AVAILABILITY AND MOBILITY OF ESSENTIAL ELEMENTS ALONG THE SLOPES OF OROBA VALLEY, WINAM GULF CATCHMENT, KENYA

BY

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DECLARATION

Declaration by the Candidate

This thesis is my original work and has not been submitted for any other academic award in any other institution, and it shall not be reproduced in part or in full or any format without prior written permission from the author and the University of Eldoret.

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Declaration by the Supervisors

This thesis has been submitted for examination with our approval as university supervisors.

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DEDICATION

This thesis is a special dedication to my family members; mother, Ruth Fillman Mokwanga; wife, Venus Moraa; daughter; Destiny Jewel; brother; Jeff Fillman. Their immeasurable sacrifices, both socially and financially, contributed directly or indirectly to the success of this thesis.

ABSTRACT

The human body depends solely on the soil to obtain essential elements for proper physiological function; therefore, depletions or inadequate uptake of essential elements from soil would negatively affect the health of a human being. Soil erosion is a key driver that may affect soil nutrient supply. The study investigates the availability, mobility, and health implications of essential elements along the gradient of pilot plots of Oroba Valley, Winam Gulf. Soil Erosion is a challenge in the Oroba Valley catchment as the upper part of the valley has steep slopes that rapidly drop from 1,131 m to 929.7 m above sea level over a distance that <1km. This area experiences high rainfall ranging between from 1310 to 2268 mm m-1. The highest recorded soil erosion risk at the Oroba Valley is along the escarpment ranging from 11 > 50 t ha-1 yr -1. An increase of both agricultural land and settlement in the study area between 2013 to 2022 with an increment of 27891 ha and 1958 ha respectively shows the population growth in the study area. Much of the vegetative cover has been converted into agricultural land and wetland with a decrease of 16759 ha between the study periods. Soils collected from pilot plots one and two were analyzed for essential elements and soil characteristics. Soil pH for both the pilot plots one and two ranged from 5.4 to 6.11 which are calcareous while the organic matter (Loss on Ignition - LOI) ranged from 5.42 to 11.12 and 5.99 to 7.82 for plots 1 and plot 2, respectively. Soil Iodine was analyzed in which plot one concentration ranged from 5.33 mg kg-1 to 12.12 mg kg-1 which was higher than in plot two, which ranged from 3.68 mg kg-1 to 4.81 mg kg-1. Thirteen essential elements were analyzed in this study from both soil and plants. Total elements (Acid extract) and plant available (EDTA extract) concentration were deduced. Essential elements Na, Mg, P, S, K, Ca, Cr, Mn, Fe, Cu, Zn, Se, and Mo were analyzed. Iron in soil extracted with EDTA correlated with the concentrations in the plants, with an r2 of 0.4316. The presence of molybdenum in the soil enhances the uptake of calcium in soil by a variance of 2.07, as indicated from soil analyzed by EDTA extraction. Essential elements are majorly obtained through the food chain which is channeled through soil, plants, and animals. Erosion is a main major cause of risk of depletion of essential elements from the soil. The elements' distribution in both plots was mainly affected by their solubility to in water molecules. Each essential element supports the human body's physiological process, which is at risk due to the depletion of the elements in the soil. As soil is the main reservoir that supplies essential elements into the food chain that is soil –plants – animals. Soil erosion and land degradation remediation strategies should be implemented.

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LIST OF ABBREVIATIONS

1. **DEM** - Digital Elevation Model
2. **GIS** - Geographic Information System
3. **LC/LU** - Land use/ Land Cover
4. **LOI** - Loss of Iginition
5. **MN** - Micronutrients
6. **NEM**A - National Environment Management Authority of Kenya
7. **NLC** - National Land Commission
8. **PTEs** - Potential Toxic Elements
9. **RUSLE** - Revised Universal Soil Loss Equation
10. **TMAH** - Tetramethylammonium Hydroxide

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CHAPTER ONE

INTRODUCTION

1.0 Introduction

Detrimental land use changes and soil erosion are the key drivers that affect the ecosystems' status and integrity to support and supply ecosystem services (Quintas-Soriano *et al.*, 2016). Anthropogenic activities are key drivers of land cover changes that have increased the degradation of the ecosystem. This has negatively influenced human health (Myers et al., 2013), e.g., emerging new strains of diseases and deficiency of essential elements in the body like iron, calcium, and iodine leading to anemia, osteoporosis, and goiter, respectively.

Soil is the main reservoir and distributor of essential elements that animals obtain from through plants (Abrahams., 2016). Soils influence various ecosystem functions, such as hydrological and carbon cycles supporting human survival and significantly as a plant growth medium. Minerals, chemicals, and biological components of soil get into the human body through the food chain, direct inhalation, ingestion, or dermal absorption. The compounds in the soil can either be directly beneficial (macro and micronutrients) or detrimental (PTEs) to human health (Abrahams, 2012; Abrahams., 2002).

Environmentalists pay considerable attention to land-use change and soil erosion, impacting biodiversity and aquatic ecosystems. Different land use practices affect the availability and concentration of nutrients and contaminants in the soil, water, and air, which plants and animals can then absorb and transfer up the food chain (Turner *et al.*, 2001). This impact is due to cultivation patterns change, crop farming frequently, resulting in increased surface runoff, depleting micronutrients and accumulating pollutants (toxic elements) into the base of the hills and rivers (Bhaduri *et al.*, 1999) Poor crop farming techniques on steep land slopes encourage a high rate of soil erosion, affecting water quality. Soil swept from high to low areas moves with micronutrients and toxic elements (Bhaduri *et al.*, 1999). De(/re)forestation and human settlement result in a change in land cover/land use, which initiates and accelerates soil erosion; this continuously affects the mobility and transfer of micronutrients and toxic elements exerted into the food chain (Geoghegan *et al.*, 1997).

Kenya is one of the African countries categorized as developing, Presently, in many developing countries, poor soil fertility, low levels of available mineral nutrients in the soil, improper nutrient management, along with the lack of plant genotypes having high tolerance to nutrient deficiencies or toxicities are significant constraints contributing to food insecurity and malnutrition (i.e., micronutrient deficiencies) and ecosystem degradation. Western Kenya is an area with fertile land and contains the largest freshwater Lake in Africa- Lake Victoria. The northeastern extension of the Lake and its surroundings into the Kenya part is known as the Winam Gulf. Through the Winam Gulf, the Lake is fed by different rivers that emanate from the upper part of western Kenya and empties water into the Lake. Rivers draining into the lake are Nzoia, Sio, Yala, Nyando, Kibos, Sondu-miriu, Kuja, Migori, Riaria, and Mawa (Kayombo *et al.*, 2006). Due to the increased population in the upper catchment area, places sensitive to soil erosion have been encroached on and affected by different anthropogenic activities; hence, there is a tremendous change in land use and land cover. These areas are; Nandi hill, Mau forest, Tinderet forest, Mau escarpments, Kiabonyoru highlands, and Oroba valley. Depleted land cover accelerates the mobility of micronutrients and potentially toxic elements, leading to poor nutrition in the Winam Gulf catchment.

1.1 Problem Statement

Around 10 million Kenyans suffer chronic food insecurity and poor nutrition, and 30% of children are classified as undernourished (Mutisya *et al.*, 2015; Olielo, 2013). Subsistence farmers depend on soil and water as natural resources for agriculture to produce food for their consumption. Altered rainfall patterns, droughts, extreme weather events, and soil erosion have depleted crop harvest and ruined soil fertility. The emerging and past anthropogenic activities such as land clearance, agriculture, overgrazing, usage of fertilisers, mining, construction, and poor land management practices have resulted in soil erosion, nutrient mobilization, and potentially toxic elements (PTEs) bioconcentration. Focus on the supply of adequate calories and protein in diets often ignores the need for adequate intake of essential micronutrients, thus resulting in “hidden hunger” (Marriott, 2018), and generally, Africa lags the rest of the world in dietary micronutrient density (Beal *et al.*, 2017). Long-term exposures to PTEs (e.g., mercury, lead, nickel, manganese, cadmium, arsenic) may occur due to soil erosion from agricultural practices and human activities such as artisanal mining in Africa, especially among poor rural communities. For instance, erosion can carry and deposit PTEs from excavation locations to other areas where such elements can be bio-concentrated up the food chain and the loss of micronutrients associated with fine soil particles that would otherwise be available for soil-to-plant transfer and overall loss of soil quality.

The project investigates how land-use changes and erosion affect the concentrations of MNs in soil, pasture, and subsequent dietary intake of people dependent on subsistence farming and a more static proxy to individual ‘shambas’ farming plots. Spatial analysis using GIS and satellite imagery was applied to characterize risk and associated soil managerial practices in the study area, and a comparison of the levels of elements was estimated between the plants and soils.

1.2 Justification

In the ongoing studies on basin-wide transfers of nutritional and PTE elements through soil – crop –human in Winam Gulf, soil, water, urine, and plants (vegetables and fruits) were collected. Data gaps and procedural variations that can limit and compromise the utility of animal samples were identified. This study includes plants (grass(pasture)) to close the gap. These will contribute to a complete understanding of the study area's dynamic transfer of essential micronutrients and potentially toxic elements (PTEs).

Mapping provides essential information on the characteristics and conditions of the land. The mapping of the Winam Gulf provides baseline information on risks associated with both environmental and anthropogenic activities. Plants which serve as fodder are analyzed for deficiency of essential elements and concentrations of potentially toxic elements. Elemental distribution maps help make decisions for interventions for health issues, e.g., Anemia, Cancer, and Goiter.

1.3 Aim and Objectives

To investigate the impact of land-use change and soil erosion on essential element mobility and availability in the Oroba Valley, Winam Gulf

1.3.1. Specific objectives

i. Assess soil erosion in the river Kibos water catchment using the RUSLE equation.

ii. Assess the land use/land cover change in the Oroba valley.

iii. To determine the spatial distribution and concentration of essential elements in top soils along a gradient of pilot plots in Oroba valley.

iv. Assess the factors affecting the bioavailability of essential elements uptake in the grass from pilot plots in Oroba valley.

1.4 Research Hypotheses

Ha_1: Oroba valley is characterized by high rate of Soil erosion annually

Ha_2: Land use change affects the rate of soil erosion and distribution of micronutrients along the pilot plots

Ha_3: The combination of soil erosion and land use change impacts on soil-plant mineral uptake in pilot plots in the Oroba Valley.

Ha4: Most of the factors affecting uptake of essential elements are anthropogenic.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

The prominence of environmental conservation awareness and action has risen in the past few decades to combat the effects of human activities on various ecologies. The degradation of ecosystems stems from various activities over millennia where humans have established colonies and altered the fabric of nature to suit their needs. For instance, food production traditionally relies on tilling the land to grow crops or rear animals whose products humans consume. Agriculture has evolved to suit humans' needs for subsistence consumption and industrial activities as a significant economic undertaking that has brought various aspects that have led to environmental degradation. This investigation focuses on how agriculture and other human activities impact ecosystems through soil erosion and the mobility of MNs/PTEs. This section of the research highlights historical findings on the issues that can be useful to this evaluation. The literature review shall focus on the relevant issues in the Winam Gulf Oroba valley of Lake Victoria study areas and research from other sites to articulate the problem in the most appropriate context for the investigation.

2.1 Conceptual Framework

This research aims at identifying the impacts of land use and soil erosion on the mobility of essential elements in the Human-Animal food chain in Winam Gulf. This investigation has three sets of variables in the categories of independent, dependent, and intervening variables. The independent variables of any assessment are those parameters that do not derive their influence from other factors within the context and constraints of the study (Aneshensel, 2012). On the other hand, dependent variables rely on various independent variables or different values to influence their outcomes in the investigation. Intervening variables are hypothetical intermediary values that explain causation between two or more variables in an evaluation (Aneshensel, 2012). Understanding these variables is essential to ensure that the study meets its conceptual objectives. The conceptual framework of this study has soil erosion as the independent variable. While soil erosion is a product of other factors, this study is not interested in those causes and focuses on that phenomenon as an existing environmental action. Soil erosion can cause various environmental and human damages from the relevant events. The impacts of soil erosion on the human-animal food chain are the dependent variables that rely on soil erosion. The scope of this investigation only focuses on soil erosion's effects on the movement of MNs and PTEs through different regions in the Winam Gulf. The mobility of MNs and PTEs then stands as the intervening variable that explains the relationship between soil erosion and its effects on the human-animal food chain. Figure 1 below summarises this relationship on a conceptual framework.

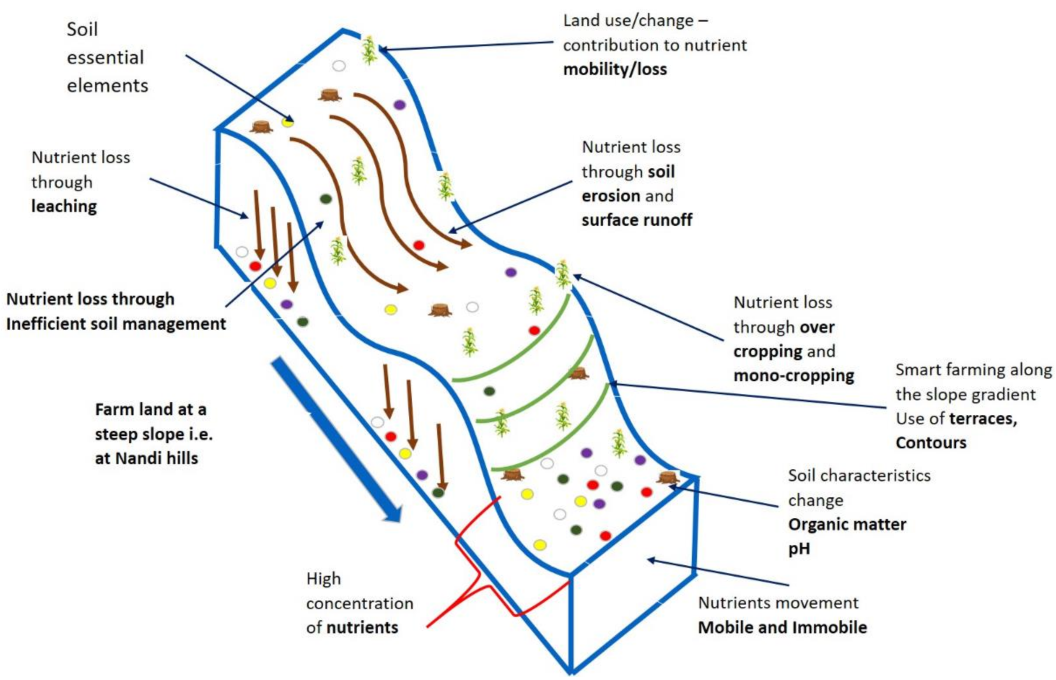

Figure 2. 1 Conceptual Framework of impacts of soil erosion on the transfer of elements along the food chain

2.2 Land-Use Activities and Patterns Influencing Soil Erosion in the Winam Gulf

The Oroba valley is an extensive area to the northeast of Lake Victoria covering a significant part of western Kenya, with the Winam Gulf draining point into the Lake. This area is sufficiently fertile due to its rich soils and rainfall, making it suitable for human settlement (Woomer & Mukhwana, 2004). As a result of its fertility, the most prominent human activities in the area include crop farming, animal husbandry, and fishing, a major economic undertaking in Lake Victoria (Abong'o *et al.*, 2014). The area's topography varies significantly throughout the region, from flatlands near Lake Victoria to mountainous terrains around the Nandi Hills and its surroundings (Cheruiyot, 2020). Evaluating all those activities is essential to understand how they influence land-use changes, their connection to soil erosion, and their impact on the pertinent ecosystems.

2.2.1 Soil Types in the Winam Gulf and Oroba valley

The fertility of the land around the Winam Gulf and Oroba valley derives from its variety of soils suitable for various human activities. Clay soil (mostly black cotton) is a prominent occurrence across the Basin, particularly in rice-growing areas that rely on its water retention capability to support this crop (Boniface, 2015). A small pottery industry also benefits from the area's clay soil, making it a significant economic activity (Owino, 2016). The region also has various rivers draining into the Lake, which is responsible for silting and other forms of erosion. As a result, some low-lying areas of the region have an abundance of sand whose mining supports the local construction industry (Rakama *et al.*, 2017). Loam soils are also common in the Winam Gulf, and they support the production of crops such as maize and wheat (Lipińska *et al.*, 2013). Alluvial soils are another common occurrence in most areas of the Winam Gulf. The most common deposits of alluvial soils are along the banks of rivers in the Winam Gulf (Ngure *et al.*, 2014). Erosion from different upstream areas is responsible for such deposits, which would also indicate variations in the nutrient setup of the soils.

