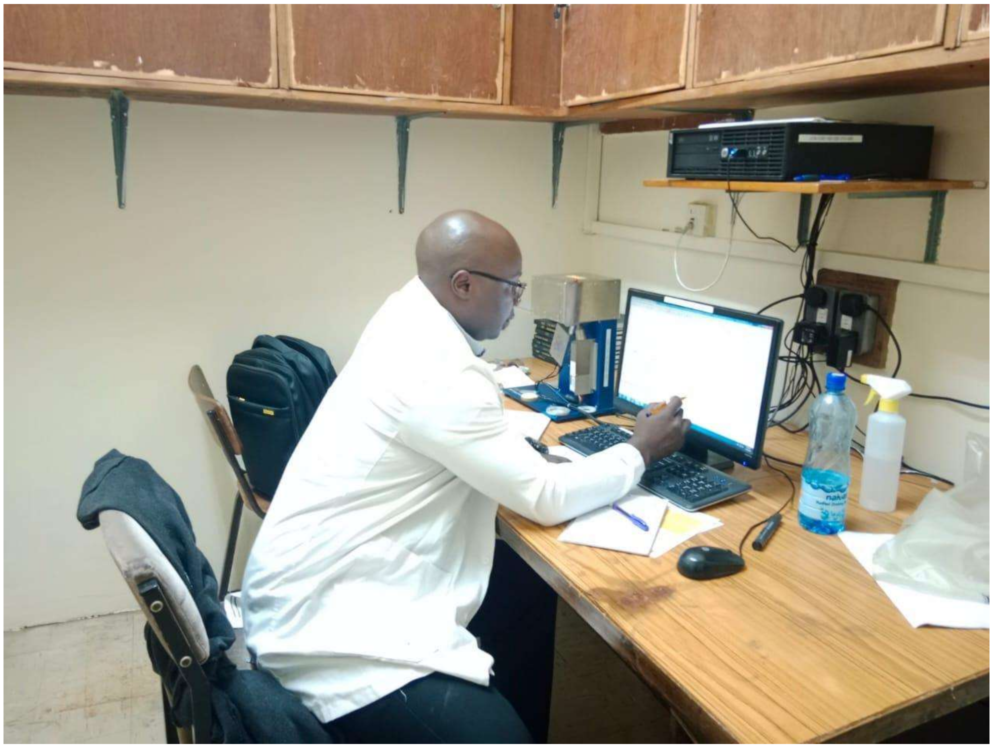


Figure 3. 8: EDXRF Spectrometer, Institute of Nuclear Science and Technology

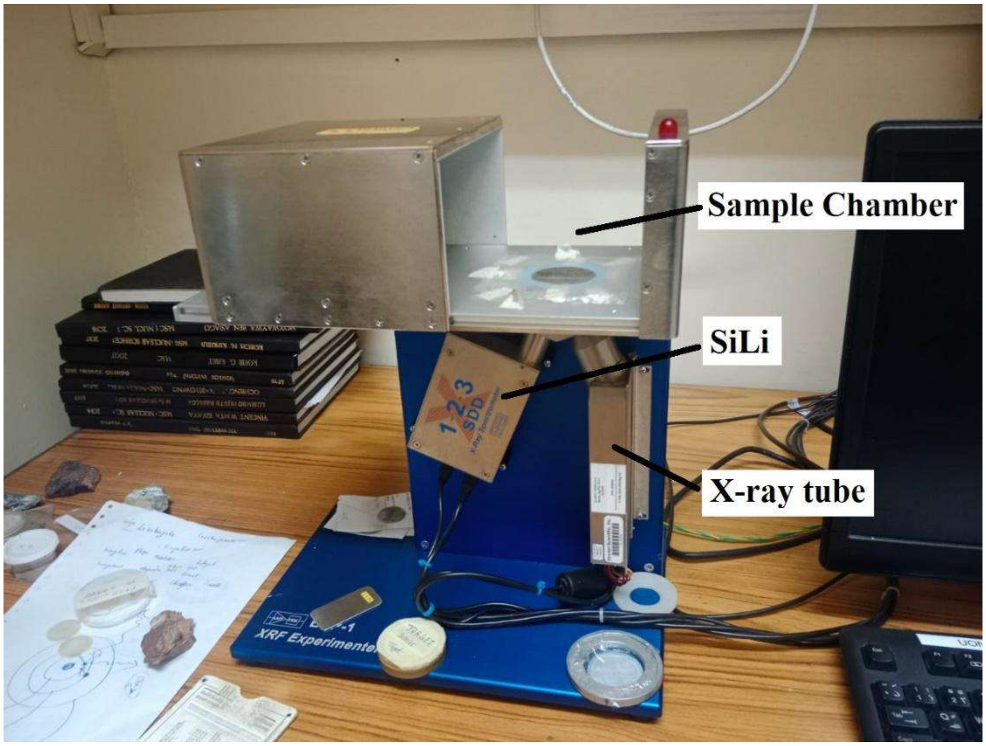


Figure 3. 9: EDXRF Spectrometer, Institute of Nuclear Science and Technology

Fundamentally, the EDXRF technique relies on the distinctive atomic structure of each element, enabling the emission of radiation signals in the form of identifiable peaks with known energies in the electromagnetic spectrum (Lyman et al., 2012). When high-energy x-ray beams interact with a sample target, the excited atoms' inner shell electrons are expelled, causing the atom to become unstable. The atom subsequently returns to its ground state through de-excitation, releasing characteristic energy specific to the metals involved (Lyman et al., 2012).

Consequently, an element can be identified by determining the energies of the photons that are emitted during the electron transition in the energy states shells (Brouwer, 2010; Ene et al., 2010). The count rate (photons per second, cps) of a fluorescent emission line corresponding to a specific element is directly related to the concentration of that element within the analyzed sample during X-ray analysis. The emission rates of photons are determined by measuring the photons detected by the sensor over a given time period for the various recorded X-ray spectral peaks associated with the elements.

Analyses of the x-rays energy lines spectrum and their corresponding count rates (Brouwer, 2010) enables for qualitative and quantitative analyses. The intensity of the incoming signal for a specific element is directly proportional to the amount of the element in the sample under the study.

According to Yao et al. (2015), the preamplifier converts the characteristic X-rays into pulses of low voltage. The amplitude of these pulses corresponds directly to the energy of the incoming X-rays, which is unique to each element. The amplified voltage is subsequently converted into a digital signal by the Analog to Digital Converter (ADC), following the method outlined by Yao et al., (2015). This data, stored by the Multichannel Analyzer based on its amplitude, is subsequently transformed into X-ray fluorescence spectral line data for further analysis.

3.5.2 EDXRF Measurements and Method Validation

This study employed an EDXRF spectrometer to assess the overall concentrations of essential trace metals in all the samples, including soil, vegetables, and water.

Bowen Kale SRM and River Clay SRM - PTXRF-IAEA-09 from the International Atomic Energy Agency (IAEA) laboratories, Seibersdorf were analyzed, to evaluate the accuracy of the EDXRF method.

The Standard Reference Materials samples were prepared and analysed using the same procedure as that used in the analysis of soils and vegetable samples.

Table 3.4 shows the results of EDXRF analyses of Standard Reference Material, IAEA-PTXRF-09.

Table 3.5 shows the results of EDXRF analyses of Standard Reference Material, Bowen Kale.

Table 3.6 shows the results of EDXRF analyses of ICP Multi-Element Liquid Standard VI.

Table 3.7 shows the results of Elemental lower limits of detection with EDXRF analyses

Table 3. 4: EDXRF Analyses of Standard Reference Material, IAEA-PTXRF-09 ; n=3, X+1SD- µg/g- unless otherwise stated

Element	**Exp Value**	**Certified Values**	**Certified Range(95% CI)**
K	(1.76 ± 0.04)%	(1.95 ± 1.06)%	(0.89 - 3.01)%
Ca	(1.32 ± 0.09)%	(1.38 ± 0.79)%	(0.59 - 2.17)%
Ti	(0.40 ± 0.03)%	(0.43 ± 0.29)%	(0.14 - 0.72)%
Fe	(2.89 ± 0.01)%	(2.97 ± 1.51)%	(1.46 - 4.50)%
Mn	1003 ± 58.8	1000 ± 80	920 - 1080
Zn	102 ± 7.1	96.1 ± 11.6	84.5 - 107
Rb	102 ± 7.4	107.0 ± 12.7	94.3 - 119
Sr	99 ± 7.0	106.0 ± 12.6	93.4 - 118
Y	33.5 ± 4.0	31.8 ± 4.53	27.3 - 36.3
Zr	285 ± 14.1	302 ± 30.7	271 - 333

Table 3.5: EDXRF Analyses of Standard Reference Material, Bowen Kale ; n=3, X+1SD- µg/g- unless otherwise stated

Element	**Experimental values**	**Certified Value**	**Certified Range(95% CI)**
Fe	132 ± 26	122 ± 20	102-142
Mn	17.6 ± 5.4	16 ± 4	12-20
Zn	35.4 ± 6.2	34 ± 6	28-40
Cu	5.2 ± 1.1	5 ± 0.6	4.4-5.6

Table 3.6: EDXRF Analyses of ICP Multi-Element Liquid Standard VI ; n=3, X+1SD- µg/g- unless otherwise stated

Element	Experimental values (ppm)	Certified Value (ppm)	Certified Range (95% CI) (ppm)
Cr	8.6 ± 2.5	10 ± 0.5	9.5 -10.5
Ni	7.4 ± 1.4	9.9 ± 0.5	9.4 -10.4
As	83.4 ± 16.2	97 ± 5	92 -102
Pb	9.2 ± 1.1	9.9 ± 0.5	9.4 – 10.4 -

The water quality results obtained in this study can be confidently justified through the robustness of the chemical preconcentration process employed. Chemical preconcentration is a crucial step in water quality analysis, enhancing the sensitivity of detection for metal ions. The verification of water quality results using International Atomic Energy Agency (IAEA) Inductively Coupled Plasma (ICP) multi element standard VI further strengthens the reliability of the findings. The use of co-precipitation reagents, such as ammonium pyrrolidinedithiocarbamate (APDC), as chelating agents for metal ions has proven to be highly effective in various analytical and environmental applications. APDC ability to form stable complexes with metal ions, leading to their selective precipitation. This chelating agent demonstrates a high affinity for a wide range of metal ions, including transition metals and heavy metals (IAEA-TECDOC-950, 1997).

Table 3.7: Elemental lower limits of detection with EDXRF analyses ICP Multi-Element Standard VI; n=3, X+1SD- µg/l- unless otherwise stated

Element	Atomic number, Z	Lower limits of detection
Pb	82	5
Hg	80	4
As	33	3
Ni	28	5
Cr	24	15

The results indicate that for elements of interest; Fe, Mn, Zn, and Cu analysed, the accuracy is < 10%. The elemental sensitivity is within 5 - 15 µg/g for most high Z elements.

3.6 Statistical methods for Data analysis

The data of results of measurements, elemental concentrations acquired from the EDXRF measurements were statistically analyzed for the interrelationship between variables, to show trends and distributions with histograms, and for variations, using tables and charts by using statistical tools such as Microsoft Excel to determine means, medians, z-tests and correlations.

The concentration values were subjected to Pearson's correlation analyses to test if there was a substantial correlation of the essential trace metal amounts in the soil and vegetable samples. z-test was used in evaluating whether there was a significant difference at 95% confidence interval. To assess the statistical significance of the correlation, a scale ranging from zero to one was employed.

A correlation coefficient close to zero suggests no association between the two elements, indicating a weak correlation. The terms " strong," "moderate," and " weak " were used to describe correlation coefficients falling within specific ranges: 0.1–0.4 for weak correlation, 0.4–0.6 for moderate correlation, and higher than 0.6 for strong. The examination of correlation within a dataset is valuable as it helps determine potential associations among variables.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents and discusses the results of the study in accordance with the objectives, which were to determine the impact of floods on Soil, Water Quality and availability of Essential Trace Elements in Selected Vegetables Grown in Budalangi, Busia County. Sampling was done before and after flooding. The soil samples were analysed for the parameters; pH and a few selected trace elements. The vegetable and soil samples were analyzed for; Fe, Mn, Cu and Zn content, while water samples were analysed to determine their content of mercury (Hg), lead (Pb), chromium (Cr), nickel (Ni), and arsenic (As).The results of this study are presented and discussed in 4 sections; Section 4.2: Soil pH Analysis, Section 4.3: Soil Quality Analysis: Available Total Essential Trace Elements, Section 4.4: Essential Trace Elements in Selected Vegetables and in Section 4.5: Water Quality Analysis: Toxic heavy metal Pollutants.

4.2 Soil pH Analysis

Table 4.1: shows the results of the soil pH measurements for the top soils (5-10 cm depth) and subsoils (10-20 cm depth) before and after the floods over the sampling period (Appendix 1).

Fig 4.1: shows the results of the soil pH variations for the top soils (5-10 cm depth) before and after the floods over the sampling period.

Fig 4.2: shows the results of the soil pH variations for the subsoils (10-20 cm depth) before and after the floods over the sampling period.