2.2.2 Crop Farming in the Winam Gulf Region

Crop farming is the economic activity covering the most extensive parcels of land in the Oroba valley. For instance, rice farming is a popular agricultural undertaking in the Ahero area of the lake region that is part of this Basin (Aduda, 2020). Since rice growing requires large amounts of water to flood the fields, it is one of the crop farming activities that significantly influences the mobility of MNs/PTEs that drain from the farms into the nearby rivers and eventually into Lake Victoria. Other common crops, including wheat and maize, dominate most parts of the Oroba valley, mainly around Nandi County (Marete *et al.*, 2020). Sugarcane farming is also prominent in the Oroba valley and its surrounding area, the most notable being the Chemilil Sugar Belt (Waswa *et al.*, 2012).

Similarly, tea farming dominates the nearby Nandi Hills escarpment comprising mainly large-scale establishments with factories to support them (Sitienei *et al.*, 2017). As a result, the Oroba valley and Winam Gulf crop farming comprise large-scale and smallholder farmers, establishing land-use variations and management practices. For instance, planting, weeding, and harvest methods and periods vary significantly in those areas due to differences in the crops that farmers grow and the specific management necessary. Crop farming in the Winam Gulf and its surrounding areas significantly impacts soil erosion and land use (Cheruiyot, 2020).

Crop farming has various influences on both soil erosion and land-use practices. Primarily, the farming of different crops influences soil disruptions in the ecosystem, which exposes it to erosion through wind and rain. For instance, farming in the Nandi escarpment loosens the soil in the hilly areas, increasing erosion during runoffs. Rice farming is another practice that increases the incidence of PTEs through agrochemicals, particularly when flooding the fields and releasing the water downstream (Aduda, 2020). All farming activities in the Oroba valley region involve fertilizers and other agrochemicals, which contribute to the availability of PTEs in the fields (Kiage & Obuoyo, 2011).

Similarly, those practices introduce various MNs that should be suitable for the growth of the crops. However, the high drainage levels in the area due to the topography and frequent rains increase the risk of those MNs/PTEs moving into the nearby streams and rivers and eventually into Lake Victoria (Kiage *et al.*, 2011). For instance, farming on escarpment leads to the loss of vegetation cover that would have prevented soil erosion. As a result, such actions accelerate soil loss from upstream areas in the Winam Gulf with devastating effects even in the downstream regions.

2.2.3 Animal Husbandry in the Winam Gulf Region

Animal rearing is another common economic activity in the Oroba valley region. Most of the Winam Gulf animal husbandry is predominantly for satisfying the subsistence needs of the locals (Abong'o *et al.*, 2014). As a result, most family farms combine rearing various livestock with crop farming to satisfy their nutritional needs. Dairy animals are the most prominent for their milk, chicken for meat and eggs, and goats and sheep as the most common animals on most local farms (Achonga *et al.*, 2011; Bett *et al.*, 2009; Olwande *et al.*, 2010). The nature and structure of those farms vary significantly from indoor to free-range systems depending on the land and capital availability and each farmer's specific needs. For instance, zero-grazing systems for cows and caged chicken rearing are common to maximize returns among farmers (Nalunkuuma, 2013; Olwande *et al.*, 2010). Rearing of goats and sheep is dominantly free-range in the area as the most suitable approach for the local farmers. Livestock husbandry in the Winam Gulf significantly influences land-use practices with a close connection to soil erosion, consequently influencing the mobility of MNs/PTEs in the region.

Livestock farming is a prominent factor influencing the land-use patterns in the Winam Gulf and the larger Oroba valley Basin. Overgrazing is probably one of the key causes land degradation in the valley (Makalle *et al.*, 2008) and together with inappropriate land use it may lead to loss of vegetation cover that exposes the soil to erosion (Osoro *et al.*, 2016; Yamane *et al.*, 2015).

2.2.4 Other Land-Use Activities in the Winam Gulf

Sand mining is another common activity around the Lake Victoria region. Past findings have indicated the threats that emerge from sand mining in the riparian regions around Winam Gulf, including the potential to displace some members of the local communities (Oyoo, 2021). The incidence of sand mining and its significance as an economic activity in the area is rising due to the local construction sector's growth, which has increased demand for the commodity (Rakama *et al.*, 2017). The sand in the riparian areas results from erosion from other upstream areas that leave behind sediments of the material along river banks and other water bodies (Ouko, 2012). The harvesting of sand is relatively accessible to locals since it does not require complex machinery or processes, making the practice a common undertaking among the locals that perceive it as a viable income-earning opportunity (Rakama *et al.*, 2017). However, sand harvesting increases erosion in riparian areas, (Oyoo, 2021). Equally, sand mining influences the mobility of MNs and PTEs through riparian areas due to increased erosion. Therefore, sand harvesting is another land-use activity influencing soil erosion and soil-borne elements' mobility in the Winam Gulf.

Forestry and wildlife conservation are other land-use activities worth recognizing in the Winam Gulf and the larger Oroba valley. Governmental efforts to support the conservation of local biodiversity in the Winam Gulf have seen the establishment of forest and wetland reserves in the region (Oduor *et al.*, 2015). For instance, the Winam Gulf area consists of multiple wetlands dominantly comprising papyrus plants that are integral to the weaving industry of the local economy (Okeyo *et al.*, 2019). Such wetlands are an integral part of the local land-use programs as they serve as water catchment areas (Olima *et al.*, 2015). The Kenyan government has also instituted laws to protect riparian lands by emphasizing growing specific species of trees near river banks and shores of water bodies to enhance water catchment and increase vegetation cover (Nzau *et al.*, 2018). Similarly, the government has invested in various forestry programs through its agencies to increase vegetation cover, which is essential as a part of the climate change action program (Osoro *et al.*, 2016). Such conservation efforts are an important approach to land use that can help alleviate the challenges of climate change and reduce the impacts of soil erosion and MN/PTE mobility.

While conservation efforts are growing in the Winam Gulf, deforestation is prominent. For instance, deforestation rates are growing around the Nandi Hills escarpment and Chemelil area as people clear more areas to pave the way for farming (Koech, 2018). Sugarcane growing requires large tracts of land for the farmers to realize a profit (Waswa *et al.*, 2012). Consequently, farmers are clearing forests and other forms of vegetation cover around the Oroba valley to allow them to access the land for crop growing. The main challenge emerging from this pattern is that deforestation disturbs and loosens the soils in the area, which exposes them to erosion (Juma *et al.*, 2014). Forests and vegetation areas are efficient ways to create and accumulate organic matter from dead flora and fauna decomposing in the ground below (Njue *et al.*, 2016). Deforestation stops those processes and replaces them with mono-cropping and possibly inappropriate land management practices that deplete those nutrients from the soil (Makone *et al.*, 2021). For instance, most farmers are unlikely to invest in any systems that may prevent soil erosion after removing vegetation covers as they focus more on their crops. Therefore, the outcome of deforestation is an increase in soil erosion that heightens the rate of nutrient mobility and depletion.

2.3 Environmental Factors Influencing Soil Erosion and the Mobility of MNs/PTEs

2.3.1 The Influence of Topography

Various natural and human factors influence the occurrence of soil erosion and deposits in the Winam Gulf and its surrounding areas. Topography, and its variations across the region, are some of the most significant elements of soil erosion and deposits (Misigo *et al.*, 2018). Upstream regions of the Winam Gulf include escarpments, such as Nandi Hills, that drain into large rivers, such as River Sondu (Tanui & Practice, 2013). Human activities on such a steep topography accelerate soil loss, particularly in the rainy seasons, which is common on most farms in the Winam Gulf (Cheruiyot, 2020). Deforestation is also common on those escarpments, which implies that the localities have insufficient forest cover to prevent soil loss through erosion (Makone *et al.*, 2021). Riverbanks around the Winam Gulf are equally steep, which implies that erosion is also more prominent among them. The combination of upstream slopes and fast-flowing rivers increases the impact and incidence of soil erosion in the Winam Gulf area, particularly in the absence of management practices to prevent the phenomenon (Lufafa *et al.*, 2003). The steep topography of the upstream areas of the Winam Gulf is then an integral contributor to the patterns of soil erosion across the region.

Another topographical feature of some of the areas of the Winam Gulf involves flatlands in the low-lying sections of the region. For instance, the Ahero area comprises flat fields that are convenient for flooding the rice farms that dominate the locality (Aduda, 2020). As a result, the area experiences topographical changes from steep slopes, where soil erosion is prominent, to flatlands, where soil deposits are common. Silting is a prominent occurrence around the low-lying flat areas of the Winam Gulf, which can be beneficial or detrimental at the same time (J. Otieno & Otieno, 2019). For instance, silting around the farms can destroy crops or fill up fish ponds and other groundwater storage systems (Ngonzo *et al.*, 2013).

Similarly, silting along river banks can increase the incidence of flooding, which is detrimental to the local communities. However, silting can bring about fertile and nutrient-rich soil deposits, enhancing farming (De Trincheria *et al.*, 2016). The changes in topography from steep areas to low-lying flat ones influence the mobility and availability of soil MNs and PTEs across any region (Misigo *et al.*, 2018). For instance, the leaching of MNs and PTEs from upstream steep areas implies that those places may experience the depletion of those minerals while deposits in flat areas increase their concentration in the soil. Therefore, the topographical changes are influential to soil erosion and the mobility of MNs and PTEs across the region.

2.3.2 The Influence of Weather on Soil Erosion and Nutrient Mobility in the Winam Gulf

Weather events significantly influence the trends of soil erosion and the mobility of MNs and PTEs. For instance, wind can carry soil particles through vast distances in areas that have low vegetation cover and experience dry weather (Fenta *et al.*, 2020). The Winam Gulf is in a high rainfall area, experiencing annual averages of over 1000mm of rain in two seasons each year (Fusilli *et al.*, 2013). Rain-related erosion occurs through surface runoffs that carry loose soil particles and deposit them in low-lying areas or carry them into water bodies, such as rivers and lakes (Misigo *et al.*, 2018). This pattern presents a dual impact for both upstream and downstream areas. For instance, upstream erosion is detrimental to most human activities, such as farming, where the events may destroy crop fields (Makalle *et al.*, 2008). Deposits in low-lying farms are also harmful since they can damage crops as well. Therefore, rain and wind are the most prominent weather events in the Winam Gulf that increase the incidence and impact of soil erosion in the region.

Combining rainwater with soil erosion poses a second threat relating to nutrient and element mobility, which holds a significant interest in this evaluation. Surface runoff and water in various bodies contain suspended matter and elements that it collects from their environment (Fusilli *et al.*, 2013). For instance, runoff on farms carries various available MNs and PTEs and transports downstream along with the soil that it erodes (Ongeri *et al.*, 2009). Flooding is common in the Winam Gulf areas, such as Ahero, where floods contribute to growing rice (Too *et al.*, 2020). This aspect points to a frequent incidence of rainfall that directly increases the risks of soil erosion in the region. Leaching of such elements upstream contributes to mineral loss as a compounding effect on soil erosion (Ongeri *et al.*, 2009). Areas with low vegetation cover are likely to experience higher impacts of those patterns than those with sufficient surface cover. As a result, weather events, such as rainfall and wind have a significant influence on the patterns of soil erosion in the Winam Gulf and other regions.

2.4 Factors Influencing Patterns and Changes in Land-use and Land Management Practices

Various socioeconomic factors influence the land-use patterns and their historical changes in the Winam Gulf. Population growth is the most influential factor in the changes and practices of land use in the Winam Gulf and other regions (Juma *et al.*, 2014). Historical settlements of the region by various communities paved the way for the need to clear the land to allow the settlers to farm and build homes (Kipkoech, 2015). For instance, the population of the Kisumu metropolitan area increased from about 258,000 people in 2009 to around 344,000 in 2019, as per the census data (Macrotrends, 2020). As the populations of those communities grew, it became necessary for the locals to clear more land to increase food production to match the increasing demand (Gordon *et al.*, 2009).

Consequently, events of deforestation and changes in agricultural techniques to enhance harvests emerged to cater for the growing needs of the residents (Mulinge *et al.*, 2016). Similarly, more people needed to spread out and settle into unoccupied areas to access the land that they needed for their settlements (Gordon *et al.*, 2009). These patterns are clear indications that population growth is one of the most influential socioeconomic factors affecting land-use practices in the Winam Gulf.

The urbanization of most of the surrounding areas of the Winam Gulf contributes significantly to changes in land-use practices in the region. Urbanisation and population growth have similar effects on land use and management as they both necessitate an increase in farming intensity and land area to build settlements (Juma *et al.*, 2014). Kisumu is the largest town in the Winam Gulf, with nearby metropolitan centers such as Sondu, Nandi Hills, and Kakamega among others. Such developments require landowners to invest in housing facilities and other social amenities to support the metropolitan population (O. S. Otieno, 2014). Urbanization also influences farmers in the neighboring rural farming areas to find ways to increase food products to cover their subsistence needs and sell the surplus to the markets in local urban centers (Mireri, 2013). Both scenarios indicate patterns that are likely to increase the incidence of land use in the area in ways that also elevate soil erosion and the availability and mobility of MNs and PTEs. For instance, waste matter from industrial effluent and other human activities in the urban centers alters the physicochemical properties of the soil around them (K'oreje *et al.*, 2016). Therefore, urbanization has a significant influence on land use along with the availability and mobility of MNs and PTEs.

Government legislation and investments in Kenya significantly influence land use in the country. The most influential policies pertinent to the Winam Gulf are those regulating the protection of riparian lands in Kenya (NLC, 2018). These laws provide for a minimum distance from the water source where landowners can conduct specific activities. (Fusilli *et al.*, 2013; NLC, 2018). Other laws and investments involve government efforts through the National Environmental Management Authority (NEMA) and other agencies to increase forest cover and biodiversity within and outside designated reserves (NEMA, 2019). These actions influence the forms of activities that different socioeconomic agents can undertake on their respective parcels of land, which points to the influence of legislation and government investment on land use in the country.

2.5 Major Impacts Resulting from Soil Erosion in the Winam Gulf

An evaluation of land-use practices in the Winam Gulf highlights how various activities lead to soil erosion in the area. The Winam Gulf covers diverse ecosystems, including human settlements, natural reserves, and aquatic systems like Lake Victoria. The mobility of soil nutrients through soil erosion significantly impacts those ecologies that can be negative or positive in some instances (De Trincheria *et al.*, 2016). Understanding such influences is essential to identify the problems that require resolutions and establish the most appropriate solutions.

2.5.1 Nutrient and PTE Mobility and Mineral Loss

Most of the soil around the earth is rich in micronutrients, minerals, and other elements that can support or destroy biodiversity. Those elements include nitrogen, phosphorous, potassium, calcium, sulfur, and magnesium, which are useful for plants (Holb *et al.*, 2009). Some examples of PTEs in soil include mercury, lead, nickel, manganese, cadmium, and arsenic (Sikka *et al.*, 2012). Equally, human activities, such as agriculture, can contribute to the introduction of such elements into certain areas to enrich the soils for various uses when they have measured and Identified deficiency in the area. the fortification through fertilizer is recommended (Kundu *et al.*, 2017). For example, the application of fertilizers is a common method for introducing specific MNs to deficient areas to enhance agricultural productivity (Nyilitya *et al.*, 2020). Agricultural activities can also lead to the introduction of PTEs to different areas resulting from the use of agrochemicals on farmlands (Osoro *et al.*, 2016). Both MNs and PTEs and their mobility through soil erosion have varying impacts on ecosystems.

Soil erosion is responsible for the mobility of MNs and PTEs during the movement of particles through different areas. For instance, the erosion of soil particles through surface runoff involves the water dissolving MNs and PTEs and carrying them from their initial location into another area (Misigo *et al.*, 2018). As a result, nutrient losses occur in the area of origin with potential increases of the same elements in the area where the erosion deposits the soil (Mwamburi *et al.*, 2020). For instance, surface runoff can erode nutrient-rich soil from farmlands in hilly areas and deposit them along riverbanks. That action results in deposits of fertile soils in silt form in low-lying areas.

Consequently, the mobility of MNs and PTEs has varying effects from the source of erosion and the deposit of those elements across those two areas (Wanyonyi, 2019). A common occurrence in the Winam Gulf is the loss of MNs from farmlands with deposits in Lake Victoria that lead to devastating aquatic and on-land effects (Kiage *et al.*, 2011). Similarly, soil erosion can transfer PTEs from various sources and deposit them in different ecologies where they can devastate the residents and other organic occupants (Ongeri *et al.*, 2009). Understanding the effects of MN and PTE mobility is essential to establish the most appropriate resolutions for the ecosystems it affects.

Mineral loss around the Winam Gulf is a prominent problem evident through various evaluations in the past. Lufafa et al. (2003) highlight the loss of soil mass along with MNs from the mainland into Lake Victoria through rain and wind erosion in the area. The topographical properties of the Winam Gulf and its surrounding, including large rivers and steep slopes, increase the risks of erosion in many parts. Similarly, pollution through surface runoff and other forms of erosion is prominent as wastewaters move through certain parts of the Winam Gulf (K'oreje *et al.*, 2016). Such pollution involves effluent and human waste from nearby urban centers that move through the lands into the natural drainage systems of the region, such as streams, rivers, and lakes (Naigaga *et al.*, 2011). Both mineral loss and pollution activities affect the physicochemical properties of the soil and water, which is significantly detrimental to the local ecologies. Resolutions are necessary to understand and address the advent of those problems and alleviate their effects on ecosystems in the Winam Gulf.

2.5.2 Effect on Biodiversity

Erosion can lead to the loss of topsoil, which is the layer of soil that contains the most nutrients and supports the growth of plants. As a result, vegetation cover may decrease, and the types of plants that can grow in the area may change. This can alter the habitat of many animal species, leading to declines in biodiversity. Plant loss may lead animals that depend on vegetation for food and survival to migrate to other areas where those resources are plentiful (Cheruiyot, 2020; Gordon *et al.*, 2009; Humphrey *et al.*, 2021; Mulinge *et al.*, 2016). As a result, soil erosion and the mobility of the elements in its cause the loss of flora and fauna from different areas. (Rakama *et al.*, 2017). Therefore, care is necessary to alleviate these challenges and the impact of soil erosion by practicing better land management strategies around that region (De Trincheria *et al.*, 2016). For instance, the accumulation of silt in waterways may lead to blockages and flooding that harm biodiversity (Ong *et al.*, 2002). Deposits of eroded soil can introduce foreign plants, along with MNs that enrich the silt, into destination areas and encroach on the native flora of that region (Asmare, 2017). The Winam Gulf contains rivers and other water sources flowing over long distances, increasing the risk of contamination from the areas through which those bodies flow. Siltation may lead to the introduction of invasive species of plants in different areas, which encroaches on the native ones (Asmare, 2017). Equally, those deposits can introduce PTEs that harm to the local animal and human populations and harm biodiversity (Ngure *et al.*, 2014). Therefore, erosion and the mobility of MNs and PTEs have significant effects on on-land biodiversity from the sources and destinations of the soil mass.

2.5.3 Effect on Aquatic Ecosystems

Waterways and aquatic ecosystems face major risks from soil erosion and its effects resulting from the mobility of MNs and PTEs (Misigo *et al.*, 2018). For instance, the presence of soil particles and other elements in the water increases risks relating to Total Suspended Solids (TSS), Total Dissolved Solids (TDS), and the general physiochemical composition of the water (Vuai *et al.*, 2012). The effects may include TSS hindering the penetration of sunlight through water bodies, which affects the biodiversity in that ecology (Vuai *et al.*, 2012). Poor water quality also implies that those sources of water are relatively unusable even to the human population around them (Muinde *et al.*, 2013).

Aquatic animals face significant effects of soil erosion and the presence of PTEs and MNs in their environments. For instance, increasing MNs in an aquatic ecosystem may lead to enhance plant growth and improve the presence of phytoplankton (Simiyu *et al.*, 2018).

Erosion entering aquatic environments and introducing MNs and PTEs can also impact flora biodiversity. Increases in MN concentration can enhance the growth of various plants in the aquatic environment (Wanyonyi, 2019). Eutrophication is a common challenge in many water bodies exposed to soil erosion, where the introduction of MNs into the ecosystem increases algal and plant growth (Kabaka, 2014). An example is the growing menace of the water hyacinth in Lake Victoria, an invasive species that hinder the proliferation of native plants (Agwanda & Iqbal, 2019; Vuai *et al.*, 2012). Equally, those elements can alter the chemical composition of water to reduce the amount of oxygen available to the plants in the ecosystem, affecting the relevant ecology's biodiversity. Therefore, soil erosion and its contribution to the mobility of MNs and PTEs significantly affect the plant biodiversity of aquatic ecologies.

2.5.4 Effects on Humans and Their Economic Activities

Soil erosion and its role in the mobility of MNs and PTEs significantly impact humans and their economic activities in the affected areas. For instance, land degradation due to soil erosion is a common problem hindering agricultural productivity (Makalle *et al.*, 2008). The primary problem involves the loss of fertile topsoil leaving behind barren land with low production after cultivation (Yamane & Asanuma, 2015). Similarly, excessive erosion leads to the loss of MNs in rich soils and exposes land users to risks of low productivity (Kiage *et al.*, 2011). As a result, agricultural production faces the most intense risks relating to soil erosion and the mobility of MNs in different areas. This challenge is prominent in farming areas around the Winam Gulf and has pushed more farmers to adopt artificial fertilizers to cope with nutrient loss in the region (Simonit & Perrings, 2011). Therefore, on-farm land-use activities face one of the major impacts of soil erosion and loss of MNs throughout the region.

PTEs present in the human food chain is a major risk emerging from soil erosion and the mobility of those elements. For instance, surface runoff can erode waste from urban areas in higher regions to farms in lowlands with the potential to carry PTEs with it (Outa *et al.*, 2020). The direct impact of those PTEs exists in the human consumption of the water after it is deposited in those destination areas (Oyoo-Okoth *et al.*, 2010). However, a more concerning problem exists in the presence of those PTEs in the plants and animals that humans consume from those farmlands and aquatic habitats (Nyakairu *et al.*, 2010). For instance, crops can absorb the PTEs from the soil on the farms and threaten the health of their consumers after harvest (J. Mwamburi, 2016).

Another example is humans consuming contaminated fish from nearby rivers or lakes after the introduction of PTEs through soil erosion (Oyoo-Okoth *et al.*, 2010). Both scenarios represent risks that threaten humans' well-being and economic activities. The effects of erosion on aquatic ecosystems may alter fish populations, which affects fishing as an economic activity for humans

(Simonit *et al.*, 2011). Therefore, soil erosion and its influence on MN and PTE mobility can affect both the natural and human environment in the affected area.

2.6 Biomarkers for MNs/PTEs Mobility through Soil Erosion

Biomarkers are measurable indicators that can provide information about the status of essential elements in the body. Essential elements are minerals that are required in small amounts for proper physiological function, including zinc, iron, copper, and selenium(Holen *et al.*, 2016). Zinc: The level of zinc in the blood or hair can be used as a biomarker of zinc status. Low levels of zinc in the blood or hair can indicate a deficiency of this essential element. Iron: The level of ferritin in the blood is a biomarker of iron status. Ferritin is a protein that stores iron in the body. Low levels of ferritin can indicate iron deficiency. Copper: The level of ceruloplasmin in the blood is a biomarker of copper status. Ceruloplasmin is a protein that transports copper in the blood. Low levels of ceruloplasmin can indicate copper deficiency. Selenium: The level of selenium in the blood or urine can be used as a biomarker of selenium status. Low levels of selenium in the blood or urine can indicate a deficiency of this essential element (Holen *et al.*, 2016). As a result, biomarkers are an integrated approach to evaluating the impact of soil erosion in different areas by involving the flora and fauna that reside in the study region in the investigation. Understanding the local environment of the Winam Gulf is essential in selecting the most appropriate biomarkers for the study.

Selecting the most suitable biomarkers for this investigation is integral to ensuring that it meets its objectives within its context. Humans are among the most prominent residents of the Winam Gulf region, which necessitates their inclusion as biomarkers for this evaluation. Human hair is a convenient choice of a biomarker because it captures the relevant data and keeps it over a longer period than other tissues and body fluids along with its ease of retrieval from the subjects (Albar *et al.*, 2013). Livestock rearing is also prominent in the Winam Gulf and the Oroba valley, which necessitates the selection of biomarkers that are relevant to them. Fluid samples from livestock milk and blood are useful biomarkers for research since they contain sufficient information to understand their exposures to various elements (Burnett *et al.*, 2015). Other aquatic biomarkers are equally useful for evaluating soil erosion's influence and MN/PTE mobility in the Winam Gulf. Plant-based biomarkers are equally instrumental in evaluating the impact of both soil erosion and nutrient mobility in the area. Comparing such indicators between the source and destination of soil masses, MNs, and PTEs can enable the investigators to understand the relevant patterns and address the objectives of this evaluation.

2.7 Conclusions

this study investigates land use change and soil erosion as factors influencing the uptake of essential minerals from the soil to plants. From the literature, soil erosion is geared up by the increase in population in the Winnam gulf, leading to increased anthropogenic activity. This slopes has been invaded by agricultural activity without many mitigation measures for soil erosion. The area experiences much rainfall, which is over 1000mm per year, increasing the washdown of the topsoil and losing essential elements into the rivers and eventually into the lake.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

The study was conducted in the Winam Gulf of Lake Victoria, Oroba River catchment, for the changes in erosion, land use, and land cover. Essential elements loss and mobility study was established in the pilot plots located at the Oroba valley, a tributary of river Kibos, as mapped in figure 3.1 within Kenya.

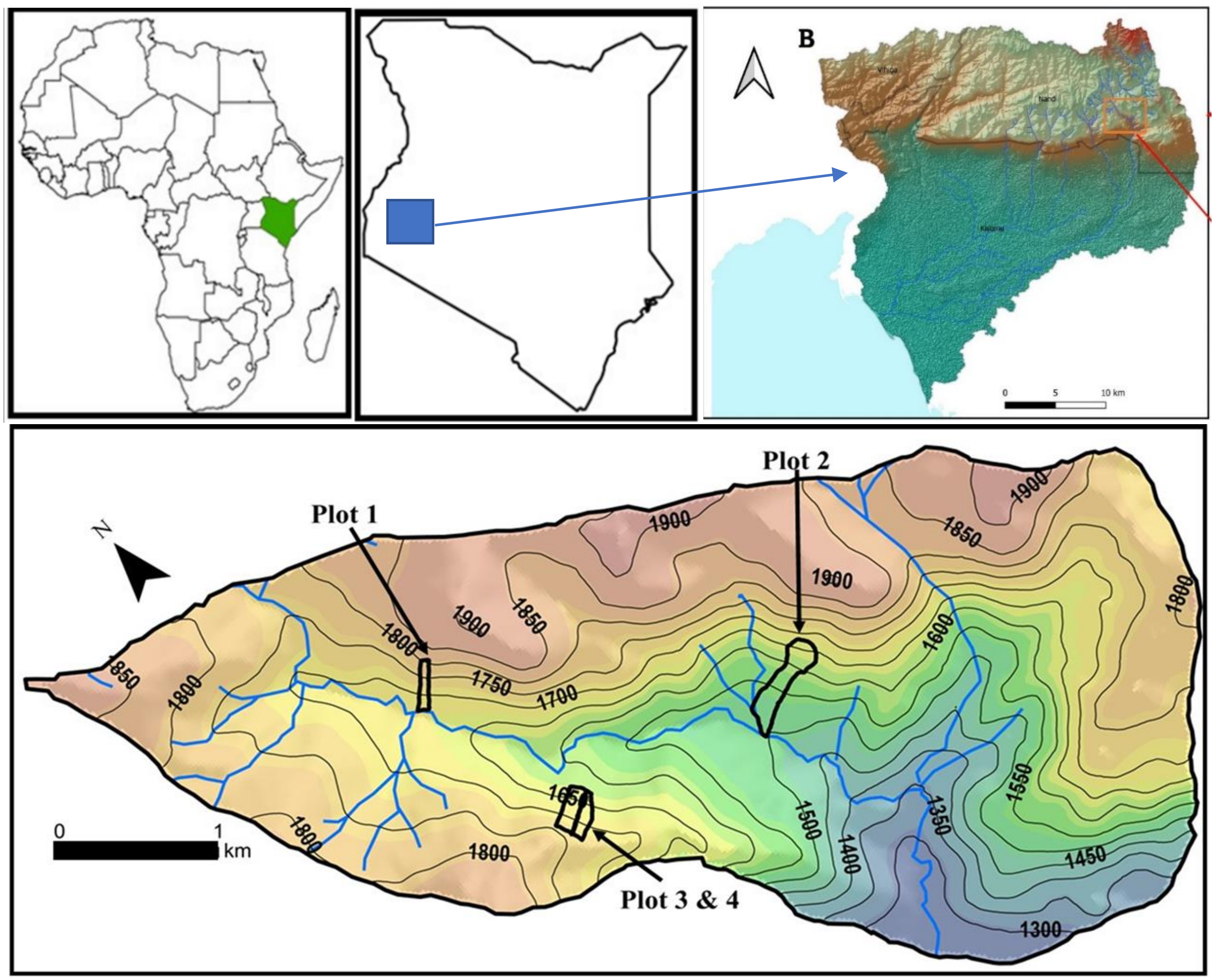

Fig 3.1. The Kenya map shows the location of the study area. This comprises the DEM of the Kibos water catchment area . Contains the map of the Oroba valley with the pilot plots within the catchment of the Kibos river for soil and plant study.

3.2 Study design

The study aims to survey the status of elemental concentration as it has been affected by land use change and soil erosion in the study area along the food chain. Hence the project employed a descriptive research design.

3.3 Sampling technique

Pilot plots were identified within the studied valley (Oroba valley). Plot one, with no mitigation, and plot two, with mitigation, were divided into five sections along the gradient. After subdividing, randomly three points were selected within the section to collect soil samples and grass within that particular point.

3.4 Analysis of Factors governing soil erosion

The Revised Universal Soil Loss Equation (RUSLE) model was used to analyze the mean Annual Soil Loss, which required a land use/land cover map, rainfall, slope length/steepness, soil types and properties, and management practices. The method's parameters were measured from the study site and used secondary data, which were integrated with GIS for the analysis (Wynants *et al.*, 2019). This model was adopted because it is known to describe and estimate erosion in the basins (Zerihun *et al.*, 2018). Data input for integrating the RUSLE model was obtained from the digital elevation model (DEM), land use/land cover (LU/LC) maps from satellite images, ground truthing, soil, and rainfall data. The model was used to describe the erosion trend of the studied valley.

3.4.1. The RUSLE Equation

The equation that is used to solve annual soil erosion, RUSLE, according to (Maqsoom *et al.*, 2020; Yoder *et al.*, 2001), is

Equation 1: $$A = R.\ K.\ LS.\ C.\ P$$

Whereby **A** is mean annual soil loss (usually expressed in ton acre^{-1} yr^{-1}); **R** is rainfall erosivity factor (MJ mm ha h^{-1}). **K** is the soil erodability (hundreds of ft-ton) in acre hr^{-1} yr^{-1}); **C** is a cover-management factor (dimensionless); **LS** is slope length/slope steepness factor (dimensionless), and **P** is the support practice factor (dimensionless). All dimensionless parameters were normalized relative to the Unit Plot Conditions

The study area's geomorphology and rainfall characteristics were used to determine soil Erosivity, Erodibility, and management factors (Mihi *et al.*, 2019).

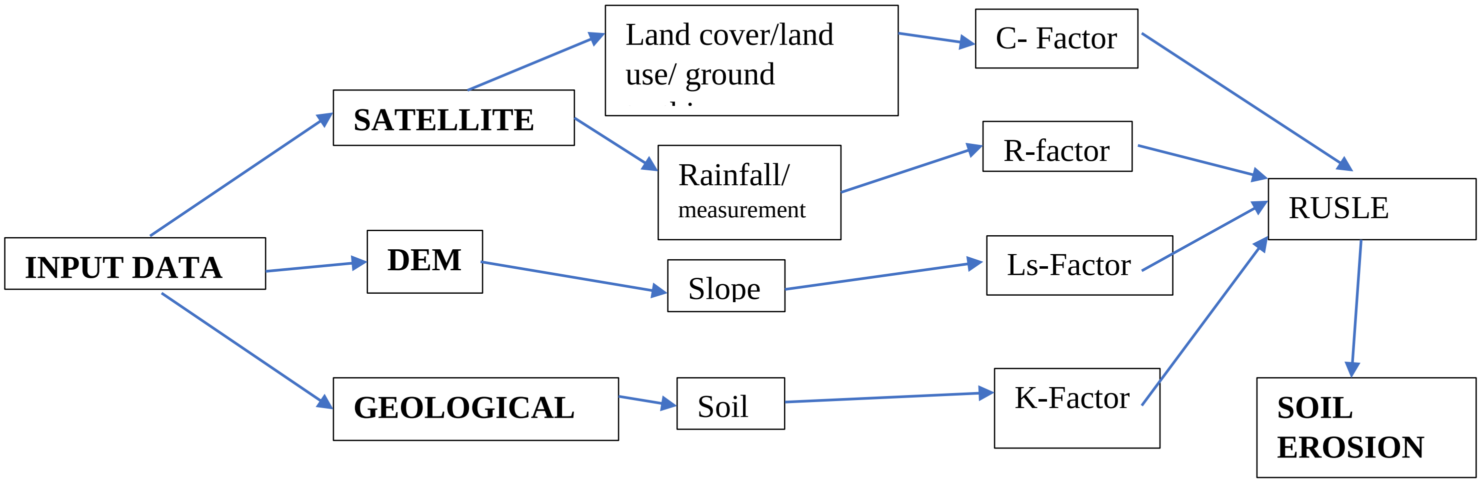

Fig 3.2: RUSLE model data input flow chart for soil erosion risk

3.4.2. Rainfall Erosivity Factor

The rainfall erosivity Factor (R) is the power of rainfall to cause soil erosion by water, and a mean annual value was calculated as the summation of event-based energy intensity value for a location divided by the number of years over which the data was collected. R-factor is computed as total storm energy multiplied by the maximum 30 min measurement of rainfall intensity with autographic recorders (Renard, 1997). And kinetic energy is the ability of raindrops to detach soil particles from the whole soil mass (M. Nearing & Bradford, 1985). In this study, mean monthly rainfall was acquired from the climate hazards group infrared precipitation with stations (CHIRPS) dataset for over 30 years using Google Earth Engine (GEE). Using the regression equation, kinetic energy (KE) possessed by the raindrops is calculated as (Humphrey *et al.*, 2022a):

Equation 2: $$KE = 3.96 * MMR + 3122$$

Where MMR is the mean monthly rainfall

After obtaining the kinetic energy, the rainfall erosivity factor was calculated each month for two and a half years (January 2017-June, 2020). The equation was used to find the erosivity factor(Humphrey *et al.*, 2022a; Moore, 1979; Wynants *et al.*, 2018):

Equation 3: $$R = 17.02(0.029 * KE - 26)$$

Where R is rainfall erosivity (MJ mm ha^{-1} h^{-1} yr^{-1}) (Gelagay & Minale, 2016; H Hurni, 1985; V. P. Singh & Singh, 1992; Zerihun *et al.*, 2018).