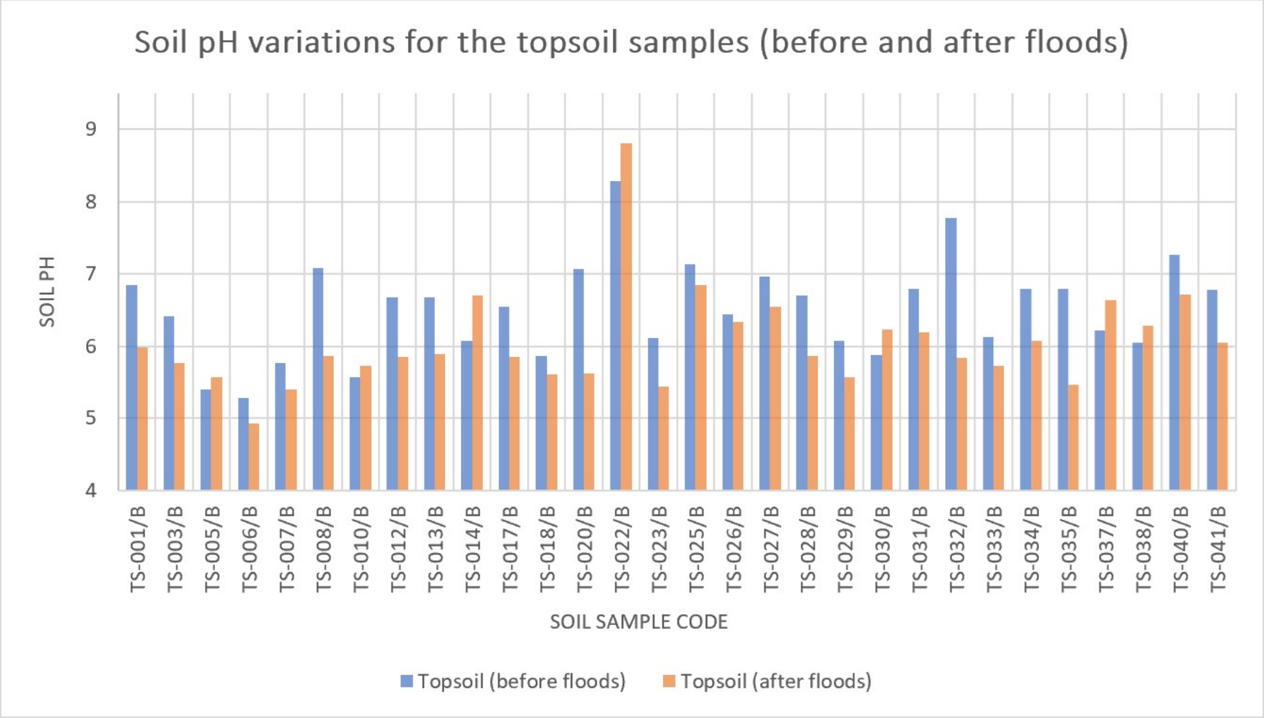


Figure 4. 1: Soil pH variations for the topsoil samples (before and after floods)

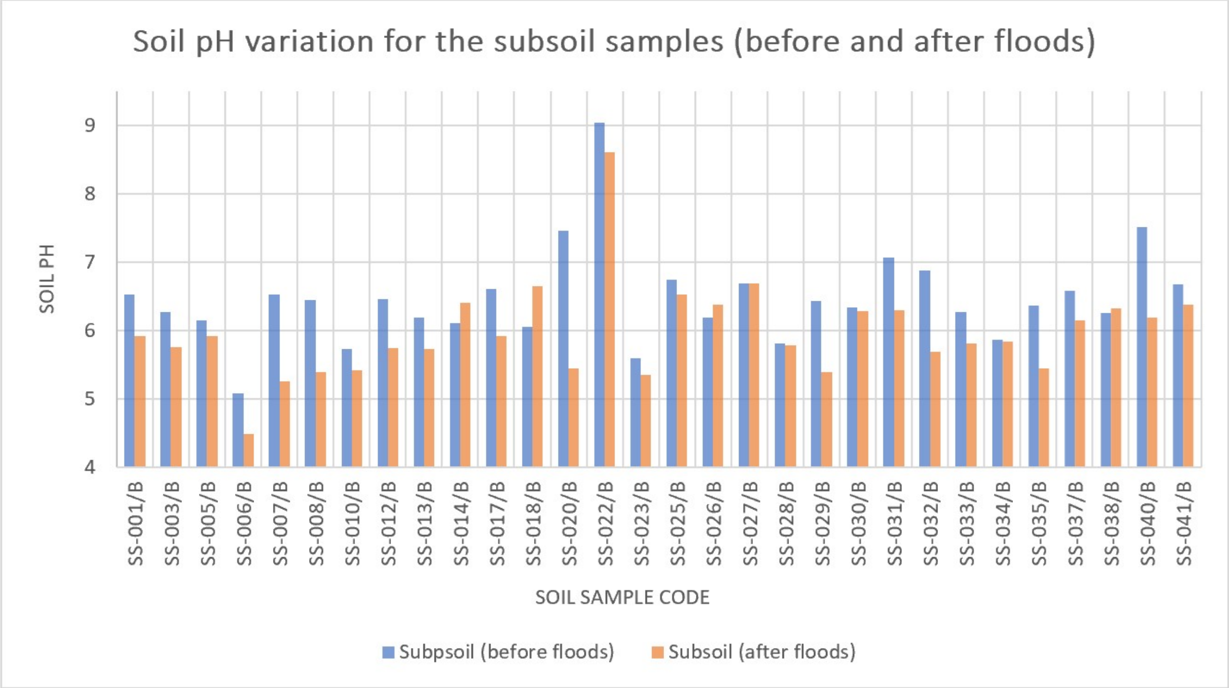


Figure 4. 2: Soil pH variations for the subsoil samples (before and after floods)

The results of measurements show that the average pH of the topsoil recorded was 6.51 ± 0.67(range 5.28 to 8.28) and 6.04 ± 0.69 (range 4.93 to 8.80) before and after the floods, respectively, whereas the average pH of subsoil samples recorded was 6.46 ± 0.70 (range pH 5.08 to pH 9.04) and 5.97 ± 0.70 (range pH 4.48 to pH 8.60) before and after the floods, respectively.

Both results show a decrease of pH by approximately 7.2% and 7.6 %, for topsoil and subsoil samples, respectively. The floods appear to have contributed to a slight decrease in pH. However, there is a significant difference ($p > 0.005$) in pH variations in each of soil substrata, before and after the floods (Table 4.2 and Table 4.3 in the Appendix). In general, the soils are slight to moderate acidic, floods effects notwithstanding.

A study by Recha et al., 2022 on East African soils showed that Kenyan soils pH ranged from 6.19 to 8.48 and indicates that productive soils typically have a pH range of 5.5 to 7.2. This pH range is considered favorable for flora as it allows access to essential components and nutrients necessary for their growth and development. In this study, the average pH results for both soil strata are within the acceptable range for agricultural purposes.

The difference between the average pH for the top soil and subsoil strata was less than 0.7 (<1%). The slight pH changes could be attributed to run off water during the flooding season and also surface contamination from agricultural processes that occur in the region. Numerous studies have indicated the significance of temperature and precipitation in regulating soil pH. Climate, to a certain extent, can impact soil chemical reactions and subsequently influence the pH of the soil (Slessarev et al., 2016b).

It is commonly observed that soils from humid climates tend to have acidic characteristics and low soil pH levels (Zhang et al., 2019). The findings of this study are in line with this observation, indication similar acidic soil conditions. Budalangi is a well-watered, humid and semi-humid region (Onywere et al., 2011). The factors contributing to variations in soil pH can differ based on location and scale. Various factors, such as geological composition, climate, vegetation, land use practices, and soil management, can influence soil pH differently across different locations and scales. Studies by Reeves & Liebig, 2016 indicate that significant differences at various depths change over time, with smaller pH change observed at deeper depths.

4.3 Soil Quality Analysis: Total Essential Trace Elements

Table 4.4 shows the results of the average elemental concentration in Budalangi Soils Samples.

Table 4.5 – 4.6 show the results of elemental concentrations for the soils strata before and after the floods (Appendix).

Table 4.7 – 4.10 show the inter-element correlations in the soils before and after the floods (Appendix)

Figure 4.3- 4.4 shows the box plots of elemental concentration distributions in soils before and after floods.

Fig 4.5- 4.12 shows a summary of the distribution of the respective essential trace elements in the sampled soils before and after the floods.

In general, the relative abundance of Essential Trace Elements in the soil samples was found in the decreasing order Fe>Mn > Cu > Zn during the sampling periods, before and after the floods. The levels of the all the elements of interest, Mn, Cu and Zn were all within the global limits suitable for agricultural soils. Fe levels are enhanced by factor 2-fold in this study (Table 4.4). There is a wide variation in the distribution of each of the trace elements of interest in the soil strata sampled in this study (Fig 4.3 & 4.4). However, no significant differences in the concentration levels for most elements were observed, before and after the floods for each of the soil strata. The levels of most elements decreased between 1-15 %, for Fe (7%); Mn (4%); Cu (1-5%); Zn (11-15%) in all the soil strata sampled before and after the floods (Table 4.4).

According to this study, the concentrations of all four elements examined were found to be within the reported values for agricultural soils worldwide. The results suggest that the average elemental concentrations in soil samples decreased between the two sampling periods. This decrease could be attributed to the flooding acting as a transport agent for trace elements from the soil surface, resulting in nutrient depletion.

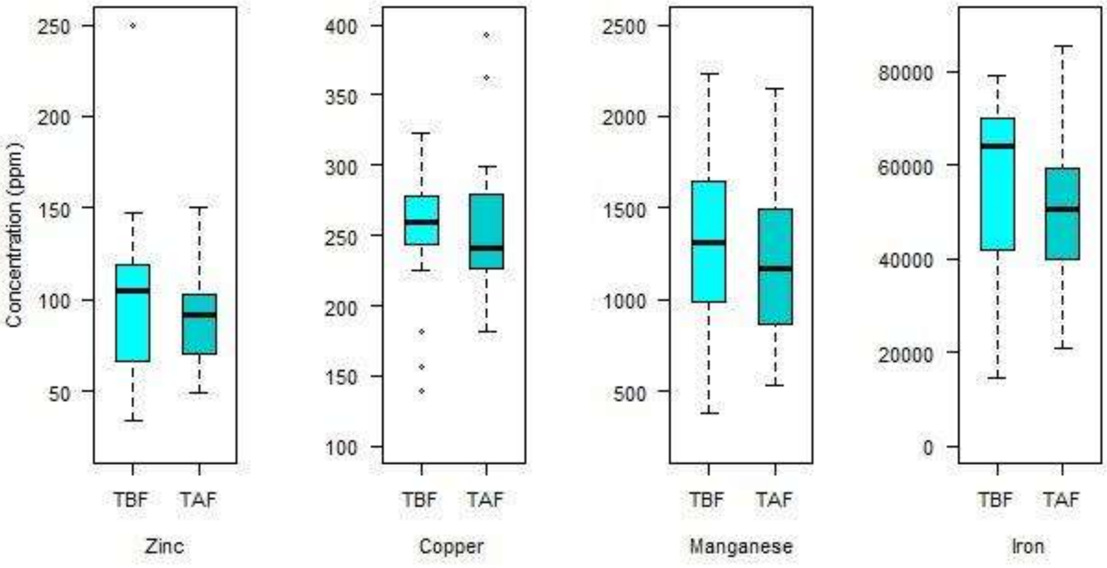
The following is a summary of the observation for the variations of the trace elements in the soil's strata:

The results of Fe concentrations levels indicate that the average Fe elemental concentration between the two sampling periods decreased from 5.6 % to 5.2 % which translates to 7% decrease after the floods for the top soil (60%) samples. While the average Fe concentration for sub soils (50%) decreased from 5.92 %w to 5.51 %w which translates to a 7% decrease in elemental concentration.

There was no significant difference in the average Fe concentrations between the soil's strata after the floods ($p>0.05$).