3.4.3. Soil Erodibility Factor

Soil texture, structure, permeability, and organic matter determine the erodibility of a particular soil (Efe *et al.*, 2008). Organic matter reduces soil erodibility and its susceptibility to detachment but increases infiltration. Data from Kenya Soil Survey (Batjes, 2013) was acquired and used to calculate the soil erodibility. Soil erodibility monograph, which includes texture, organic matter, coarse fragments, structure and permeability, was used to calculate the k factor.

Equation 4: $$K = [(2{:}1 * 10-4\ M^{-1.14}\ (12-OM) + 3.25\ (S-2) + 25\ (p-3))/100]*0.1317$$

where OM (%) is the organic matter content of the soil, S is the soil structure class described in Table 1, and p is the permeability class (Humphrey *et al.*, 2022a) described in Table 2. respectively and M is the textural factor calculated as shown in Eq. (5)

Table 3. 1 Soil structure class (Humphrey et al., 2022a; Panagos et al., 2014).

Structure class (s)	European Soil Database
1. (Very fine granular: 1–2 mm)	G (good)
2. (Fine granular: 2–5 mm)	N (normal)
3. (Medium or coarse granular: 5–10 mm)	P (poor)
4. (Blocky, platy, or massive: N10 mm)	H (humic or peaty top soil)

Table 3. 2 Soil permeability classes estimated from major soil textural classes (Humphrey et al., 2022a; Panagos et al., 2014)

Permeability Class (P)	Texture
1 (Fast and Very Fast)	Sand
2 (Moderate Fast)	Loamy sand, sandy loam
3 (Moderate)	Loam, silty loam
4 (Moderate Low)	Sandy clay loam, clay loam
5 (Slow)	Silty clay loam, sand clay
6 (Very Slow)	Silty clay, clay

Equation 5: $$M = (mSilt + Mvfs) * (100-mc)$$

Where msilt (%) is the silt fraction content (0.002–0.05 mm); mvfs (%) is the very fine sand fraction content (0.05–0.1 mm); and mc (%) is the clay fraction content (<0.002 mm). The very fine sand structure (0.05–0.1 mm) as sub-factor (mvfs) in Eq. (6) was estimated as 20% of the sand fraction (0.05–2.0 mm) according to Panagos et al. (2014b).

3.4.4. Topographic Factor

Slope length and slope steepness is the other main factor for estimating soil loss, which measures the sediment transport capacity of the flow. LS does not consider the 3D complexity of the topography but assumes soil loss increases with slope length and upslope contributing area (Wischmeier & Smith, 1978). Digital Elevation Model (DEM) of the resolution of 30m was obtained from the Shuttle Rader Topography Mission (SRTM) to estimate the Topographical factor. Using ArcGIS software version 10.3, the LS factor was computed in equation 6;

Equation 6: $$Ls = \left(\frac{cell(flow\ accumulation * map\ resolution)size}{22.13}\right)^{0.4} * \left(\frac{Sin(slope)}{0.0896}\right)^{1.4}$$

Flow Accumulation is a raster-based total accumulated flow in each cell weight for all cells computed using Arc hydro tool (Ligonja *et al.*, 2015).

3.4.5. Cover Management Factor

The cover management (C) factor is the soil loss ratio from the land with vegetation to continuous fallow. It depicts the link between soil loss in an area with specified plant cover and management and soil loss in an area with tilled soil that is permanently barren throughout the cropping season, with values closer to 0 indicating denser vegetation and values closer to 1 meaning bare land. Monthly C factors were calculated using Moderate-Resolution Imaging Spectroradiometer (MODIS) pictures from the Terra platform.

Data for the MODISTerra MOD13Q1 product, a 16-day vegetation index composite with a spatial resolution of 250 m, were gathered monthly between January 2017 and June 2020 for MODIS tiles 'h21v08' and 'h21v09'. The normalized difference vegetation index (NVDI) was used to compute the cover factor using the eq 7

Equation 7: C=((-NDVI + 1)/2)

(Fleitmann *et al.*, 2007a; Fleitmann *et al.*, 2007b).

3.4.6. Conservation Support Practice Factor

The conservation support practice factor is the ratio of soil loss after doing a conservation practice to soil loss for up and downslope in straight-row cultivation and is used to understand the conservation practices in the study area. Assigned the P factor value by categorizing the area into agricultural land and other land-use types by considering the support practices (Wischmeier *et al.*, 1978; Yoder *et al.*, 2001; Zerihun *et al.*, 2018). The P factor accounts for runoff erosion management methods that impact drainage patterns, runoff concentration, runoff velocity, and hydraulic pressures applied by runoff on the soil surface.

P factor values around 0 often indicate vital conservation practices, such as terracing, contour tillage, and permanent barriers or strips that reduce the overall risk of erosion, whereas values near 1 suggest poor conservation management.

The RUSLE model was run with a P factor of one due to a lack of data on conservation measures in the research region.

3.5 Land Use and Land Cover Change Detection

This research followed the fundamental land use land cover change detection protocols. First, satellite pictures from 2013, 2016, 2019, and 2022 were acquired from glovis.usgs.gov (USGS, 2022), and Ground Control Points (GCP) for land use land cover classes were gathered using a portable GPS tool.

Signatures were created using GCP points, and supervised image classification was performed using the Maximum likelihood classification algorithm to generate the supervised image classification results. The supervised image classification results were then extracted using the river Kibos catchment extent, and the areal tabulation method was used to assess the changes using the transitional matrix.

3.5.1. Image Preprocessing

Preprocessing refers to the operations normally performed before the main data analysis and information extraction. The first task in image data processing was to select appropriate satellite imagery.

3.5.2. Image Enhancement

Image enhancement aimed to improve an image's visual interpretability by increasing the apparent distinction between scene features (Lillesand *et al.*, 2015). When an image is enhanced, the distinct features become more visible, allowing for better image analysis, classification, and interpretation. Furthermore, image enhancement was used to increase image details by assigning the image's maximum and minimum brightness values to maximum and minimum display values, which is done on pixel values, making visual interpretation easier and assisting the human analyst.

3.5.3. Image Processing (Satellite Image Classification Analysis)

Supervised classification methods were used in this study. The method of supervised image classification involved the analyst defining small training sites on the image representative of each desired land cover category. The delineation of training areas representative of a cover type was most effective when an image analyst had knowledge of the geography of a region and experience with the spectral properties of the cover classes.

The supervised classification was then performed using the training points by observing and recording identifiable coordinate points of features in Google Earth. For mapping, a simple classification scheme comprised of seven land use and land cover types was developed for this study. The legend was effectively prepared using a combination of information gathered in the field and a satellite image. Identifying some land use and land cover classes necessitated several field visits and discussions with farmers to clearly understand the main land use and land cover types and what changes are expected over time. To interpret satellite images, it was necessary to know what stage and type of land use and land cover to expect at what time of year. The classification of land use and land cover types culminated in the creation of the land use and land cover legend, the definition of its characteristics, and the identification and mapping of the various land use and land cover types (Tegene, 2002).

One of the most popular methods of satellite image classification in remote sensing is maximum likelihood classification, in which a pixel with the highest likelihood is classified into the corresponding class or pixel (Peng *et al.*, 2018).

3.6. Top soil and Grass sampling and analysis

3.6.0. Materials used

Shovels, augers, tape measure brown packaging bags, and a pen for labeling were used for soil and plant sampling. Samples were prepared in the laboratory using an oven, grinder, mortar, pestle, and 2mm sieves. After preparation, samples were digested using the microwave digester and the hot block, then analysed using the Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). The procedure required the following chemicals; analytical grade Nitric Acid, Hydrochloric acid, and Perchloric acid. The following types of equipment were also used; Weighing balance, Digestion fume chamber, volumetric flasks (100 ml and 250 ml), test tubes, pipettes, dispensers, microwave oven including high-pressure rotor, and pressure-temperature probe.

3.6.1 Soil sampling (G-Base Field procedural)

In the field, soil sampling followed the rules and guidelines for sampling by the British Geological Survey (Johnson, 2005). Soil samples were collected from four selected plots. The plots were subdivided into sections where each section was randomly sampled for the top soil between 0-10 cm, as shown in Figure 2.

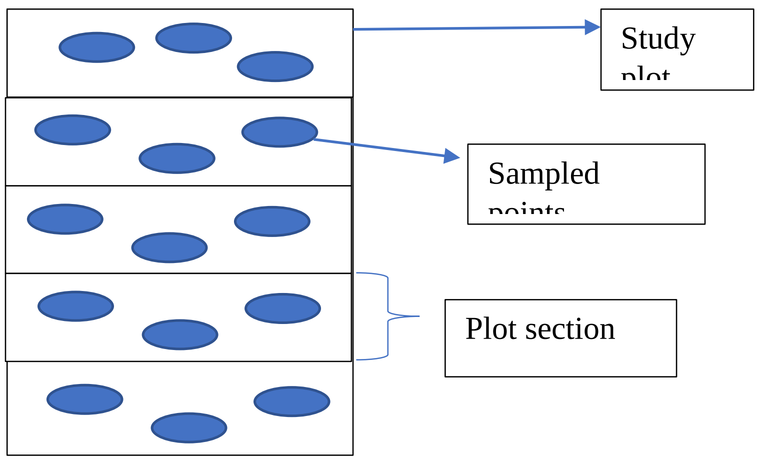

Figure 3. 1 Topsoil sampling design.

3.6.2 Plant sampling

Plants (grass) were sampled from the points at which the soils had been collected. Plants were recorded according to the collection location, washed, and then packed in brown bags for laboratory analysis.

3.6.3 Soil sample preparation

The samples were transported to the laboratory for preparation in Kraft paper bags. The samples were air-dried at room temperature, crushed using mortar and pestle, sieved to <2mm, and stored in paper bags.

3.6.4 Plant samples preparation

Plants collected from the selected study plots were air-dried in the laboratory, crushed using the grinder (KG40 – coffee grinder), and then packed in Kraft paper bags for digestion.

3.6.5 Soil pH and Loss on Ignition (LOI)

Soil pH

After the soil preparation, Soil pH was determined with a pH combination electrode in a 1: 2.5 soil: water suspension. The total soil exchangeable acidity (H^+ and Al^{3+}) was extracted with 1.0 M KCl and titrated with 0.01 M NaOH to pH 7.0 (Pansu *et al.*, 2006). The exchangeable Al^{3+} differed between exchangeable acidity and exchangeable H^+ (Miller & Kissel, 2010).

Loss on Ignition (LOI)(Organic matter)

To determine the organic matter content LOI method was used. 1 g of the sample at <53µm particle size was heated at a high temperature, of 450^{o}C, in a muffle furnace. The sample was then weighed before and after heating, and the difference in weight was used to calculate the loss of weight, which was assumed to be due to the loss of organic matter(Singh *et al.*, 2022).

3.6.6 Soil acid digestion process

Soil samples for total metal analysis were acid-digested; a mix of acids, namely HNO_3, HF, and $HClO_4$ 0.25g of the sample were pre-digested overnight in a series of nitric acid, with a start of 3 ml 5% HNO_3 and then 3 ml 50% of HNO_3 at a temperature of 80^{o}C. It was then cooled down to room temperature. After cooling, 2 ml HNO_3, 2.5 ml HF, and 1 ml $HClO_4$ were added then the mixture was placed in a programmable hot block for a series of heating for; 8 hours at a temperature of 80 ^{o}C, 2 hours at a temperature of 100 ^{o}C, 1 hour at a temperature of 120 ^{o}C, 3 hours at a temperature of 140 ^{o}C, and 4 hours at a temperature of 160 ^{o}C (Watts. *et al.*, 2017). The resultant solution was allowed to cool at room temperature up to 50 ^{o}C, then 2.5 ml 50% HNO_3 was added;

then the solution was maintained at 50 ^{o}C for 30 minutes, after which it was allowed to cool to 30 ^{o}C. At 30^{0}C, the solution was topped with 10 ml MQ water and 2.5 ml, in which the temperature was maintained for 15 minutes. Afterward, the solution was transferred to a 30 ml bottle, made up to 25 ml with 10 ml of MQ water, and then capped and stored for ICP-MS analysis (Watts *et al.*, 2019b).

3.6.7 EDTA Extraction

TMAH solution was freshly prepared by dissolving 10 g of EDTA with distilled water from Milli-Q® IQ Water Purification System. Air-dried soils were weighed (1 g) and mixed with 5 ml TMAH solution. The resultant solution was heated in the oven for 3 hours at a temperature of 70^{o}C, while gently shaken halfway through the process. After which, it was allowed to cool at room temperature, and 5ml MQ water was added. The resultant solution was centrifuged at 3500rpm for 20 minutes, and then the aliquot was extracted into autosampler tubes of about 5-8ml, then capped and stored for analysis (Okalebo *et al.*, 2002) with the ICP-MS.

3.6.8 Plants samples digestion

Plant samples (grass) were also analysed for micronutrients and potentially toxic elements. 0.5 g of ground grass samples were placed in a microwave digestion vessel. Then 10 ml of 65% of the HNO_3 was added, and the solution was shaken to mix and left for 30 minutes. The container was capped and placed in the microwave digester PFA vessels, then inserted into the microwave machine, which was programmed to digest under program VEG2 (temperature 200 ^{o}C, time 45min, power 1600W, and pressure 100psi). After that, it was cooled and vented. An additional 1ml of H_2O_2 was added, and the solution was left at room temperature for 30 minutes. After which it was returned to the microwave, which was switched to run on program VEG3(temperature 100 ^{o}C, time 45 min power 1000W, and pressure 100psi)

From the microwave, the resultant solution was added with 30 ml of MQ water to the vessel and then poured into a 60 ml Nalgene bottle. The 9 ml of MQ water was added to the vessel and rinsed to remove the remaining residue. Then 60 ml of MQ water was added to the bottle containing the solution (Watts *et al.*, 2019b).

3.6.9 Soil and plants analysis

After digestion and EDTA extraction, all samples were analysed by Agilent 8900 triple quadrupole ICP-MS (ICP-QQQ) using collision cell mode (He, O_2, and H_2). The analysis aimed at the following elements, namely: Li, Be, B, Na, Mg, Al, P, S, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Rb, Sr, Y, Zr, Nb, Mo, Ag, Cd, Sn, Sb, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, W, Tl, Pb, Bi, Th, U; Se; As (mass shifted at mass 91) respectively to the gas used. Sc, Ge, Rh, In, Te, and Ir were used to correct the signal drift for standardization. (da Silva *et al.*, 2014; Górecka *et al.*, 2006; Watts *et al.*, 2008; Watts *et al.*, 2019a).

3.7. Data analysis

Using Excel Office 19, data were checked for entry accuracy, performed dual entries, and cleaned up. Then was entered into SPSS version 21. ANOVA was used to compare proportional differences and determine the significance of the means. Linear regression and correlation were utilized to predict the concentration differences. All tests were two-tailed, and a p-value of 0.05 was considered significant or otherwise stated.

3.7.1. Transfer factor

Essential element concentrations in the extracts of soils and plants were calculated based on the dry weight. The plant transfer factor (TF) was calculated as follows:

$$TF = \frac{\mathrm{C-plants}}{C-soils}$$

Where C_{plant} and C_{soil} represent the concentration of the Essential element in extracts of plants and soils on a dry weight basis, respectively (Jolly *et al.*, 2013)

CHAPTER FOUR

RESULTS

The results are divided into two phases: the secondary data and field reconnaissance results for objectives one and two and Laboratory results for objectives three and four. The data was obtained from USGS (United States Geological Survey) earth explorer for secondary data. Samples collected from the pilot plots in Nandi county were dried for both soils and plants at the glass house. Soils were sieved with a two-millimeter sieve and plants were crushed then exported from the university of Eldoret Biotechnology Center and to British Geological Survey for further preparations and ICP-MS analyses.

4.1 Soil Erosion Prediction

The data for soil erosion prediction was done for the entire catchment of River Kibos.

4.1.1 Rainfall Erosivity Factor

Previous studies on the RUSLE model noted that the rainfall factor is the most valuable factor in the model (Nearing, *et al.*, 2017a), in which the rainfall factor in the study area ranged from 1310-2268 MJ mm ha^{-1} h^{-1} $month^{-1}$. The high amount of rainfall experienced in the study's high-altitude regions is shown in Figure 3. Rain seasons vary from year to year and month to month. The study showed rainfall was primarily experienced in May each year, as shown in Figure 4. Climate change can have significant impacts on rainfall patterns around the world. The Earth's climate is changing due to the increased concentration of greenhouse gases in the atmosphere, which trap heat and lead to global warming. This can lead to changes in precipitation patterns, including changes in the amount, timing, and intensity of rainfall (Arnbjerg-Nielsen *et al.*, 2013).

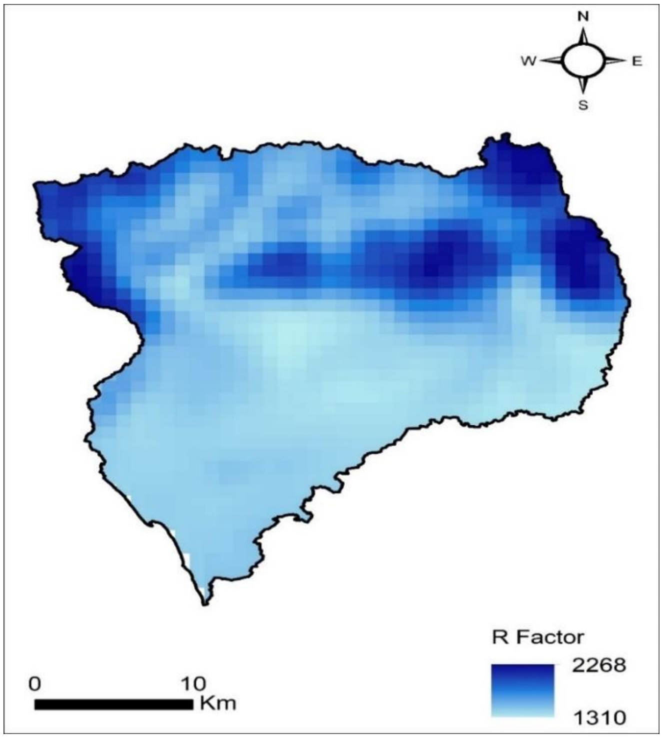

Figure 4. 1 Average Rainfall Pattern of Kibos River Catchment experienced monthly (Kenya methodological department).

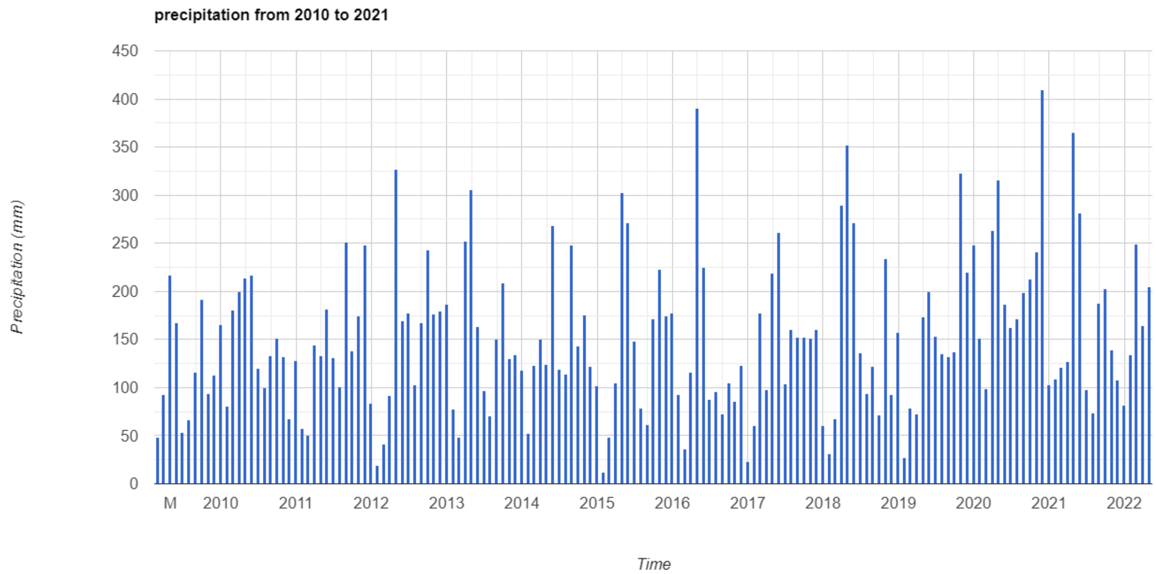

Figure 4. 2 A bar chart of precipitation of Kibos River catchment in the Winam Gulf. Shows monthly estimated rainfall from the year 2010 to 2022 present (Kenya methodological department).

4.1.2 Erodibility Factor

The topography of the area has greatly influenced the overall soil erosion of the area. The erosion factor of the study area ranged from 0.013-0.031 t ha h ha^{-1} MJ^{-1} mm^{-1}, varying the degree of erosion along the Kibos river catchment.

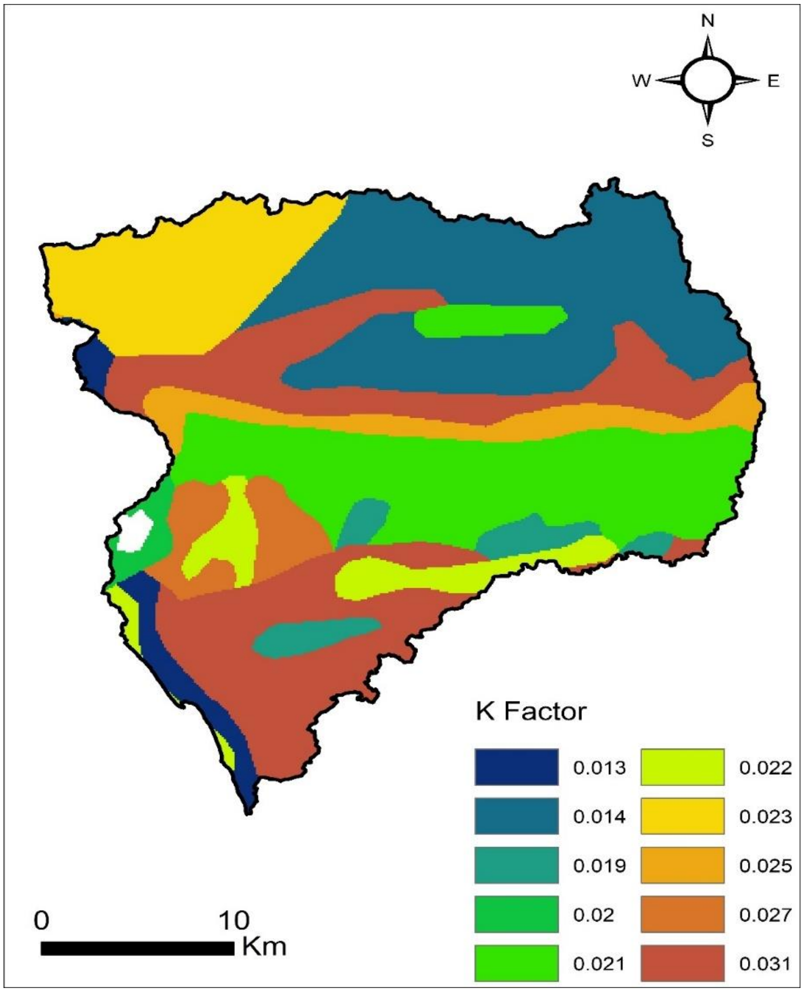

Figure 4. 3 A predictive map of Kibos River catchment showing the soil Erodibility factor in the study area.

The highest Erodibility factor in the catchment for erosion, as shown in Figure 5, is 0.031 t ha h ha^{-1} MJ^{-1} mm^{-1}. This high erosion factor is depicted on the steep slopes of Nandi Hills and the areas bordering the lake. The site is mainly farmed with rice hence the soils in the lower parts are uncosolidated, leading to a high vulnerability to erosion.

4.1.3 Slope Length-Gradient Factor

The topographical factor is the elevation of the study area, which increases soil erosion as the slope and steepness increase. This increase accelerates the fluid movement on the surface, increasing the erosion per unit area.

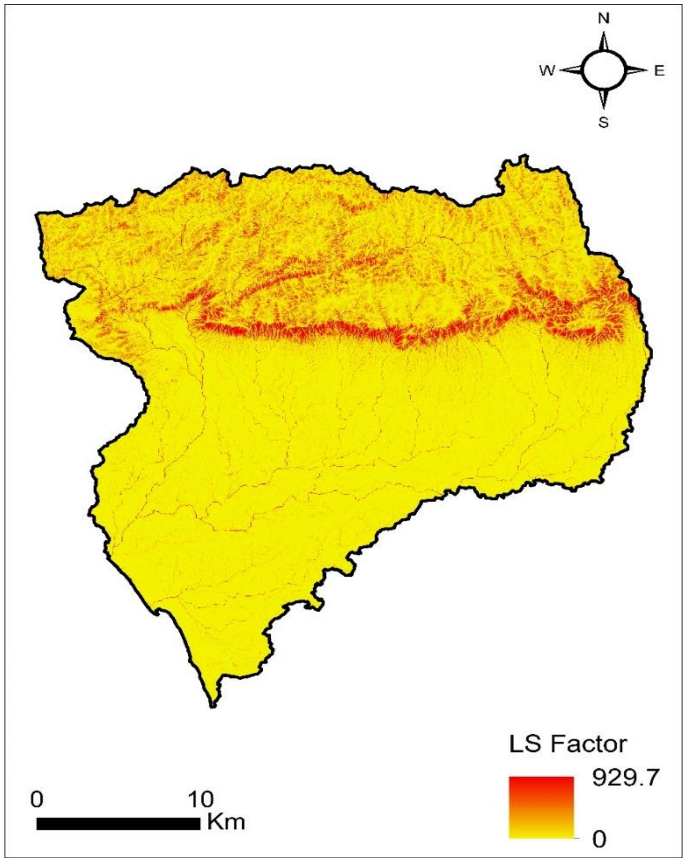

Figure 4. 4 A map shows the topographical factor from the digital elevation model of the Kibos catchment.

The slope of the study area ranges from the rise of 0 to 929.672 meters from the lowest point to the highest point. The upper part of the catchment is the hill part of Nandi hills, in which steep slopes ring, separating the mountainous and lower parts. There are also steep riverbanks all along the Kibos River. After the escarpments of Nandi hills, the catchment contains large sections with a flatbed, enhancing the erosion.

4.1.4 Crop Management Factor

The crop management factor is the assessment of the land's protective capacity against the agents of soil erosion. This agent is mainly wind and rainfall. Protected land is the land that is covered with vegetation, while unprotected is the bare land.

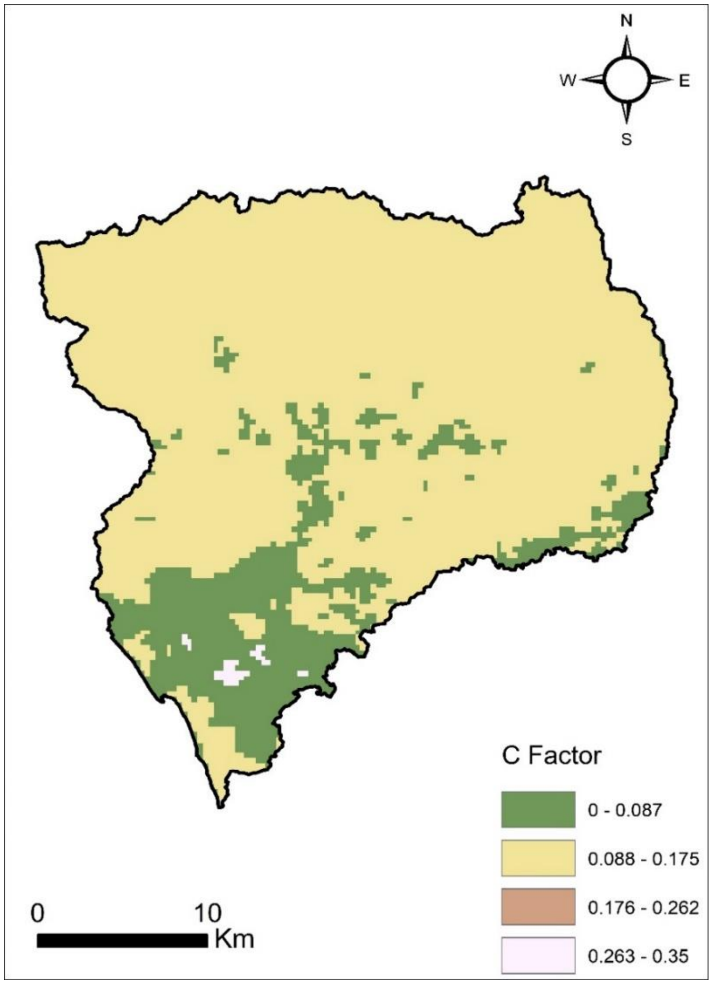

Figure 4. 5 Kibos River catchment land Crop management map.

The crop factor of the study area increased from 0 to 0.35, as shown in Figure 7. The highest value indicates no crop or bare land at the catchment, while the lowest value indicates the ground with much thick cover. The change in agricultural and rainy seasons affects the C factor. There is a different agricultural season in which farmers plant at the beginning of May every year, which increases the land cover and reduces the value of the C factor at the catchment.

4.1.5 Support Practice Factor

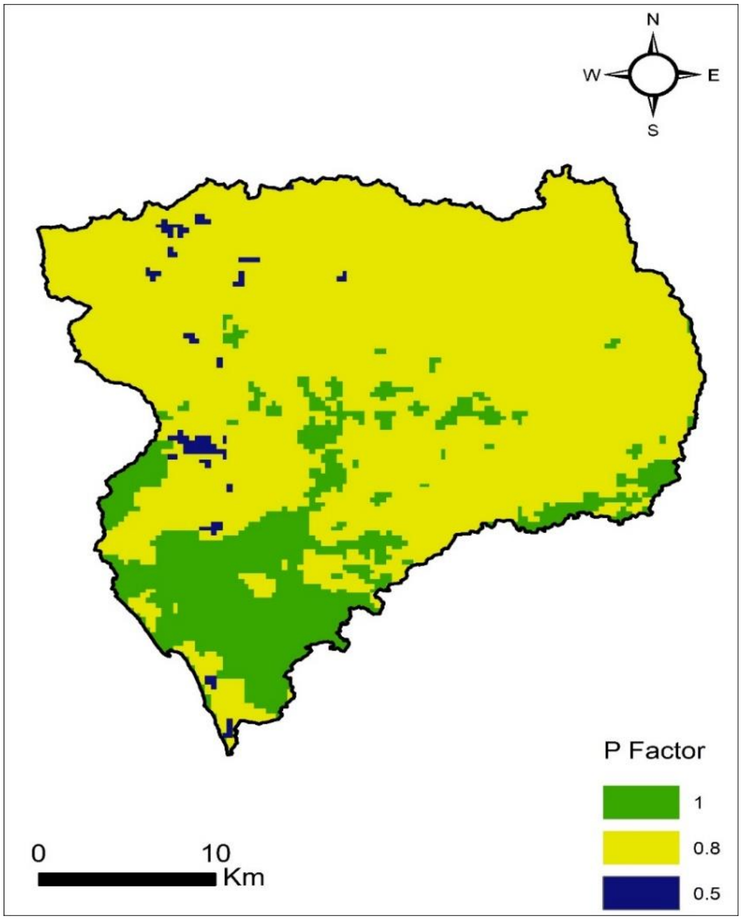

Figure 4. 6 The Map shows the support practice factor depicted in the Kibos River catchment.

After implementing soil and water conservation measures, the conservation measure factor refers to the percentage of soil loss due to planting down the slope. The p-value ranges from 0 to 1. If the number is 0, the area is not affected by soil erosion; if the value is 1, no soil or water conservation measures have been implemented. The values range from 0.5 to 1 as the p values from the catchment. This indicates that all of the areas in the catchment are affected by soil erosion by not implementing preventive agricultural measures. Most of the catchment is recorded at the p-value of 0.8, indicating that the erosion risk is very high.

4.1.6 Erosion risk

Soil erosion risk was estimated from the computational multiplication of all factors as outlined in chapter 3.4. Equation 1 was used to calculate the soil erosion risk by water, as shown in Figure 9.