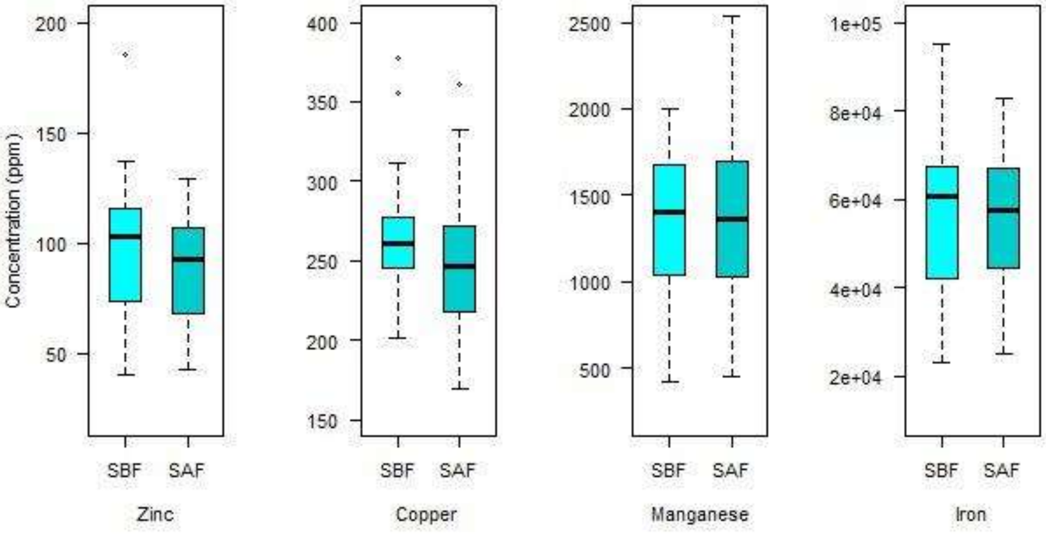
Element	Global Background levels for Agricultural soils		Soil strata	Sampling Period	Average Concentrations Levels in this study (Budalangi)-	% Change after the floods
	Average	Range				
Fe (%)	2.8	1 – 5.5	Topsoil	Before Floods	5.6 ± 1.9 (1.4 -7.9)	8% decrease
				After Floods	5.2 ± 1.9 (2.11 – 10.7)	
			Subsoil	Before Floods	5.9 ± 2.1 (2.29 – 11.5)	7% decrease
				After Floods	5.5 ± 1.6 (2.51 – 8.28)	
Mn (µg/g)	900	7 - 9000	Topsoil	Before Floods	1303 ± 436 (383 – 2230)	4% decrease
				After Floods	1251 ± 508 (535 – 2853)	
			Subsoil	Before Floods	1401 ± 539 (425 – 3307)	0.1% increase
				After Floods	1402 ± 525 (448 -2532)	
Cu (µg/g)	55	1 - 250	Topsoil	Before Floods	256 ± 41 (383 – 2230)	1% decrease
				After Floods	253 ± 45 (181 – 393)	
			Subsoil	Before Floods	266 ± 38 (201 – 377)	5% decrease
				After Floods	253 ± 51 (170 - 418)	
Zn (µg/g)	70	10 - 602	Topsoil	After Floods	99.1 ± 41.5 (34 – 250)	11 % decrease
				After Floods	88.4 ± 23.4 (49.1 – 150)	
			Subsoil	Before Floods	103 ± 47 (40.3 – 298)	15 % decrease
				After Floods	87.5 ± 24.6 (42.5 - 129)	

Table 4.4: Results of Average Elemental Concentration in Budalangi Soils Samples Before and After the Floods



***TBF = Topsoil before floods; TAF = Topsoil after floods**

Figure 4. 3: Box Plots of elemental concentration in Topsoil before and after floods



***SBF = Subsoil before floods, SAF = Subsoil after floods**

Figure 4. 4: Box plots of elemental concentration in subsoil before and after floods

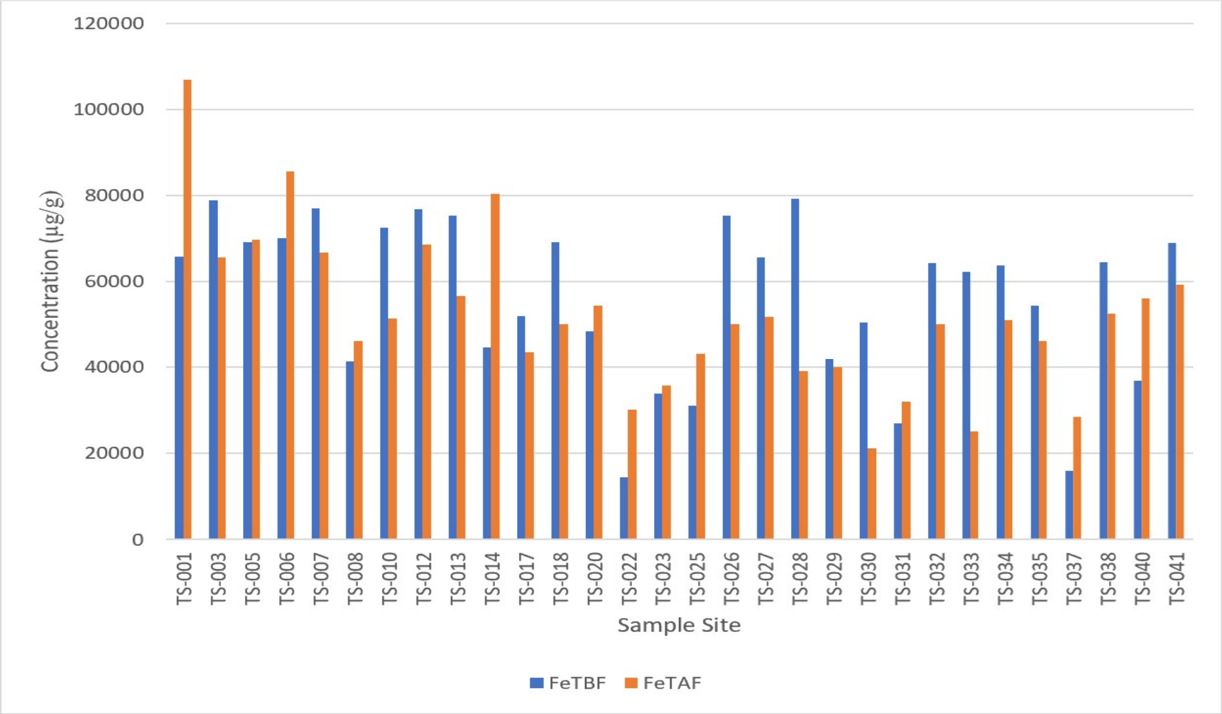


Figure 4. 5: Distribution of Fe concentration levels (Topsoil)

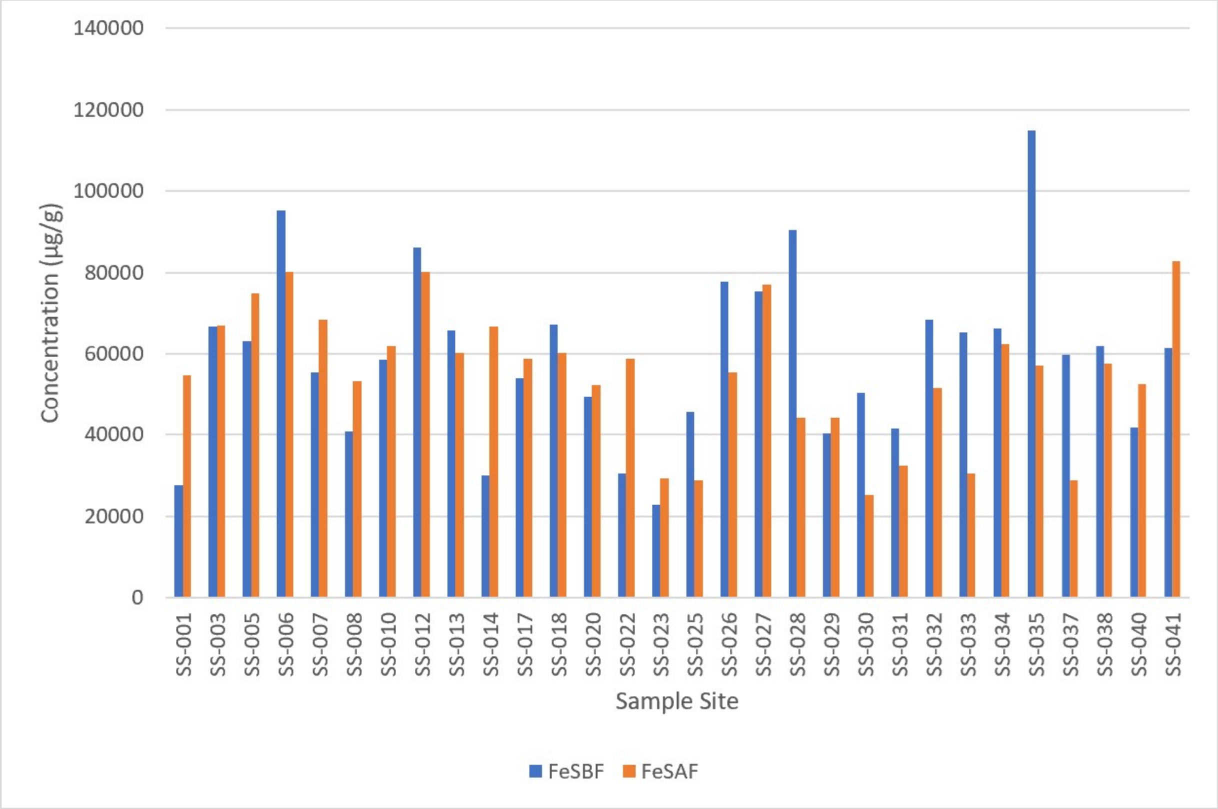


Figure 4. 6: Distribution of Fe concentration levels (Subsoil)

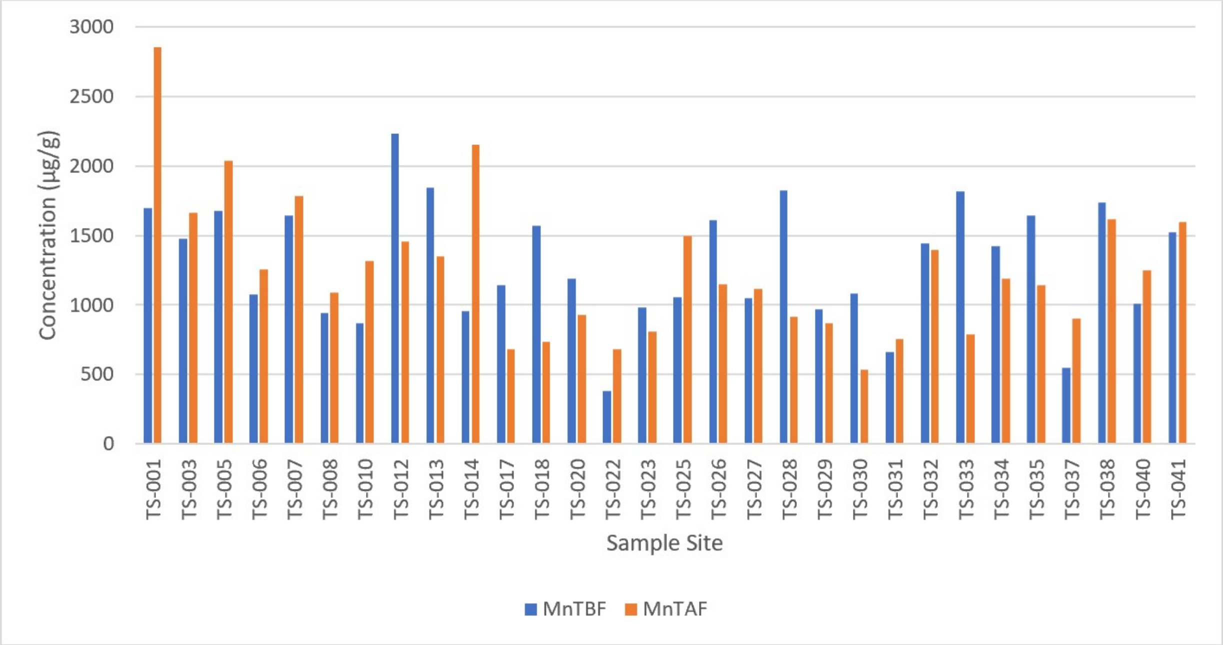


Figure 4. 7: Distribution of Mn concentration levels (Topsoil)

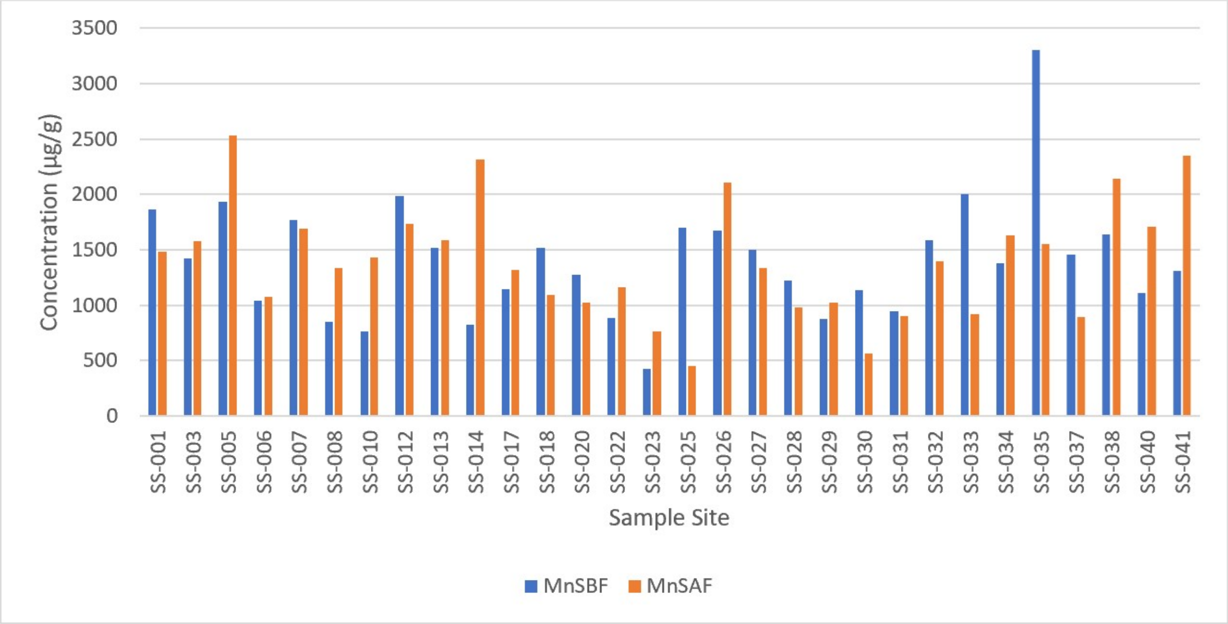


Figure 4. 8: Distribution of Mn concentration levels (Subsoil)