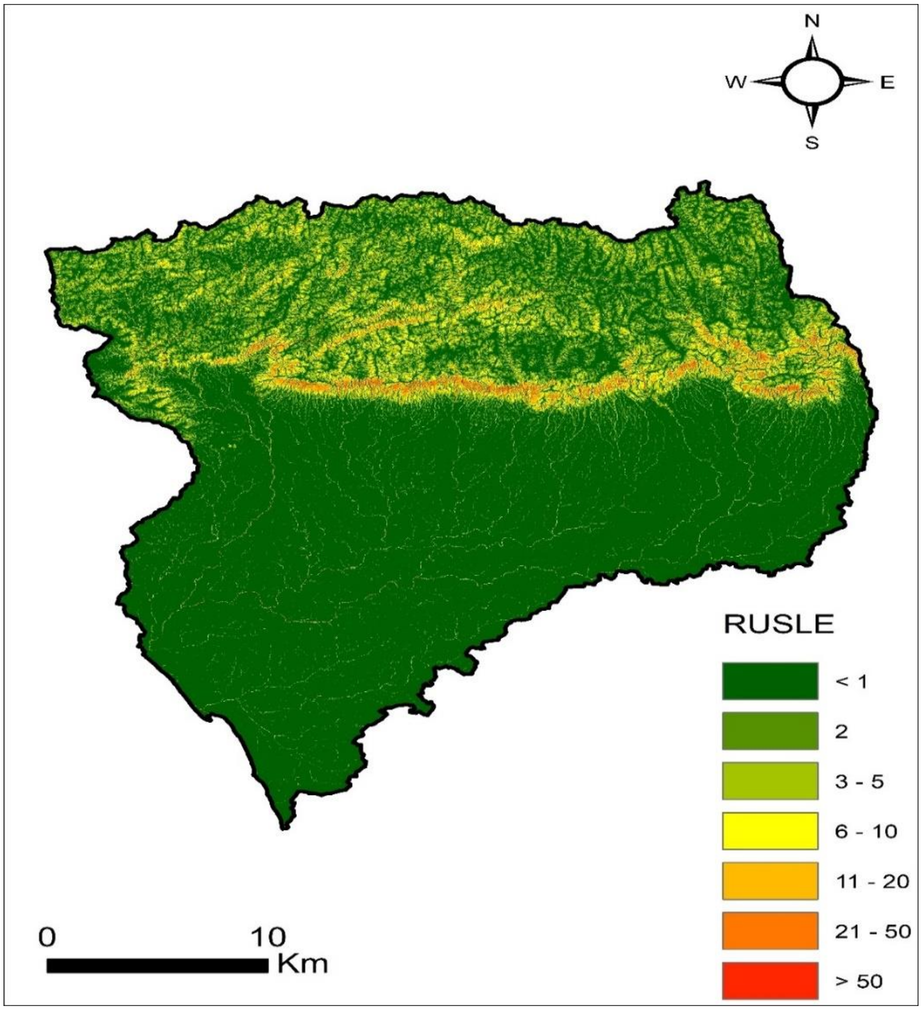

Figure 4. 7 A map from the Kibos river catchment showing the erosion risk.

The highest estimated soil erosion risk based on the RUSLE equation from GIS analysis is more than 50 t/ha/yr. According to the result, this high erosion rate is experienced on the slopes of Nandi hills, while the lowest erosion risk, <1 t ha^{-1} yr^{-1}, is estimated to be in the flat areas of Ahero.

4.2 Land Use and Land Cover Change Detection

Land use and land cover change in the river Kibos catchment area were grouped into seven classes for easy analysis and detection of change. The study used Landsat 8 maps downloaded from USGS. The study was carried out over the past ten years, from 2013 to 2022.

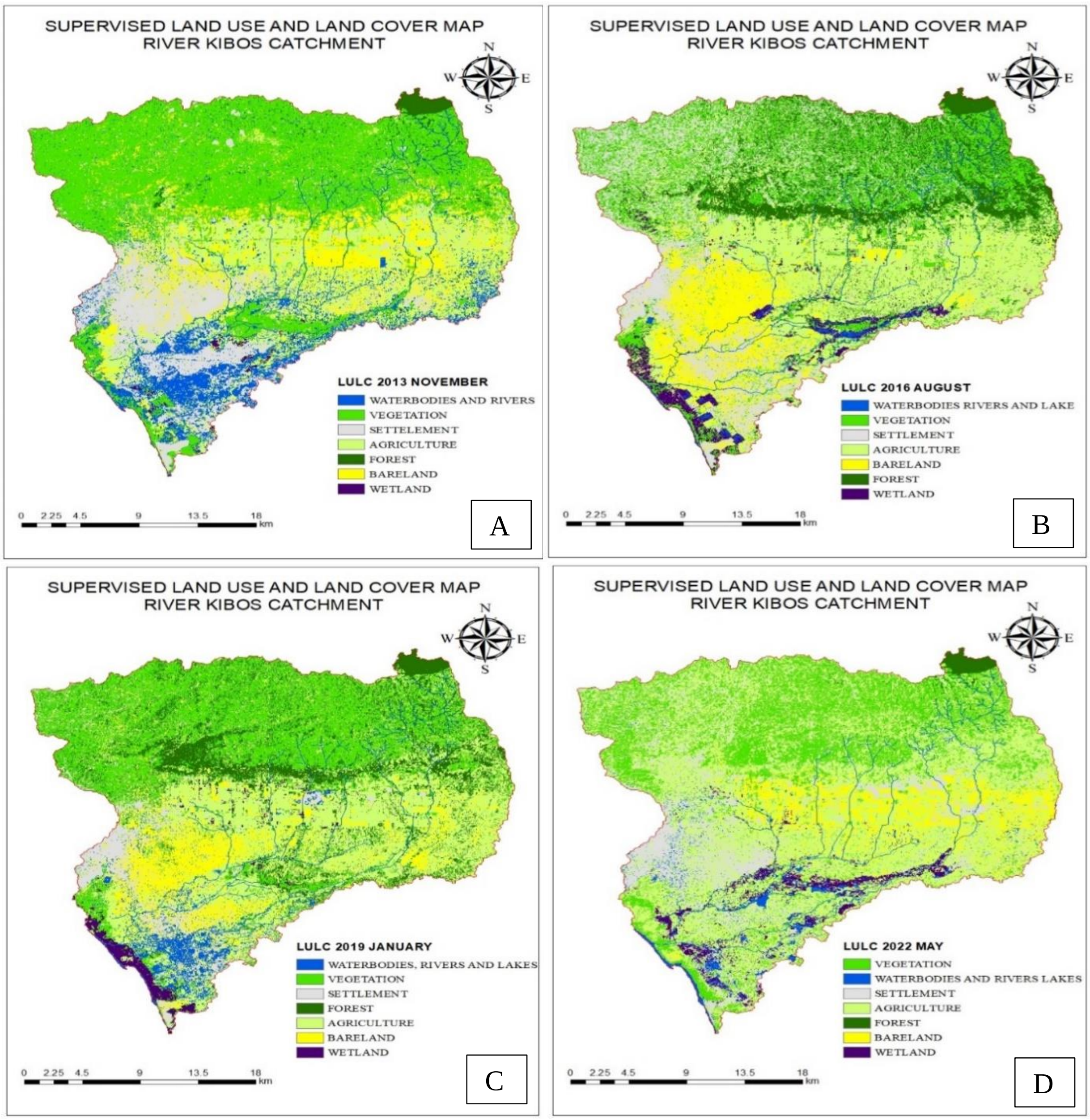

Figure 4. 8 Supervised land use land cover detection for Kibos river catchment using Landsat 8 A-2013 November, B-2016 August, C-2019 January, and D-2022 May.

The study employed supervised classification using Maximum likelihood and composition of band 7 6 2 to imply false color in helping to select Regions of Interest. The classes used in the study to detect change are; vegetation, water bodies, settlement, forest, agriculture, wetland, and bare land. Maps for the past ten years were analysed, and the change was calculated within three years, as shown in Figure 10. Table 3 shows a positive change in agricultural land, with an increase of 27891 ha for agriculture from 2013 to 2022. This indicates the addition of anthropogenic activities along the slopes of Nandi hills and climate change which causes less precipitation.

Table 4. 1 Land use change in hectors between 2013 and 2022. The negative sign indicates a decrease in the size of the land.

	Size (ha)		
Land Use	**2013**	**2022**	**LULC Change**
Agriculture	15456	43348	27891
Bare Land	11120	6659	-4460
Forest	1568	853	-714
Settlement	10236	12194	1958
Vegetation	34573	17814	-16759
Water Bodies	8086	2007	-6079
Wetland	334	2499	2165

Most other land uses changed to agricultural land, as shown in Figure 11, as 62% of bare ground has been converted to agriculture. Most of the land use from 2013 has been mainly changed to agriculture and settlement.

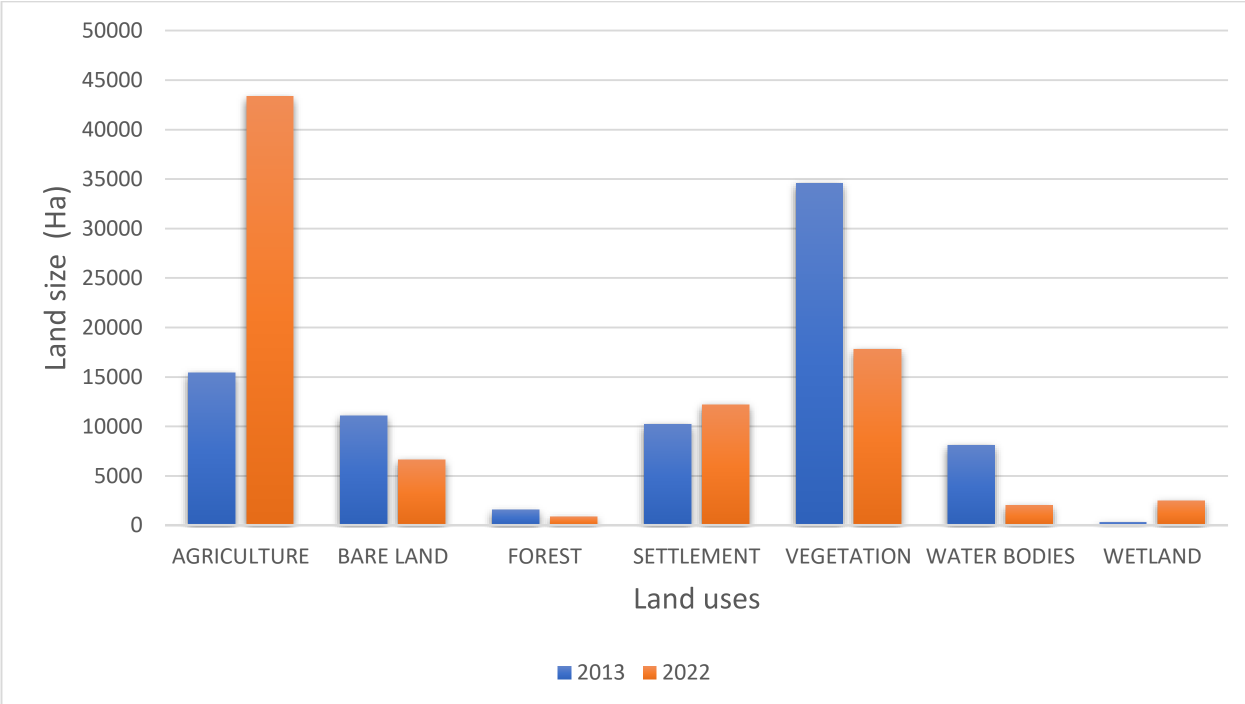

Figure 4. 9 The percentage extent to which various land cover types have changed since 2013-2022.

4.3 Spatial distribution and loss of essential elements in soils from two different land use management

Due to high soil erosion prediction on the steep slopes of Nandi hill, as predicted in Figure 9, and change in land use, as predicted in Figure 11, two different plots were selected for essential elements distribution analysis. The prediction showed a high soil erosion of >50 t ha^{-1} yr^{-1} at the slopes of Nandi hill, accelerated by land use as the area has mainly changed from vegetation to agriculture. The two plots were used for agriculture but different land use management. Plot one was cropped without any mitigation to soil erosion named plot without mitigation. Plot two was farmed with terrace mitigation to control soil erosion; hence called plot with mitigation.

4.3.1 Soil pH

Both plots' topsoil (0-5cm) was dried and analysed for soil pH and organic matter.

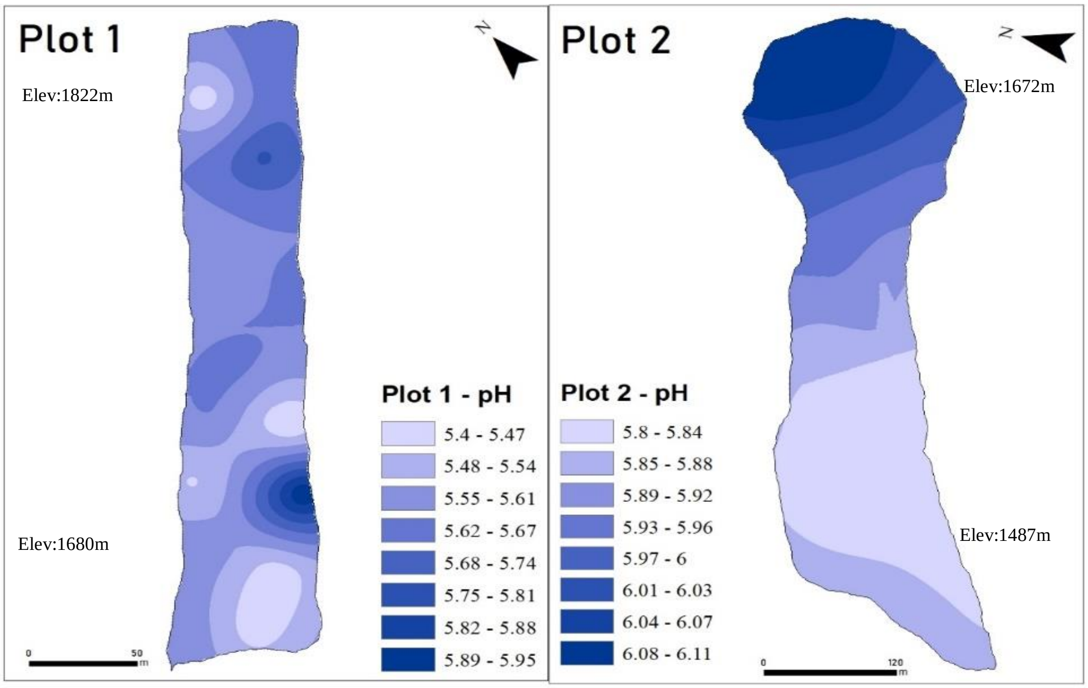

Figure 4. 10 Soil pH of plots one and two for non-mitigated and mitigated plots, respectively. Plot one contained soils with high acid values ranging from 5.40-5.95, while plot two ranged from 5.80-6.11. There is an even distribution of the pH for plot one, as shown in Figure 12. In plot two, the pH at the highest elevation is more basic, 6.08-6.11, while the lower elevation is more acidic, with a pH of 5.80-5.84. The median pH for plot one was 5.58, while that for plot two was 5.90.

4.3.2 Percentage loss on ignition (%LOI)

The organic matter was presented as a percentage of loss-on-ignition (LOI). Organic matter was measured as a loss of ignition; plot one contained more organic matter at the top ranging between 10.41% -11.12%, while reducing at the lower elevation. The lowest LOI detected in plot one is 5.42% -6.13%.

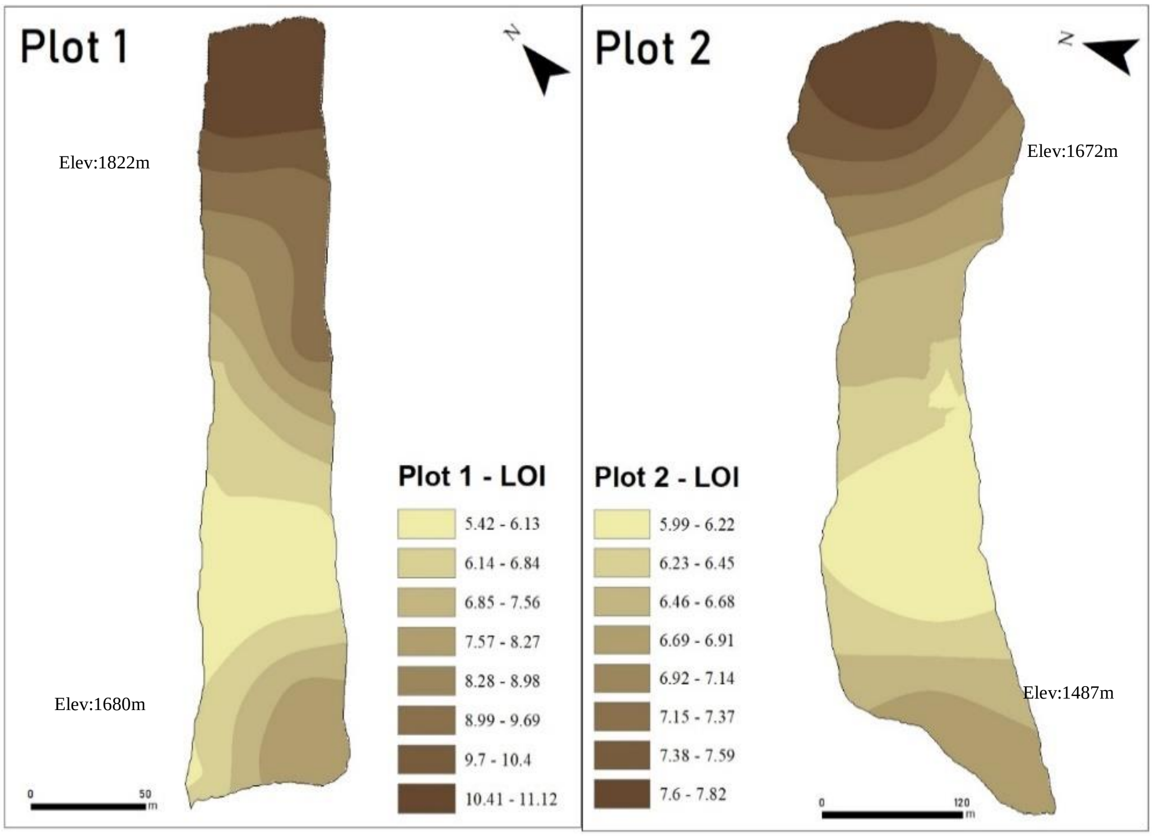

Figure 4. 11 Map Showing Organic matter measure in percentage Loss of Ignition (LOI).

In plot two, the highest detected organic matter ranged from 7.36% to 7.82%, at the highest elevation of 1672 m. The LOI reduced from the top of the plot to the lowest measured of 5.09% - 6.22%, which ranges around 1487 m above sea level. Plot one, without soil erosion mitigation, contained the highest amount of organic matter, with an average of 7.6%, while plot two contained an average of 6.83%.

4.3.3 Iodine

Soil from two plots was analyzed for Total Iodine in which plot one, iodine ranged from 5.33 mg kg^{-1} to 12.12 mg kg^{-1} while that of plot 2 ranged from 3.68 mg kg^{-1} to 4.81 mg kg^{-1}

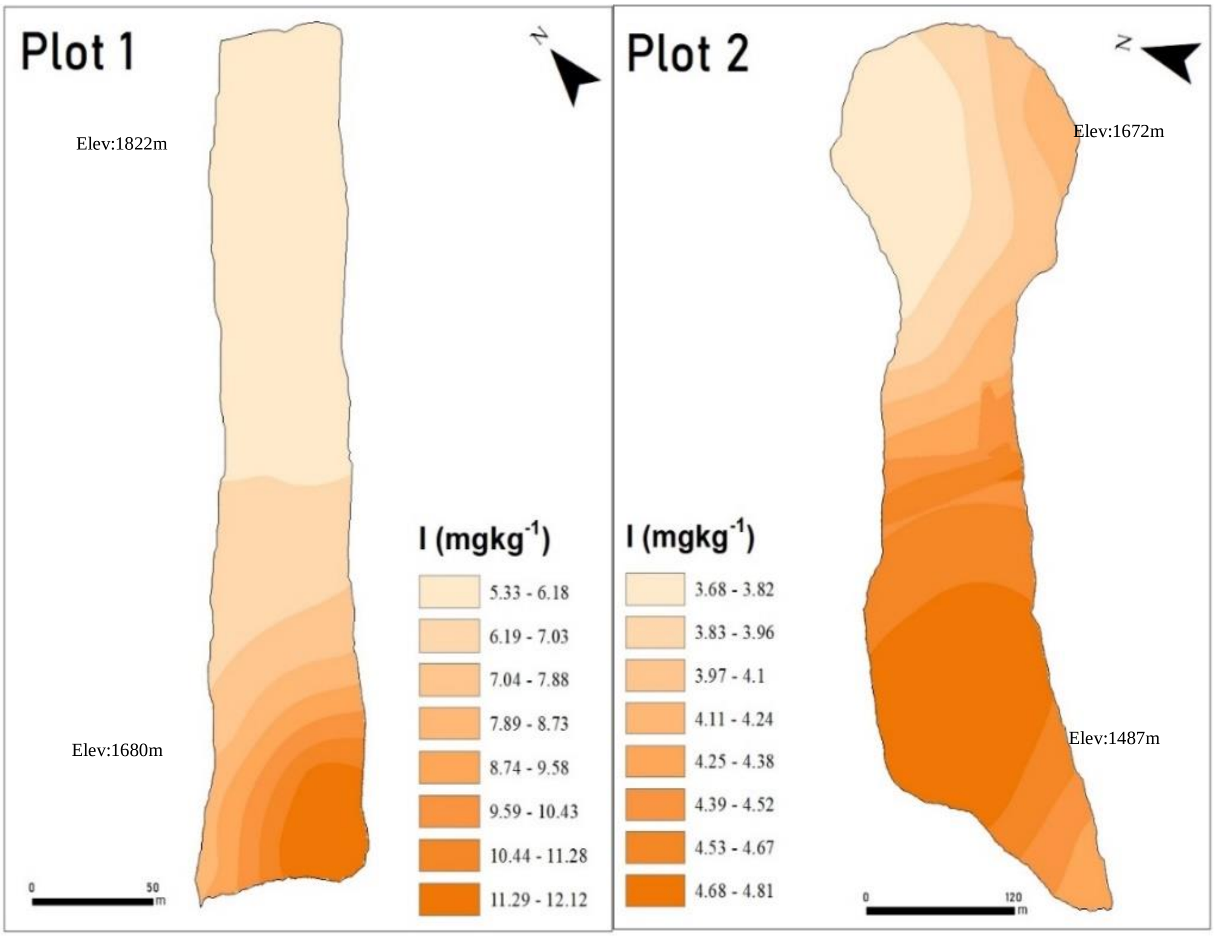

Figure 4. 12 Iodine concentration in mg kg^{-1} for two plots

In both plots, iodine is concentrated at a lower elevation than that high elevation. Iodine in plot one is highly concentrated compared to plot 2. Despite the soil erosion control measures, both plots show the trend in which iodine is washed down the slope by soil erosion, as demonstrated in Figure 14. The influence of the pH in the presence of iodine in the soil and organic matter was estimated using multiple linear regression models using log-transformed for each factor. As analyzed, it is indicated that if pH increases by one standard deviation, the concentration of iodine decrease by -0.649; when the organic matter increases by one standard deviation, iodine concentration in soil increase by 0.233 standard deviation units in both plots.

4.3.4 Calcium

Calcium as a macronutrient contributes to soil fertility by helping maintain flocculating clay particles hence good aeralation in soil. Calcium concentration in both plots ranges from 2848 mg kg^{-1} to 24,431 mg kg^{-1}.

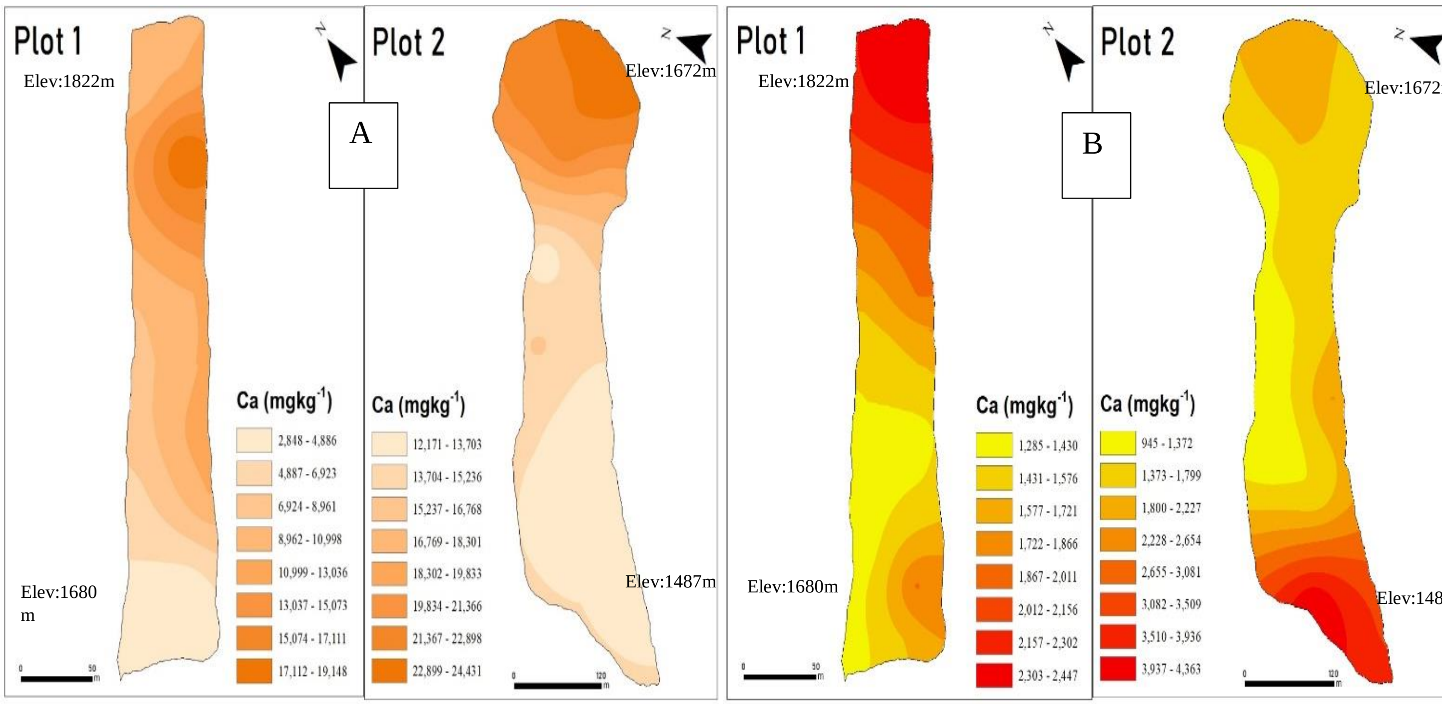

Figure 4. 13 Calcium concentration distribution from plots 1 and 2 extracted with both acid and EDTA extraction.

There is a high calcium concentration in plot two compared to plot one in the high elevation. EDTA extraction concentration represents the amount of elemental concentration that is available for the uptake of plants. As demonstrated in Figure 15b, the available concentration for plant use ranges from 945 mg kg^{-1} to 4363 mg kg^{-1}. Plot one calcium element available for the uptake of plants heavy accumulates in the high elevation compared to plot two, which is highly accumulated at the lower elevation. The highest estimated range in plot one is 2303 mg kg^{-1} to 2447 mg kg^{-1} in plot one and 3937 mg kg^{-1} to 4363 mg kg^{-1} for plot 2. Grass plant was used to determine the uptake of elements by plants

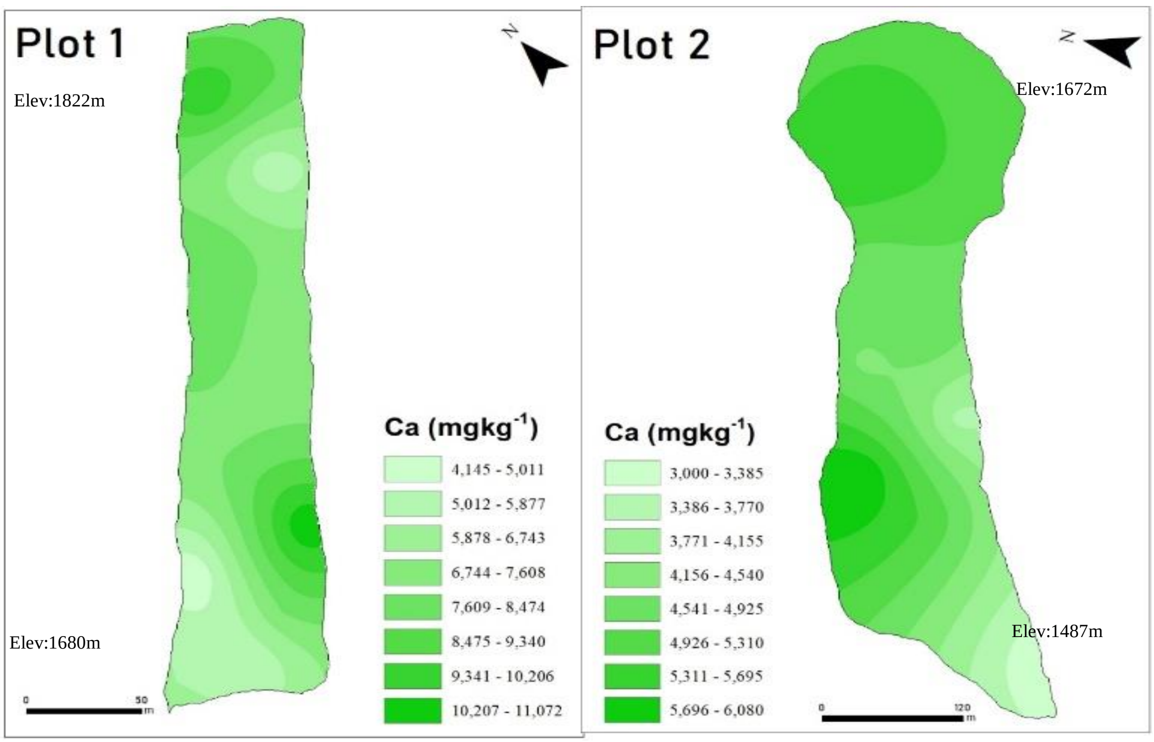

Figure 4. 14 Calcium concentration distribution from plots 1 and 2 extracted acid from the grass plant

Figure 16 shows the distribution of calcium concentration in plants. This indicated the even distribution of concentration from both plots. The highest and lowest concentration analysed from both plots is 11,072 mg kg^{-1} and 3,000 mg kg^{-1}, respectively.

Table 4. 2 Bivariate correlation between plant acid extract calcium concentration, soil EDTA, and Acid from plots 1 and 2.

Calcium						
Plot 1				**Plot 2**		
	Ca Plant	Ca EDTA	Ca Acid	Ca Plant	Ca EDTA	Ca Acid
Ca Plant	1			1		
Ca EDTA	0.307	1		-0.492	1	
Ca Acid	0.167	0.478	1	-0.104	0.304	1

Bivariate correlation between the concentration in plants and that in soil with two different extraction methods indicates that; calcium in plot one is positively more correlated with calcium extracted with EDTA (0.307) as compared to that of acid (0.167). Plot two showed a negative correlation of -0.492 and -0.104 EDTA being more correlated to acid, respectively, as shown in Table 4.

4.3.5 Copper

Copper is an essential element in soil that supports plant life. Soil contains copper in different forms for life support; hence, total copper has been analysed for both mitigated and non-mitigated plots for farming.

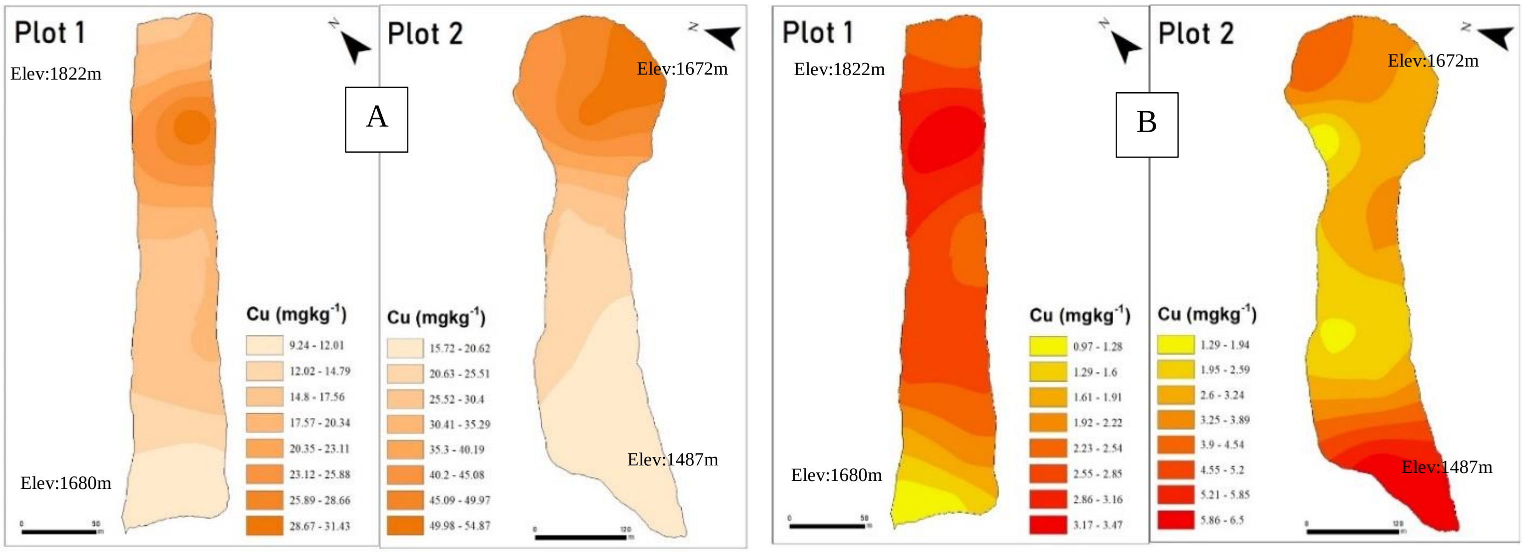

Figure 4. 15: Copper concentration distribution from plots 1 and 2 extracted with both acid and EDTA extraction.