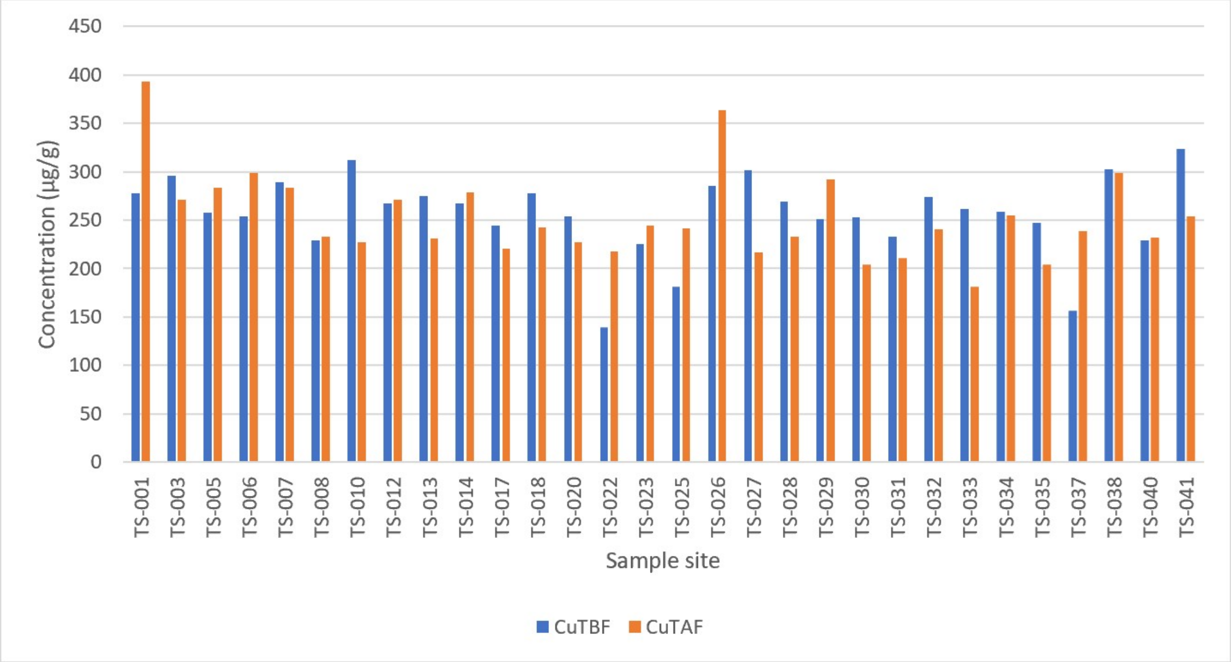


Figure 4. 9: Distribution of Cu concentration levels (Topsoil)

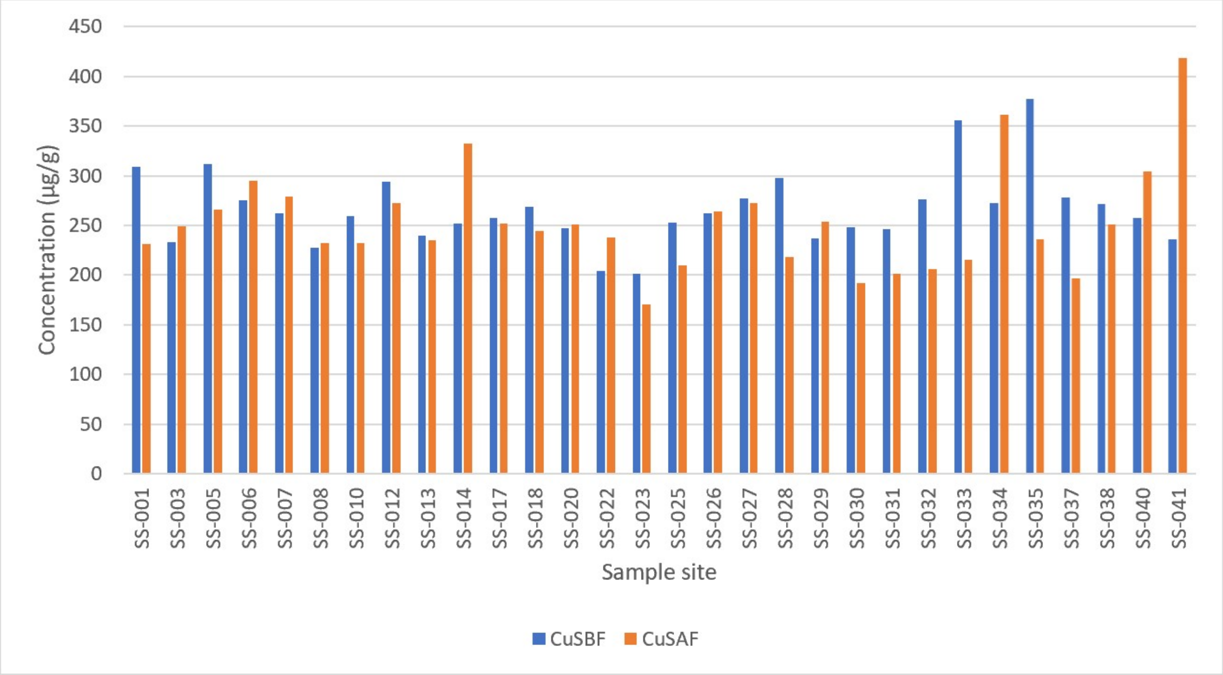


Figure 4. 10: Distribution of Cu concentration levels (Subsoil)

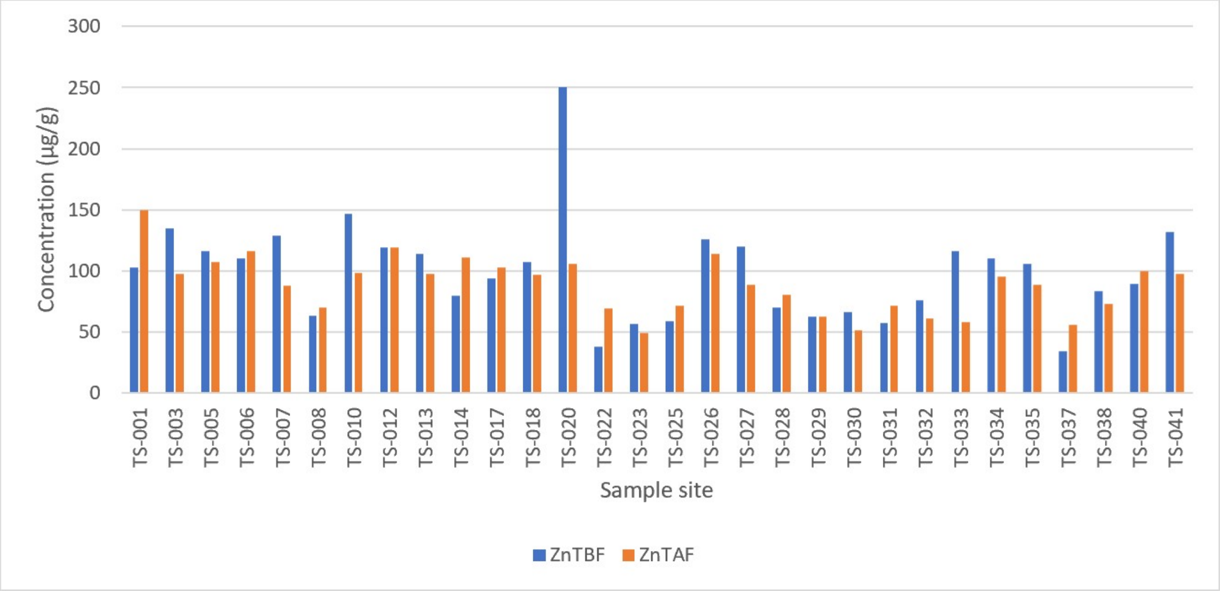


Figure 4. 11: Distribution of Zn concentration levels (Topsoil)

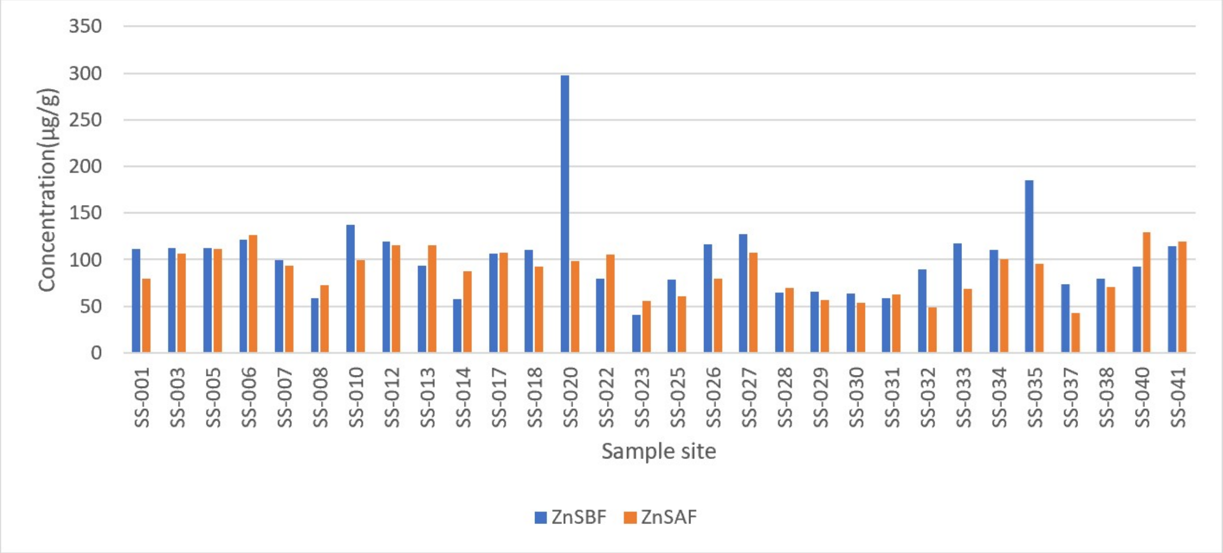


Figure 4. 12: Distribution of Zn concentration levels (Subsoil)

The iron (Fe) levels documented in this study were found to be higher compared to the findings reported by Maina et al. (2016) in Maumba Central, ranging from 0.89% to 3.1% with a mean value of 1.8%. In this study, Fe is highly correlated with Mn, Cu and Zn concentrations, and weakly with the pH in all the soil strata before and after floods (Table 4.6, 4.7, 4.8 and 4.9). Maina *et al*. 2016, also found Fe to strongly correlate with Mn and Zn.

For the top soils, it was observed that, there is a strong positive correlation relationship between Fe/Mn and Fe/Cu at 0.8 and 0.9, before floods. A strong positive correlation relationship between Fe/Mn, Fe/Cu, Fe/Zn, Mn/Cu and Mn/Zn at 0.9, 0.7, 0.9, 0.7 and 0.6 respectively after the floods (Table 4.6 - Table 4.7).

While for the subsoils, there was a strong positive correlation relationship between Fe/Mn, Fe/Cu, and Mn/Cu at 0.6, 0.6 and 0.8 respectively before the floods. And a strong positive correlation relationship between Fe/Mn, Fe/Cu, Fe/Zn, Mn/Cu and Cu/Zn at 0.7, 0.7, 0.8, 0.7 and 0.6, respectively after the floods (Table 4.8- Table 4.9).

From the study, it was evident that Fe had strong correlation with Cu and Mn, while Mn had a high positive correlation with Cu and Zn.

The results of Mn concentration for the top soils indicate that the average elemental concentration between the two sampling periods decreased from 1303 µg/g to 1251 µg/g which translates to a 4% total decrease. While average concentration for sub soils (10cm to 50cm depth) increased from 1401 µg/g to 1402 µg/g which translates to a 0.07% increase in elemental concentration. Mn concentrations of approximately 50% of topsoils samples, and 43 % of subsoils samples decreased after the floods. However, there was no significant variation in the average Mn concentration of the topsoils and subsoils after the floods ($p>0.05$). In a study on elemental content in soils in Miembeni, Kenya, Maina et al. 2016 determined Mn concentrations to average 1100 ± 600 (range 600– 2500). The results obtained by Maina et al, 2016 are consistent with those obtained in this study. Mn was found to be highly correlated with Fe, Cu and Zn concentrations in this study, in all the sampling periods (Table 4.6 - 4.8).

The average elemental concentration of Cu for the topsoils between the two sampling periods decreased from 256 µg/g to 253 µg/g, which translated to a 1% total decrease. While the average concentration for sub soils decreased by 5% from 266 µg/g to 253 µg/g. Approximately 57% of topsoils and 60 % of subsoils samples had decreased Cu levels after the floods. However, there was no significant difference in the Cu concentration levels reductions of the top's soils and subsoils after the floods ($p>0.05$). Cu is found at a range of 5.00 to 140.00 mg kg^{-1} in uncontaminated soils, and is reliant on the soil's parent material (Kabata-Pendias and Pendias, 2011). However, the results obtained in this study are higher than those reported by Kabat-Pendia and Pendias2011, and those reported by Wanjala,2020 in a study done out to assess heavy metal pollutants in soils in Ortum, Kenya. The Cu concentration reported by Wanjala et al., 2020 were average 46.91 ± 5.04 µg/g (range 38.3– 57.4). An interelement correlation analysis shows that Cu was highly correlated with Fe and Mn concentrations and moderately with Zn concentrations (Table 4.6 -Table 4.9).

The Zn results for the topsoils samples (60%) between the two sampling periods decreased from 99.1 µg/g to 88.4 µg/g representing 11% decrease. The Zn levels in the subsoils samples (63%) decreased from 103 µg/g to 87.5 µg/g, representing about 15% decrease in elemental concentration after the floods. However, there was no significant difference in the average Zn concentrations of the soil's strata after the floods ($p>0.05$).

Zinc is an essential element for both plants and humans, but excessive amounts can be toxic. The global range of zinc (Zn) concentrations in uncontaminated soils is typically below 0.01% according to the research conducted by Kabata-Pandias and Pandias (2011). The observed Zn values in this study fall within this range, ranging from 0.005% to 0.015%.

The results obtained in this study are comparable to those that were reported by Wanjala 2020, in a study done to assess heavy metal pollutants in soils in the Ortum, Kenya. The Zn concentration levels reported by Wanjala, 2020 were averaged 73.5 ± 14.2 µg/g (range 37– 89). A correlation matrix analysis with other elements show that Zn is highly correlated with Fe and Mn concentrations and moderately with Cu in soils (Table 4.6 -Table 4.9).

In summary, all four elements; Fe, Mn, Cu and Zn in the subsoil strata exhibited higher concentration levels of trace elements both before and after the floods. The mobility of these elements in the agricultural environment is influenced by natural soil and biotic factors, which are further modified by human activities. Flood events, in particular, have a significant impact on the quantity, distribution, and movement of trace elements in the environment, as evidenced by the findings of this study.

Weathering processes involves both the release and removal of nutrients from soils. While nutrients may be released through weathering, the source of trace elements in soils is primarily of geogenic origin. As depth increases, the concentrations of elements originating from geogenic sources also tend to increase (Borůvka et al., 2005). In an effort to mitigate the impact of floods in the region, the GoK has constructed Dykes to regulate the water flow. Dykes also play an important role in preventing effects associated with floods; soil erosion, crop destruction, infrastructural damage, loss of lives and livestock, contamination of water sources, water borne diseases.

4.4 Essential Trace Element Analysis in Selected Vegetables

Fig 4.13 – Fig 4.16 shows the distribution of essential trace elements in the sampled vegetable samples before and after the floods.

Table 4.11 shows the results of Essential Trace Elements in selected various vegetable species samples Before and after the Floods.

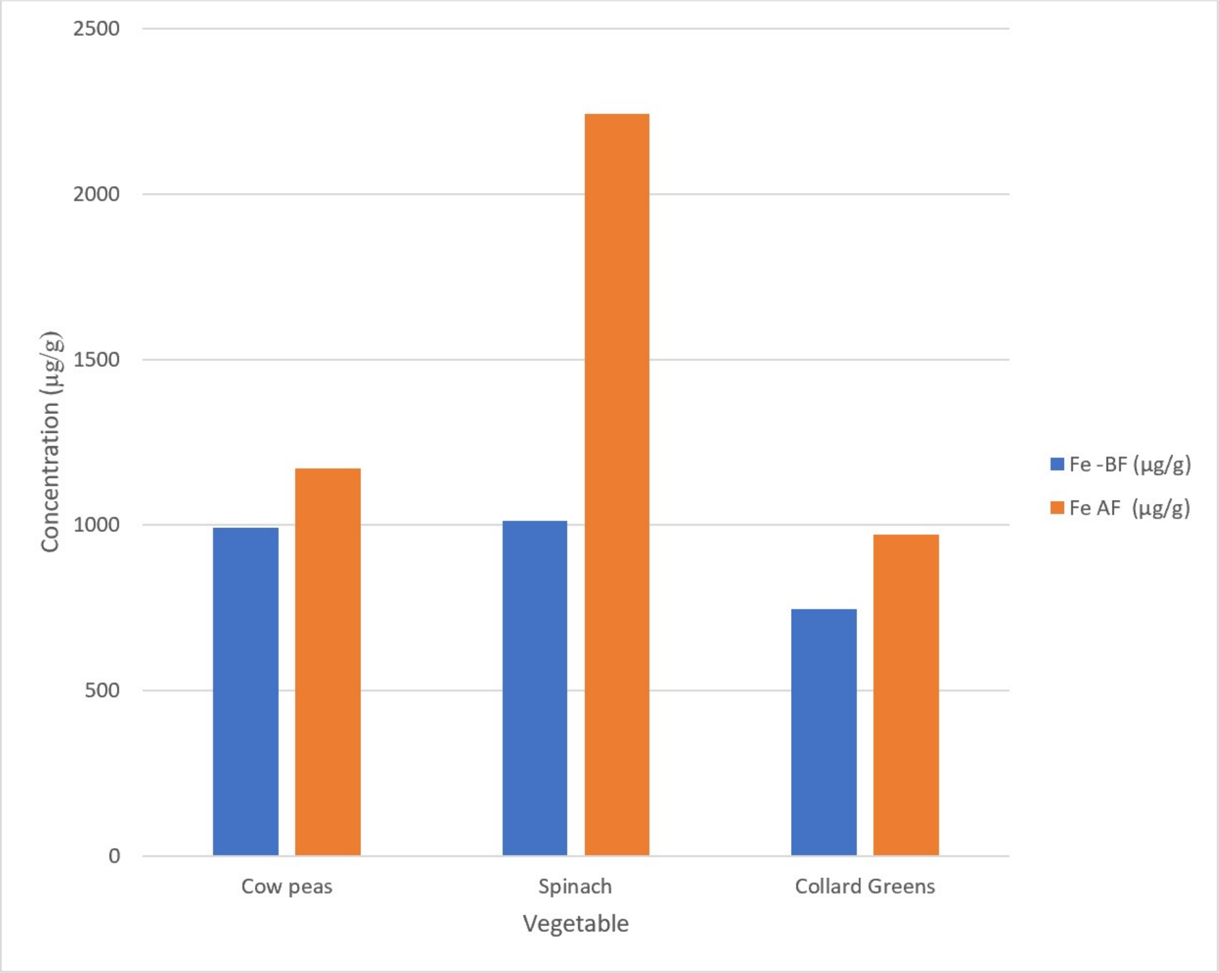


Figure 4. 13: Fe concentration in Vegetables

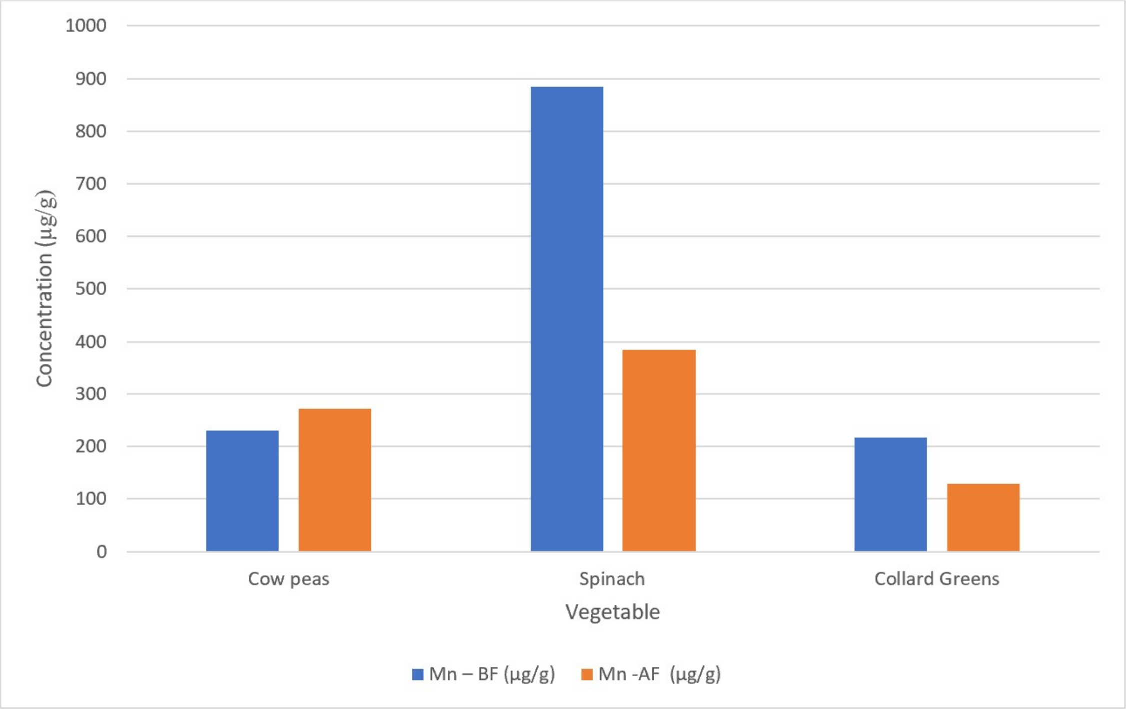


Figure 4. 14: Mn concentration in Vegetables

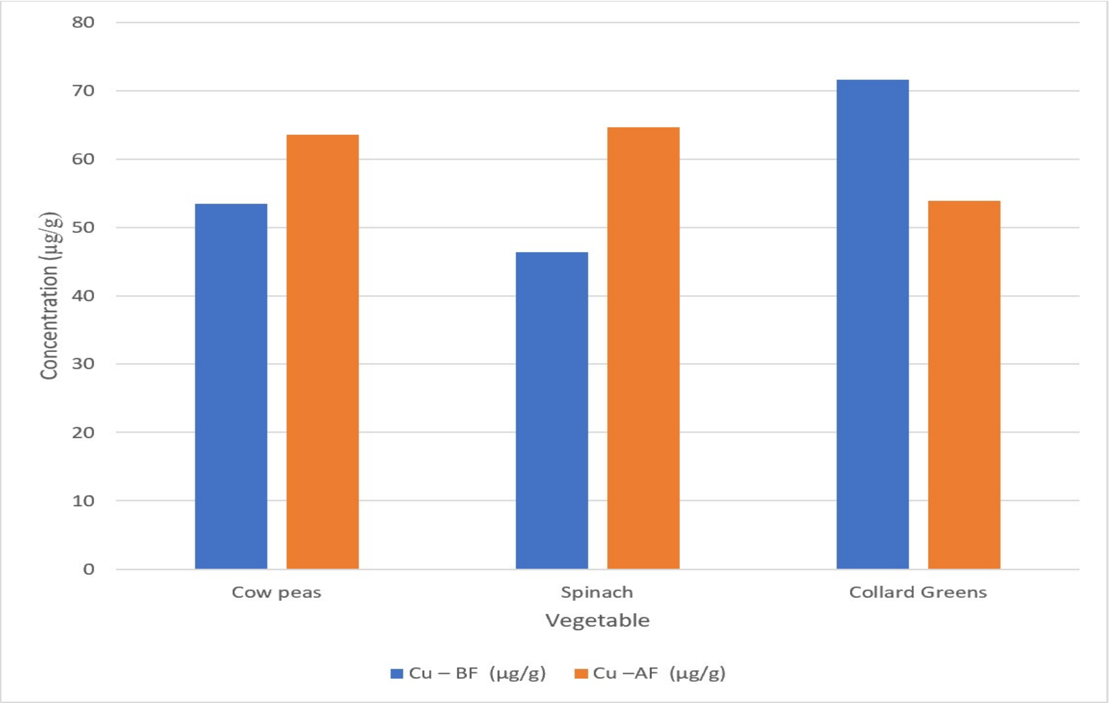


Figure 4. 15: Cu concentration in Vegetables

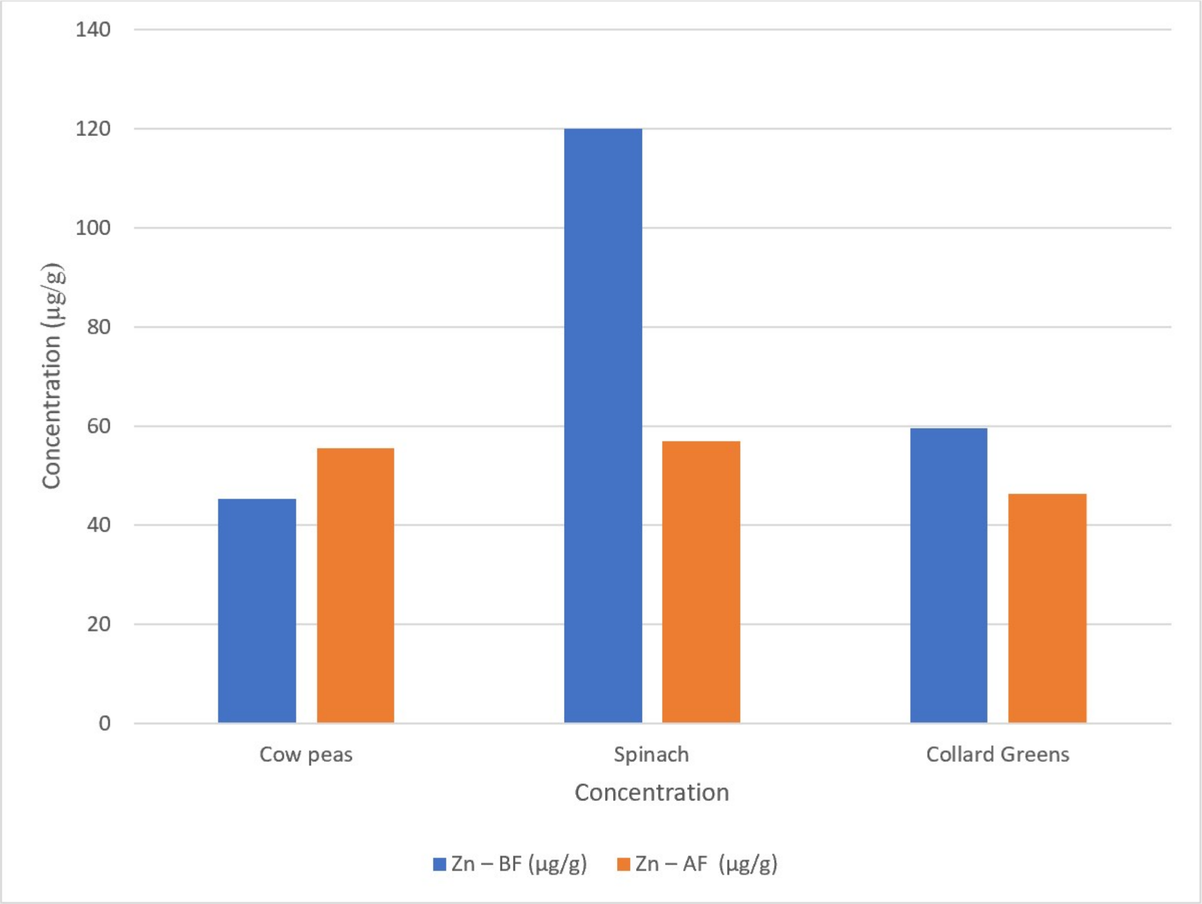


Figure 4. 16: Zn concentration in Vegetables

Table 4.11: Results of Essential Trace Elements in Selected Various Vegetable Species Samples Before and After the Floods

Trace element	**Classification (µg/g)**			**Plant Species**	**Sampling period**	**Mean concentration (µg/g)**	**Change in elemental concentration after floods (%)**
	Deficient	**Sufficient or Normal**	**Excessive or Toxic**				
Fe	-	640 -2486	-	Cow peas	Before Floods	992± 233 (808 – 1254)	18 % increase
					After Floods	1170± 284 (848 – 1385)	
				Spinach	Before Floods	1011 ± 0 (1011)	122 % increase
					After Floods	2243 ± 0 (2243)	
				Collard greens	Before Floods	744 ± 154 (755 – 873)	31 % increase
					After Floods	971 ± 138 (883 – 1112)	
Mn	10-30	30-300	400-1000	Cow peas	Before Floods	229± 107 (132 – 345)	18 % increase
					After Floods	271± 186 (160– 487)	
				Spinach	Before Floods	885± 0 (885)	57 % decrease
					After Floods	384± 0 (384)	
				Collard greens	Before Floods	217± 118 (135 – 321)	41 % decrease
					After Floods	129± 16 (118 – 153)	
Cu	2-5	5-45	45-100	Cow peas	Before Floods	53± 14 (41 – 69)	19 % increase
					After Floods	64± 17 (51 – 84)	
				Spinach	Before Floods	47± 0 (47)	39 % increase
					After Floods	65± 0 (47)	
				Collard greens	Before Floods	72± 13 (57 – 73)	25 % decrease
					After Floods	54± 9 (43 – 54)	
Zn	10-20	27-150	100-400	Cow peas	Before Floods	45± 6 (40 – 53)	23 % increase
					After Floods	56± 5 (49 – 60)	
				Spinach	Before Floods	120± 0 (120)	53 % decrease
					After Floods	57± 0 (57)	

				Collard greens	Before Floods	60± 31 (55 – 118)	22 % decrease
					After Floods	46 ± 11 (33 – 56)	

NB: Classification Adopted fromKabata-Pendias and Pendias, 2001 and (Hajar et al., 2014)

The essential trace elements Fe, Mn, Cu and Zn are variously distributed in the vegetable species analysed in this study (Fig 4.13- 4.16). The relative abundance of Essential Trace Elements in all the vegetable species samples was in the decreasing order Fe>Mn > Cu > Zn. The results show a wide variability in the distribution of the Fe, Mn, Cu, Zn in each of the vegetable species samples. In this study, the results of concentration values for all the elements of interest, in vegetables samples are within the global thresholds for human consumption, during the 2 sampling periods except for Cu, which exceeds (Table 4.10) Copper toxicity in plants can result in various symptoms, including chlorosis, necrosis, stunted growth, leaf discoloration, and inhibited root growth (Marschner, 2011; Mir et al., 2021). The iron levels increased between 13 - 122% in all the vegetable species, the highest increase was in spinach samples over the sampling period. All the other elements either increased or decreased variously dependent on the vegetable species types. Cow peas had increased levels for; Fe (18%); Mn (18%); Cu (19%) and Zn (19%) after the floods. Collard greens had decreased levels (25-53%) for all essential trace elements except for iron, which instead increased by 31% (Table 4.10).

In this study, a notable disparity was observed in the concentrations of Fe between the two sampling periods ($p < 0.05$). The increase of the iron could be attributed to the effects of flooding leading to enrichment of the soil as Fe may be sustainability susceptible to mobilization during runoff, taking into account other geological factors that influence the uptake of elements by plants, indigenous vegetables cultivated in Budalangi are generally regarded as a valuable source of iron (Fe), contributing to their nutritional significance.

The Mn concentration decreased by 41%-57% between the two sampling periods for Collard greens and Spinach vegetables. However, Cow peas had increased Mn levels by 18% after the floods.

In flooding conditions, plants may experience manganese (Mn) toxicity, and it has been suggested that on acidic soils, Mn toxicity becomes the primary factor limiting plant growth. In well-aerated calcareous soils, which are prone to induce Mn deficiency in crops, Mn availability for plant uptake is limited. Insufficient Mn supply, given its essential role in the water-splitting complex, results in reduced oxygen evolution and subsequently lower rates of photosynthesis and impaired plant growth (Andresen et al., 2018).

The results of Cu concentrations increased by 19% - 39 % between the two sampling periods for cowpeas and spinach vegetables after the floods, but decreased by 25% in collard greens. In general, Cu concentration in the vegetables sampled, exceeded of the global levels but are not in the toxic range. Cu deficiency have detrimental effects on overall plant metabolism, resulting in reduced photosynthetic performance and energy production. These consequences manifest as visible symptoms, including chlorosis of young leaves, stunted growth, decreased biomass, and eventual plant death (Marschner, 2011).

The decreased concentrations of copper (Cu) in plants can be attributed to the precipitation of sulfides caused by flood inundation, leading to the formation of insoluble metal sulfides (Kusonwiriyawong et al., 2017). These metal sulfides are highly stable under reduced conditions but become more soluble upon aeration.

The Zn concentration levels were all within normal levels expected in plants, however they decreased by 22% and 53% in spinach in collard greens vegetables, but increased by 23 % in cowpeas after the floods. When the plant-metal content exceeds 400 mg kg-1, plants exhibit symptoms of zinc toxicity. These symptoms are observed in plants grown on acid peat, mine tailings, and soils amended with sewage sludge (Kabata-Pendias & Pendias, 2001). Conversely, many alkaline soils have low zinc concentrations, resulting in zinc deficiency as the most prevalent micronutrient deficiency in crop plants (Alloway, 2009b).

In summary, the availability and accumulation of trace elements are influenced by multiple factors, including the type of vegetable and the characteristics of the soil, agronomic practices, and climatic conditions (Zahir et al., 2011). As shown in Table 4.10, the availability of trace elements in vegetables varies significantly among different plant species and tissues (Nworie et al., 2019). Additionally, precipitation and atmospheric dust can contribute to the presence of these trace elements in vegetables as they can be absorbed through the leaf surfaces. Therefore, it is crucial to maintain ongoing monitoring of trace element levels in the environment, given their significance in human and animal health nutrition.

4.5. Water Quality Analysis: Toxic heavy metal Pollutants

Fig 4.17 – Fig 4.19 shows the toxic trace elements' distribution in the water sources that was conducted before and after the floods occurred. Table 4.12 show the results of water contaminations analyses samples from water sources; five (5) boreholes, two (2) ponds, one (1) well, one (1) river and one (1) Lake Victoria, analysed for elemental concentration of Hg, Pb, Cr, Ni and As before and after the floods. Overall, the toxic heavy metal abundance in the water samples followed the order of Cr > Ni > As > Hg > Pb. These findings revealed significant variations in the elemental composition among water samples from various sources. Notably, the total concentrations of all five elements investigated remained below the permissible limits for inorganic contaminants in both drinking water and bottled drinking water according to limits by the KS EAS 12: 2014 and WHO 2011 Guidelines for drinking Water Quality. Hg and Pb levels were all below the instrumental detection limits.

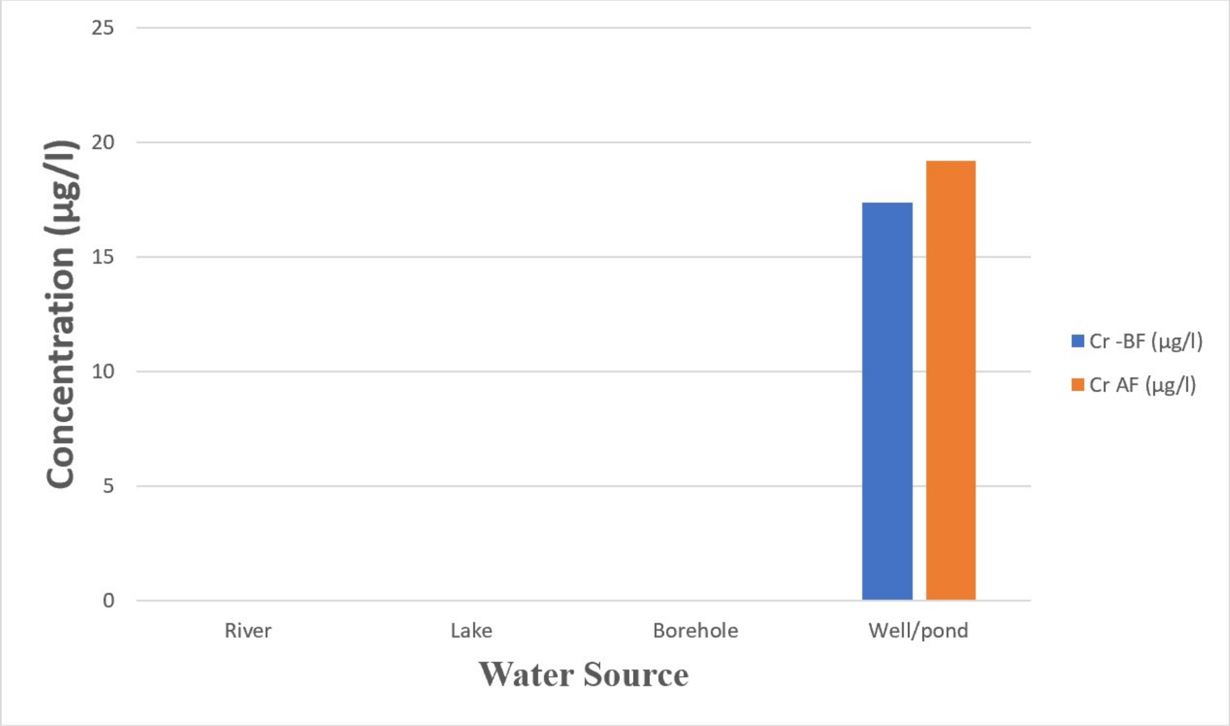


Figure 4. 17: Cr concentration in water sources

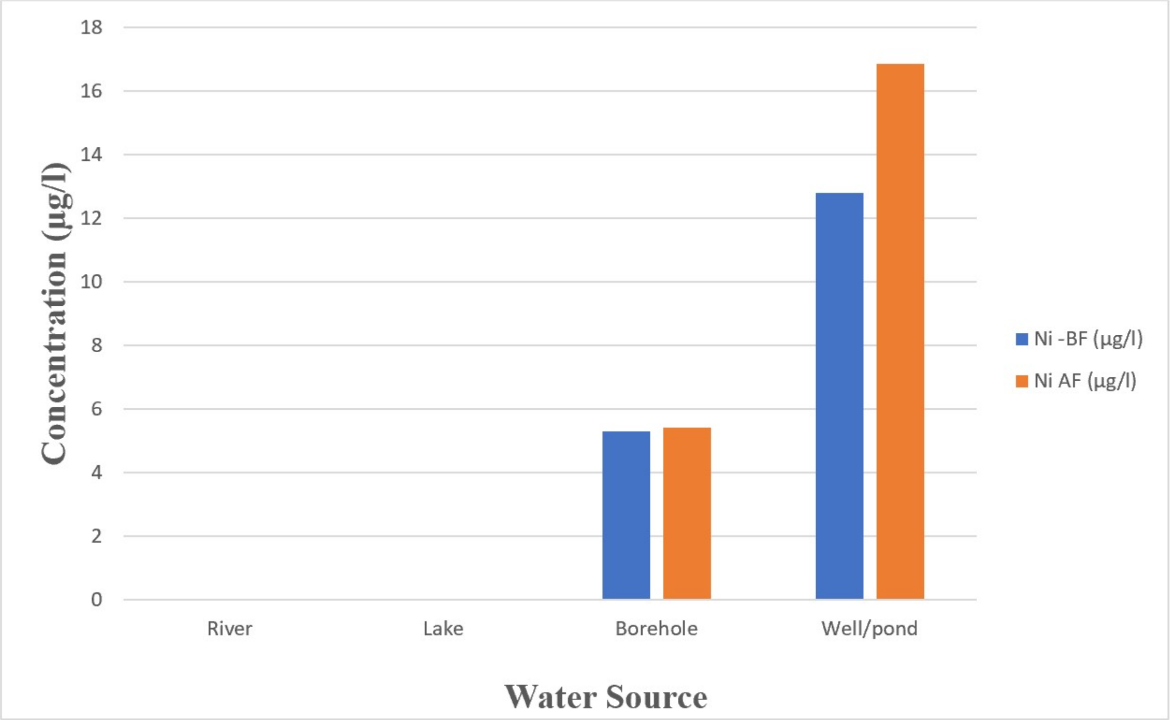


Figure 4. 18: Ni concentration in water sources

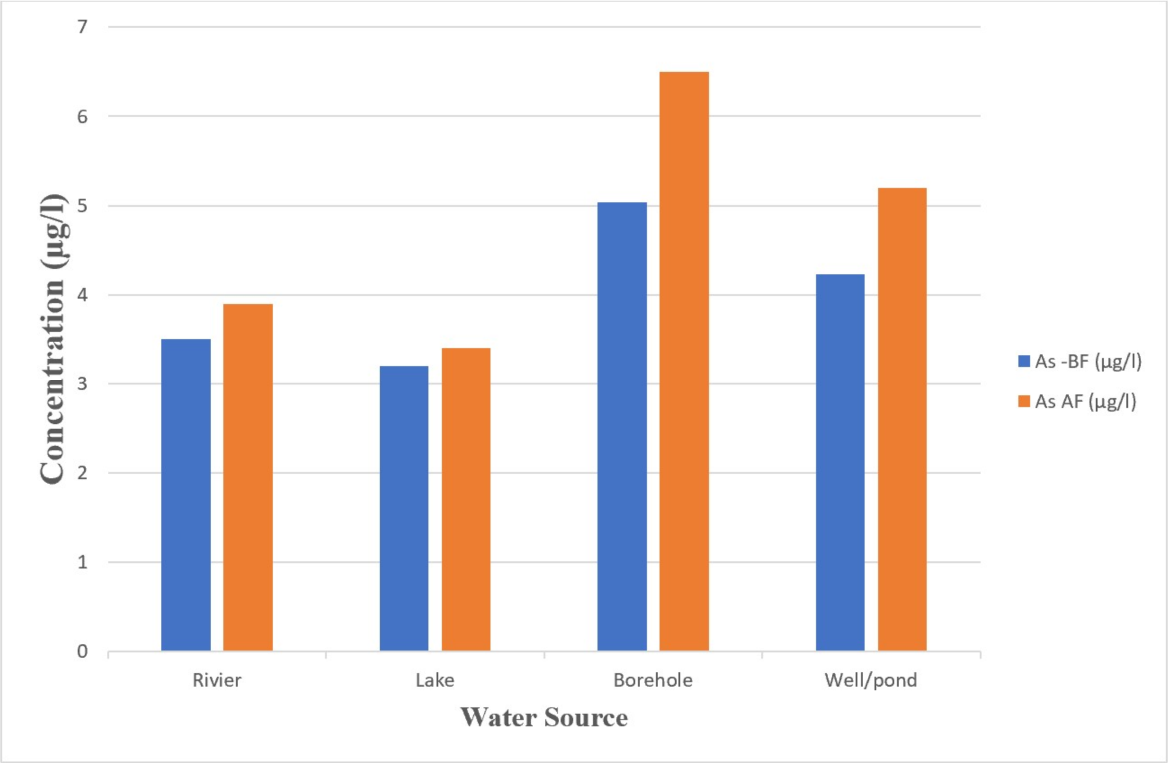


Figure 4. 19: As concentration in water sources

The results indicate that the average Cr concentration increased from 17.4 µg/l) to 19.2 (µg/l), in well/pond waters after the floods, which translates to a 10% increase. Chromium is an element that can occur in both trivalent and hexavalent states, more so in drinking water where the recommended limit is 0.05 ppm (Dkhar et al., 2014). In regulated amounts, Cr can act as an essential micronutrient with a role in regulating the blood sugar levels in the human body. However, in excess amounts, it can result in massive destructions of the DNA, which can lead to gene mutations. In addition, the respiratory system can be greatly damaged by the high concentrations of Cr, resulting in the development of nasal cavity cancers and detrimental effects on the livers and kidneys (Fashola et al., 2016).

The concentration of Pb in all water sources is less than the WHO 2011 and KS EAS 12: 2014 provisional guidelines of 10 µg/l, hence poses no ill health effects to human beings. Pb affects human body organs functions such as the kidney and liver. Some of its related ailments include long-lasting damage to the nervous system, brain damage, kidney dysfunctions, disorders in the cardiovascular and reproductive systems, loss of hearing, high blood pressure and gastro-intestinal ailments amongst others (Fashola et al., 2016; Herschy, 2012). Pb effects were also observed in studies done by Dkhar et al., 2014, where other ailments such as damage to the peripheral, hematopoietic and central nervous system were associated to lead (Pb) poisoning.

Table 4.12: Results for inorganic contaminants in drinking water Before and After the Floods

Trace Element	WHO Limits (µg/l)	Kenya Standards – KS- Limits (µg/l)	Source of water	Average Concentration values in this study (µg/l)		% Change	Comments
				Before Floods	After Floods		
Cr	**50**	**50**	River Nzoia	<15	< 15	-	Good, unpolluted
			Lake Victoria	< 15	< 15	-	
			Boreholes	< 15	< 15	-	
			Well/pond	17.4	19.2	10% increase	
Ni	**70**	**20**	River Nzoia	<5	< 5	-	Good, unpolluted
			Lake Victoria	< 5	< 5	-	
			Boreholes	5.3	5.4	2 % increase	
			Well/pond	12.8	16.85	32 % increase	
As	**10**	**10**	River Nzoia	3.5	3.9	11 % Increase	Good, unpolluted
			Lake Victoria	3.2	3.4	6% Increase	
			Boreholes	5.0	6.5	29% Increase	

			Well/pond	4.2	5.2	23% Increase	
Hg	**6**	**1**	River Nzoia	<4	<4	-	Good, unpolluted
			Lake Victoria	<4	<4	-	
			Boreholes	<4	<4	-	
			Well/pond	<4	<4	-	
Pb	**10**	**10**	River Nzoia	<5	<5	-	Good, unpolluted
			Lake Victoria	<5	<5	-	
			Boreholes	<5	<5	-	
			Well/pond	<5	<5	-	

(Source: Adopted from KS EAS 12: 2014 and WHO 2011 Guidelines for drinking Water quality)

The results of As concentration increased between 6%- 29% in all water sources after the floods. However, below the WHO 2011 and KS EAS 12: 2014 provisional guidelines of 10 µg/l. Arsenic occurs as a sulphide, chloride, or oxide, depending on the geological factors. This metal has the ability to cause serious ailments even in small amounts (Farrow, 2015). Its presence in the human system is associated with development of cancers, destruction of the nervous system; it can also lead to various cases of diabetes, damage to a gastro-intestinal tract, more so when taken for an extensive period of time (WHO, 2011).

The results of Hg concentration were all below the detection limit of 4 µg/l in all the water sources during the sampling periods. Mercury is not useful in the human body, and its presence in the human system can lead to grave health effects such as stunted growth in children. It also destroys the central nervous system resulting in the loss of memory and depending on exposure level can lead to instant death on the exposed persons. (Fashola et al., 2016).

The results of Ni concentration were indicative in only two water sources; boreholes and wells/pond increase by 2% - 32 % after the floods, all below the WHO, 2011 and KS EAS 12: 2014 provision guidelines of 70 µg/l and 20(µg/l, respectively. Nickel is regarded as a temperately toxic heavy metal. It can play crucial roles in the human body when taken in regulated amounts. It is known to prevent anaemia due to its ability to increase the intake of iron into the human body. It also plays a central function in helping the body in absorbing Ca, which inhibits the development of osteoporosis (WHO, 2011). However, excess intake of Ni can lead to shortness of breath, headaches and the development of nasal and lung cancers.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

In summary, this study has demonstrated that flooding in the region altered the pH of soil by approximately 10% decrease. In both sampling periods and soil depths, the recorded pH values are considered acidic. However, these values are within the world range for plant nutrition, pH 6 to 7. The average pH of topsoil was 6.28 and 6.22 for subsoils.

This study has also shown that the elemental concentration of all four elements of interest; Fe, Mn, Cu, Zn in the soil is within the global ranges for agricultural use (Table 4.4). The levels of most elements decreased between 1-15 %, for Fe (7%); Mn (4%); Cu (1-5%); Zn (11-15%) in all the soil strata sampled before and after the floods.

This study has also shown that there is a vertical downward increase in the soil elemental concentration for Fe (5-6%), Mn (8-12%), Cu (4%), and Zn (4%) in all the soil strata sampled before and after the floods.

For the vegetable samples collected, the concentration levels for Fe, Mn and Zn were found to fall within the recommended values for the global threshold for human consumption, while the concentration for Cu was higher than the recommended global threshold. The results revealed normal global elemental concentrations of iron (Fe), manganese (Mn), and zinc (Zn) in spinach, collard greens, and cowpeas. In spinach, Fe levels exhibited a substantial increase of 122%, ranging from 1011µg/g to 2243 µg/g. However, Mn levels in spinach showed a decrease of 57%, ranging from 885 to 384, while Zn levels decreased by 53%, ranging from 120 µg/g to 57 µg/g. Collard greens displayed a 31% increase in Fe levels, ranging from 744 µg/g to 971 µg/g, but experienced a decrease of 41% in Mn levels, ranging from 217 µg/g to 129 µg/g, and a 22% decrease in Zn levels, ranging from 60 µg/g to 46 µg/g. For cowpeas, Fe levels increased by 18%, ranging from 992 µg/g to 1170 µg/g, and Mn levels also increased by 18%, ranging from -229 µg/g to 271 µg/g. However, Zn levels decreased by 22%, ranging from 45 µg/g to 56 µg/g. In this study, Spinach is considered as a good source of Fe while cow peas and collard greens were considered a good source of Manganese. All three sampled vegetables are considered to be a good source of Zn. The implications of high levels of elemental concentration in vegetables include potential toxicity, which can lead to nutrient imbalances, reduced plant growth, and negative effects on human health; while low concentration levels can result in decreased plant growth, poor crop yields, and compromised human nutrition.

The total concentrations of all five elements investigated were below limits for inorganic contaminants in drinking water according to limits by the KS EAS 12: 2014 and WHO 2011 Guidelines for drinking Water Quality. Hg and Pb levels were all below the instrumental detection limits (Table 4.12).

5.2 Recommendations

1) Additional essential trace elements and other physiochemical parameters, should be considered in future studies to provide a comprehensive data analysis on elements profile of soils and vegetables.
2) To establish the effect of seasonal variability on trace element uptake in indigenous vegetables and bioavailability in the soils.
3) It is recommended to employ advanced spatial distribution software to visually represent the data collection on a map. Spatial distribution of the elements will add depth to the interpretation of data.
4) A long-term monitoring program be established to capture the dynamic changes in trace element concentrations over multiple flood cycles. This would provide a more comprehensive understanding of the cumulative impacts on soil health and crop quality.
5) The scope of research to be extended to include an assessment of the potential impact of trace element variations in vegetables on human health. To analyze dietary habits and nutritional intake to evaluate the risk of hidden hunger and micronutrient deficiencies in the local population.
6) The pH of water and other physical, chemical and biological evaluation parameters of water quality be extended to future water samples.

These findings emphasize the importance of systematic monitoring of the ecosystem for sustainable development and optimal resources utilization. This information will assist the locals and the Ministry of Agriculture officials to effectively advice the farmers on the management of their farms.

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APPENDICES

Appendix: Table 4. 1: soil pH measurements

No.	Soil Sample Code	Topsoil		Subsoil	
		before floods (pH	after floods (pH)	before floods (pH)	after floods (pH)
1	S-001	6.85	5.98	6.52	5.91
2	S-003	6.41	5.76	6.27	5.75
3	S-005	5.40	5.56	6.14	5.91
4	S-006	5.28	4.93	5.08	4.48
5	S-007	5.76	5.4	6.52	5.25
6	S-008	7.08	5.86	6.44	5.38
7	S-010	5.57	5.72	5.72	5.41
8	S-012	6.67	5.85	6.46	5.74
9	S-013	6.67	5.89	6.18	5.72
10	S-014	6.08	6.70	6.10	6.4
11	S-017	6.55	5.85	6.60	5.92
12	S-018	5.87	5.6	6.05	6.64
13	S-020	7.07	5.62	7.46	5.44
14	S-022	8.28	8.8	9.04	8.6
15	S-023	6.11	5.44	5.59	5.35
16	S-025	7.13	6.85	6.74	6.52
17	S-026	6.44	6.34	6.18	6.38
18	S-027	6.96	6.54	6.69	6.68
19	S-028	6.7	5.86	5.81	5.78
20	S-029	6.08	5.56	6.43	5.38
21	S-030	5.88	6.23	6.33	6.28
22	S-031	6.79	6.19	7.07	6.29
23	S-032	7.77	5.84	6.88	5.68
24	S-033	6.13	5.72	6.27	5.8
25	S-034	6.79	6.07	5.86	5.83
26	S-035	6.8	5.46	6.36	5.44
27	S-037	6.22	6.64	6.58	6.15
28	S-038	6.05	6.28	6.25	6.32
29	S-040	7.26	6.71	7.51	6.18
30	S-041	6.78	6.05	6.67	6.37
Average		**6.51**	**6.04**	**6.46**	**6.00**
Min		**5.28**	**4.93**	**5.08**	**4.48**
Max		**8.28**	**8.8**	**9.04**	**8.6**
Std Dev		**0.67**	**0.69**	**0.70**	**0.71**

Appendix: Table 4. 2: Z-Test results for Top soils, Before and after flooding

z-Test: Two Sample for Means		
	Top Soil pH Before floods	Top Soil pH After floods
Mean	6.514333333	6.043333333
Known Variance	0.4489	0.4761
Observations	30	30
Hypothesized Mean Difference	0	
z	2.682320496	
P(Z<=z) one-tail	0.003655669	
z Critical one-tail	1.644853627	
P(Z<=z) two-tail	0.007311338	
z Critical two-tail	1.959963985	

Appendix: Table 4. 3: Z-Test results for Sub soils, Before and after flooding

z-Test: Two Sample for Means		
	Sub Soil pH Before floods	Sub Soil pH After floods
Mean	6.46	5.966
Known Variance	0.49	0.49
Observations	30	30
Hypothesized Mean Difference	0	
z	2.73322	
P(Z<=z) one-tail	0.003136	
z Critical one-tail	1.644854	
P(Z<=z) two-tail	0.006272	
z Critical two-tail	1.959964	

Appendix: Table 4. 5: Elemental analysis results for Topsoil soils

Sample Code	**Fe (%)**			**Mn**			**Cu**			**Zn**		
	Before Floods	**After Floods**	**Change**	**Before Floods**	**After Floods**	**Change**	**Before Floods**	**After Floods**	**Change**	**Before Floods**	**After Floods**	**Change**
TS-001	6.59	10.7	+ve	1701	2853	+ve	278	393	+ve	103	150	+ve
TS-003	7.9	6.57	-ve	1475	1662	+ve	296	271	-ve	135	97.3	-ve
TS-005	6.92	6.98	+ve	1675	2039	+ve	258	283	+ve	116	107	-ve
TS-006	7.02	8.56	+ve	1074	1255	+ve	254	299	+ve	110	116	-ve
TS-007	7.7	6.67	-ve	1642	1783	+ve	289	283	-ve	129	88.2	-ve
TS-008	4.14	4.63	+ve	940	1088	+ve	229	233	+ve	63.5	70.4	+ve
TS-010	7.26	5.14	-ve	870	1316	+ve	312	227	-ve	147	98.6	-ve
TS-012	7.69	6.86	-ve	2230	1458	-ve	267	271	+ve	119	119	-ve
TS-013	7.54	5.67	-ve	1845	1348	-ve	275	231	-ve	114	97.6	-ve
TS-014	4.47	8.04	+ve	958	2153	+ve	267	279	+ve	79.4	111	+ve
TS-017	5.2	4.37	-ve	1144	684	-ve	244	220	-ve	93.9	103	-ve
TS-018	6.93	5.01	-ve	1569	739	-ve	278	242	-ve	107	97.2	-ve
TS-020	4.84	5.45	+ve	1188	931	-ve	254	227	-ve	250	106	-ve
TS-022	1.45	3.01	+ve	383	684	+ve	139	218	+ve	38.2	69.1	+ve
TS-023	3.39	3.57	+ve	986	808	-ve	225	244	+ve	56.5	49.1	-ve
TS-025	3.11	4.33	+ve	1057	1495	+ve	181	241	+ve	59.2	71.3	+ve
TS-026	7.53	5.01	-ve	1611	1147	-ve	285	363	+ve	126	114	-ve
TS-027	6.56	5.19	-ve	1052	1115	+ve	301	217	-ve	120	88.7	-ve
TS-028	7.93	3.91	-ve	1823	917	-ve	269	233	+ve	70.4	80.8	+ve
TS-029	4.19	4.01	-ve	970	867	-ve	251	292	+ve	62.3	62.8	+ve
TS-030	5.06	2.11	-ve	1085	535	-ve	253	204	-ve	66.5	51.6	-ve
TS-031	2.69	3.21	+ve	661	759	+ve	233	211	-ve	57.3	71.2	+ve
TS-032	6.43	5.02	-ve	1445	1398	-ve	274	240	-ve	75.8	61.1	-ve

TS-033	6.23	2.52	-ve	1817	790	-ve	261	181	-ve	116	58.5	-ve
TS-034	6.38	5.11	-ve	1427	1188	-ve	259	255	-ve	110	95.3	-ve
TS-035	5.45	4.62	-ve	1642	1142	-ve	247	204	-ve	106	88.8	-ve
TS-037	1.6	2.84	+ve	547	901	+ve	157	239	+ve	34	56.2	+ve
TS-038	6.46	5.25	-ve	1738	1621	-ve	302	299	-ve	83.8	73.2	-ve
TS-040	3.68	5.61	+ve	1008	1249	+ve	229	232	+ve	89.7	99.8	+ve
TS-041	6.91	5.94	-ve	1526	1598	+ve	323	254	+ve	132	97.7	-ve
Average	5.64	5.20	-ve	1303	1250	-ve	256	253	-ve	99	88	-ve
Min	1.45	2.11		383	535		139	181		34	49	
Max	7.93	10.7		2230	2853		323	393		250	150	
Std Dev	1.90	1.85		436	507		41	45		41	23	

Appendix: Table 4. 6: Elemental analysis results for subsoil

Sample Code	Fe (%)			Mn			Cu			Zn		
	Before Floods	**After Floods**	**Change**	**Before Floods**	**After Floods**	**Change**	**Before Floods**	**After Floods**	**Change**	**Before Floods**	**After Floods**	**Change**
SS-001	2.75	5.48	+ve	1861	1486	-ve	309	231	-ve	111	79.3	-ve
SS-003	6.67	6.69	+ve	1424	1577	+ve	233	249	+ve	112	106	-ve
SS-005	6.32	7.48	+ve	1936	2532	+ve	312	266	-ve	112	111	-ve
SS-006	9.52	8.01	-ve	1039	1073	+ve	275	295	+ve	121	126	+ve
SS-007	5.55	6.84	+ve	1768	1694	-ve	262	279	+ve	99.8	93.5	-ve
SS-008	4.09	5.32	+ve	851	1331	+ve	227	232	+ve	58.6	72.7	-ve
SS-010	5.86	6.19	+ve	764	1429	+ve	259	232	-ve	137	99.1	-ve
SS-012	8.61	8.02	-ve	1982	1732	-ve	294	272	-ve	119	115	-ve
SS-013	6.58	6.01	-ve	1513	1590	+ve	240	235	-ve	93.2	115	-ve
SS-014	3.01	6.68	+ve	823	2313	+ve	252	332	+ve	58.1	87.3	+ve
SS-017	5.39	5.87	+ve	1140	1317	+ve	257	252	-ve	106	107	+ve

SS-018	6.72	6.01	-ve	1516	1095	-ve	269	244	-ve	110	92.3	-ve
SS-020	4.94	5.23	+ve	1276	1024	-ve	247	251	+ve	298	98.5	-ve
SS-022	3.06	5.87	+ve	887	1160	+ve	204	238	+ve	79.7	105	-ve
SS-023	2.29	2.92	+ve	425	764	+ve	201	170	-ve	40.3	55.9	-ve
SS-025	4.57	2.89	-ve	1700	448	-ve	253	210	-ve	78.9	60.2	-ve
SS-026	7.78	5.54	-ve	1675	2105	+ve	262	264	+ve	116	79.3	-ve
SS-027	7.54	7.71	+ve	1498	1331	-ve	277	272	-ve	127	107	-ve
SS-028	9.04	4.41	-ve	1218	979	-ve	298	218	-ve	64.2	69.5	+ve
SS-029	4.04	4.42	+ve	875	1024	+ve	237	254	+ve	65.9	56.5	-ve
SS-030	5.04	2.51	-ve	1131	565	-ve	248	192	-ve	63.6	53.3	-ve
SS-031	4.16	3.24	-ve	940	897	-ve	246	201	-ve	59.1	62.2	+ve
SS-032	6.84	5.17	-ve	1590	1392	-ve	276	206	-ve	89.8	49.1	-ve
SS-033	6.52	3.06	-ve	2001	919	-ve	356	215	-ve	117	68.1	-ve
SS-034	6.62	6.23	-ve	1376	1632	+ve	272	361	+ve	110	100	-ve
SS-035	11.5	5.72	-ve	3307	1550	-ve	377	236	-ve	185	95.8	-ve
SS-037	5.98	2.87	-ve	1460	890	-ve	278	197	-ve	73.7	42.5	-ve
SS-038	6.19	5.77	-ve	1641	2145	+ve	271	251	-ve	79.3	70.1	-ve
SS-040	4.18	5.26	+ve	1113	1710	+ve	257	304	-ve	92.4	129	+ve
SS-041	6.14	8.28	+ve	1312	2347	+ve	236	418	+ve	114	119	+ve
Average	5.92	5.52	-ve	1401	1401	-ve	266	253	-ve	103	87.5	-ve
Min	2.29	2.51		425	448		201	170		40.3	42.5	
Max	11.5	8.28		3307	2532		377	418		298	129	
Std Dev	2.10	1.64		539	525		38	51		47	24.6	

Appendix: Table 4. 7: Correlation Matrix of the Trace Element Concentrations For Topsoils Sampled Before The Floods

Variables	**Fe**	**Mn**	**Cu**	**Zn**	**pH**
Fe	1				
Mn	0.803596	1			
Cu	0.852661	0.603313	1		
Zn	0.551967	0.396694	0.56692	1	
pH	-0.37256	-0.18176	-0.37701	-0.14967	1

* Correlation coefficients of 0.2–0.4 for weak, 0.4–0.6 for moderate, and >0.6, for strong.

Appendix: Table 4. 8: Correlation Matrix Of The Trace Element Concentrations For Top Soils Sampled After The Floods

Variables	**Fe**	**Mn**	**Cu**	**Zn**	pH
Fe	1				
Mn	0.855267	1			
Cu	0.706321	0.67562	1		
Zn	0.850525	0.627578	0.594434	1	
pH	-0.27961	-0.10133	-0.13415	-0.17982	1

* Correlation coefficients of 0.2–0.4 for weak, 0.4–0.6 for moderate, and >0.6, for strong.

Appendix: Table 4. 9: Correlation Matrix of the trace element concentrations for subsoils sampled before the floods

Variables	**Fe**	**Mn**	**Cu**	**Zn**	**pH**
Fe	1				
Mn	0.625164	1			
Cu	0.622329	0.813127	1		
Zn	0.358108	0.404648	0.32292	1	
pH	-0.37803	-0.0283	-0.25764	0.129233	1

* Correlation coefficients of 0.2–0.4 for weak, 0.4–0.6 for moderate, and >0.6, for strong.

Appendix: Table 4. 10: Correlation Matrix of the trace element concentrations for subsoils sampled after the floods

Variables	**Fe**	**Mn**	**Cu**	**Zn**	pH
Fe	1				
Mn	0.712402	1			
Cu	0.71465	0.665464	1		
Zn	0.808097	0.502516	0.643207	1	

pH	-0.0661	0.037891	0.029006	-0.00362	1

* Correlation coefficients of 0.2–0.4 for weak, 0.4–0.6 for moderate, and >0.6, for strong.