There was a high concentration at the high elevation of both plots, about 31.43 mg kg^{-1} and 54.87 mg kg^{-1}, respectively, for plots 1 and 2. As compared to a lower elevation with a lower acid concentration extracted in Figure 4.15.

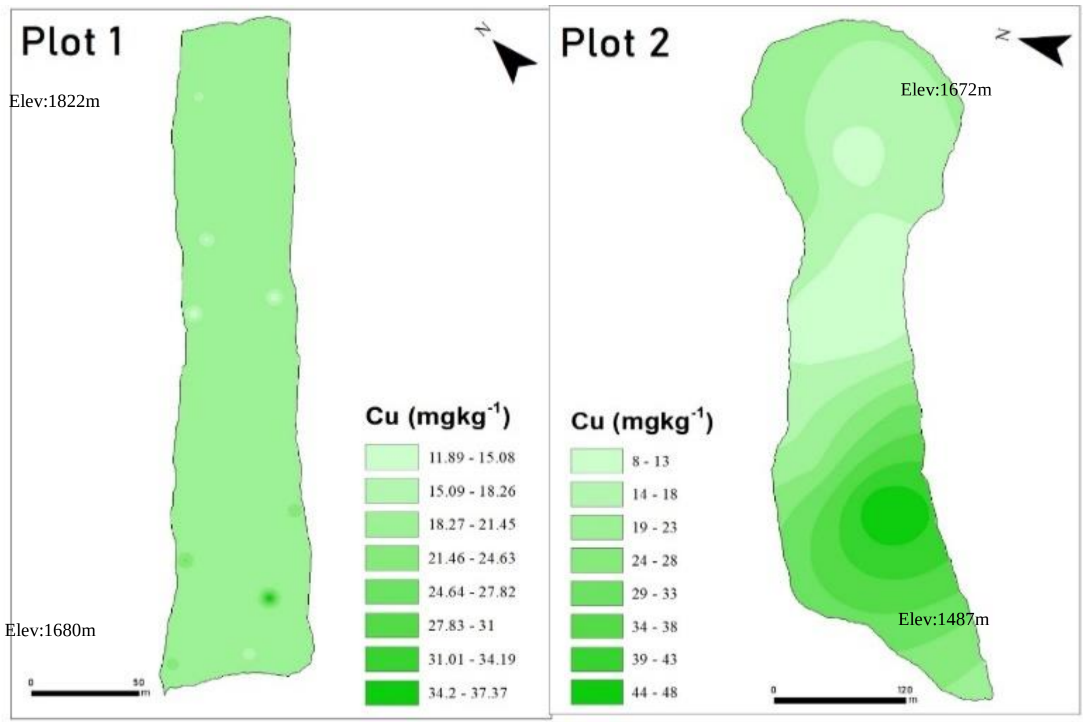

Figure 4. 16 Copper concentration distribution from plots 1 and 2 extracted acid from the grass plant

The trend of copper concentrations in plot one tends to show forms of effects of soil erosion compared to plot two, as shown in Figure 4.16.

Table 4. 3 Bivariate correlation between the copper concentration of plant acid extract soil EDTA and Acid from plots 1 and 2.

Copper						
	Plot 1			**Plot 2**		
	Cu Plant	Cu EDTA	Cu Acid	Cu Plant	Cu EDTA	Cu Acid
Cu Plant	1			1		
Cu EDTA	-0.196	1		-0.398	1	
Cu Acid	-0.104	0.867**	1	-0.328	0.466	1

**. Correlation is significant at the 0.01 level (2-tailed).

Available copper elements extracted by EDTA show a more even distribution in plot 1, as shown in Figure 17b, compared to plot two. Copper available for plant uptake from the two plots ranges from 0.97 mg kg^{-1} to 6.5 mg kg^{-1} of soil. This result generally translates to the concentration of copper in plants (grass), which is evenly distributed in the first plot and accumulated at the base of the second plot. There is more correlation relationship in plot two with negative of -0.398 and -0.328 as compared to plot one with negative -0.196 and -0.104 of EDTA and acid to that of plants, respectively.

4.3.6 Iron

Naturally occurring iron in soils are water insoluble and abundant in many rocks and minerals, which can either be depleted or enriched depending on the area's rock structure and drainage system. No mitigation plot (one) shows the wash down of iron as it more concentrated at the bottom of the plot's lower elevation of 168 m as compared to a high elevation of 182 m. from acid extracted concentration ranges from 20,873 mg kg^{-1} to 58,780 mg kg^{-1} as shown in Figure 19a. EDTA-extracted iron was more concentrated at the high altitude in plot one than in plot two, which is highly concentrated at low altitude. The iron concentration available for the plant's uptake, as shown in Figure 19b, concentrations in plot one were more at the top and bottom of the plot while less at the middle. Plot two is more concentrated at the bottom. The concentration ranged from 104.43 mg kg^{-1} to 511.43 mg kg^{-1}.

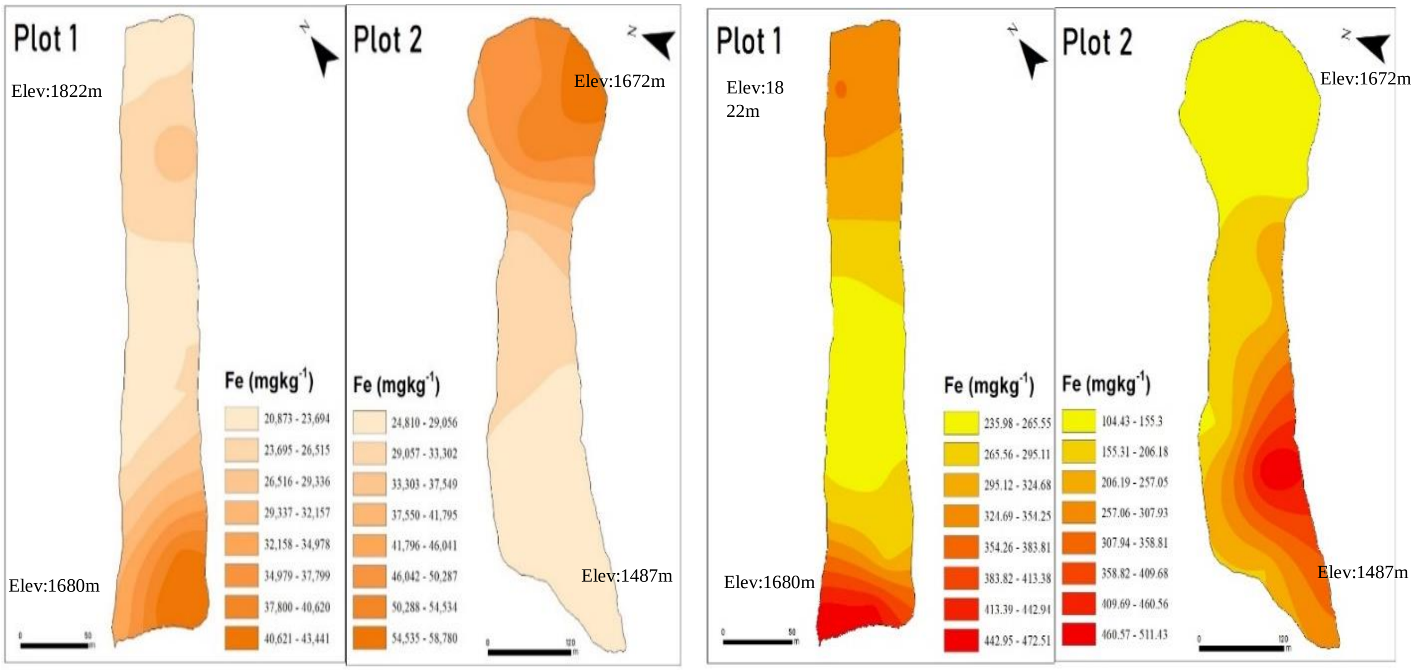

Figure 4. 17 Iron concentration distribution from plots 1 and 2 extracted with both acid and EDTA extraction.

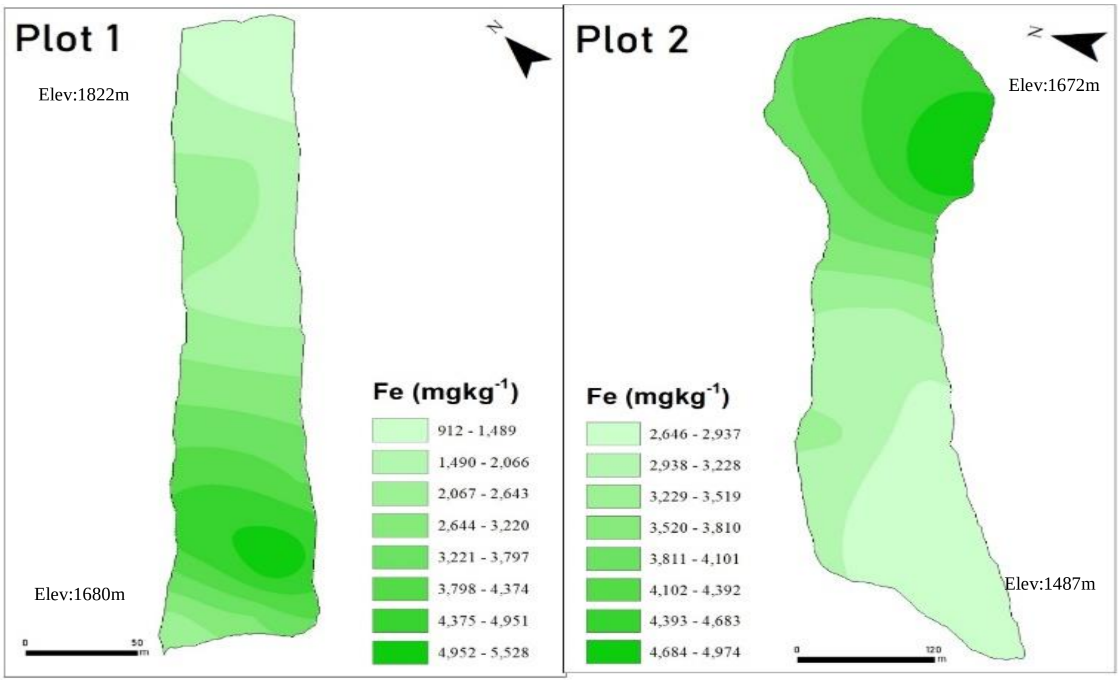

Figure 4. 18 Iron concentration distribution from plots 1 and 2 extracted acid from the grass plant

Plot two farmers practice soil erosion mitigation measures by use of terraces while farming on this sloppy plot. The amount of iron at high elevation is higher with concentrations ranging between 54,535 mg kg^{-1} to 58,780 mg kg^{-1} hence showing a reduction of runoff with soil elements compared to lower elevation with lower concentrations ranging between 24,810 mg kg^{-1} to 29,056 mg kg^{-1} as indicated in Figure 19a.

Table 4. 4 Bivariate correlation between the iron concentration of plant acid extract soil EDTA and Acid from plots 1 and 2.

Iron						
	Plot 1			Plot 2		
	Fe Plant	Fe EDTA	Fe Acid	Fe Plant	Fe EDTA	Fe Acid
Fe Plant	1			1		
Fe EDTA	0.439	1		-0.505	1	
Fe Acid	0.486	0.843**	1	0.716*	-0.543*	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

The high concentration of iron in the grass for plot one is at low altitude, which ranges from 4,952 mg kg^{-1} to 5,528 mg kg^{-1}, while plot two is more concentrated at high altitude, which ranges from 4,684 mg kg^{-1} to 4,974 mg kg^{-1} as shown in Figure 20. in the correlation plot, two concentrations in the plant were more correlated to the acid extracted concentration of iron in soil with 0.716 and a significant value of 0.05.

4.3.7 Magnesium

Magnesium is essential in forming chlorophyll in plants; hence needed, sufficiently in the soil for plant uptake. Magnesium is water soluble regardless of the form; therefore, both plots top soils were analysed for magnesium in the study area. The analysis shows that both plots contain high magnesium concentrations at the high elevation compared to the lower elevation. The concentration of acid-extracted magnesium ranges from 1,368 mg kg^{-1} to 19,236 mg kg^{-1} in both plots, as shown in Figure 21a. EDTA extracted magnesium available for plant uptake ranged from 86.24 mg kg^{-1} to 375.55 mg kg^{-1}, which it was more concentrated in plot one at high altitudes while plot two was more concentrated at lower altitudes.

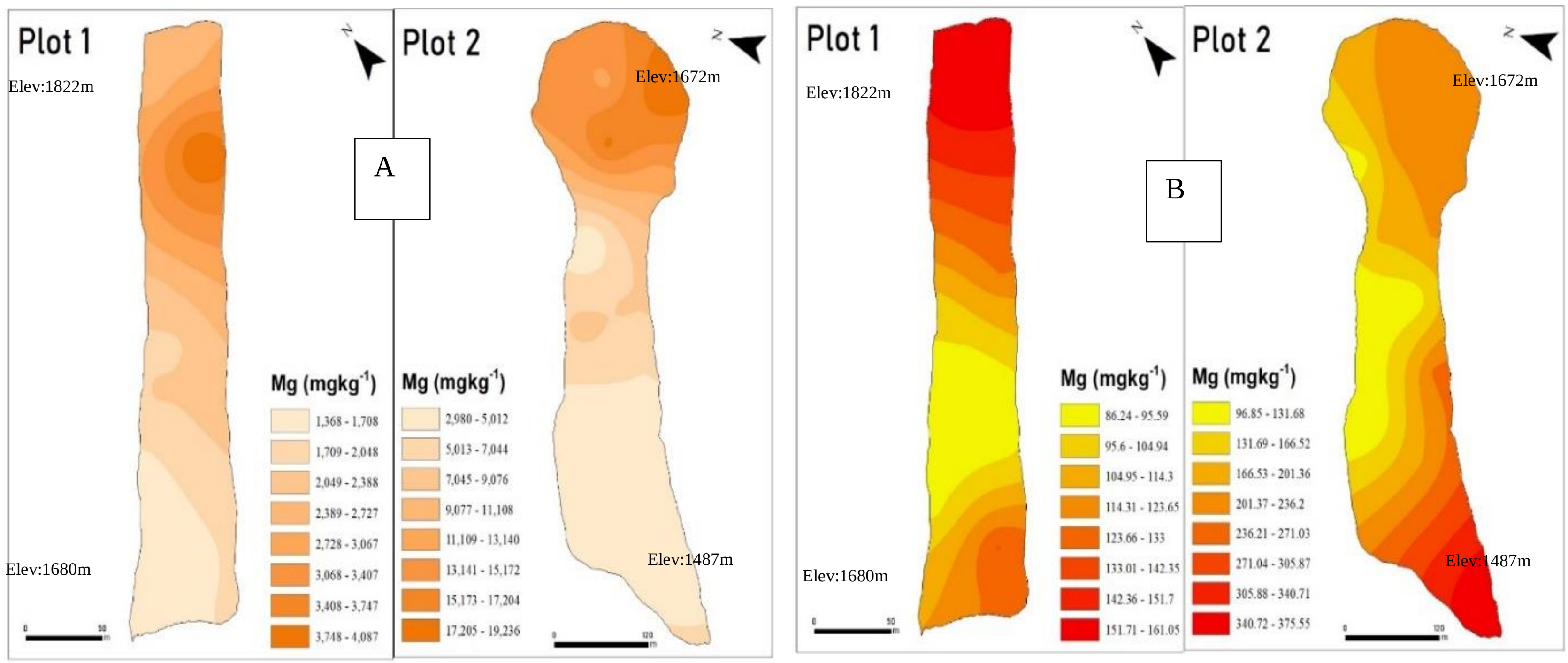

Figure 4. 19 Magnesium concentration distribution from plots 1 and 2 extracted with both acid and EDTA extraction from soil. Plant Concentration ranges from 1,771 mg kg^{-1} to 6,379 mg kg^{-1} for all the plots. Plot one has more concentration in the middle compared to the plot's top and bottom.

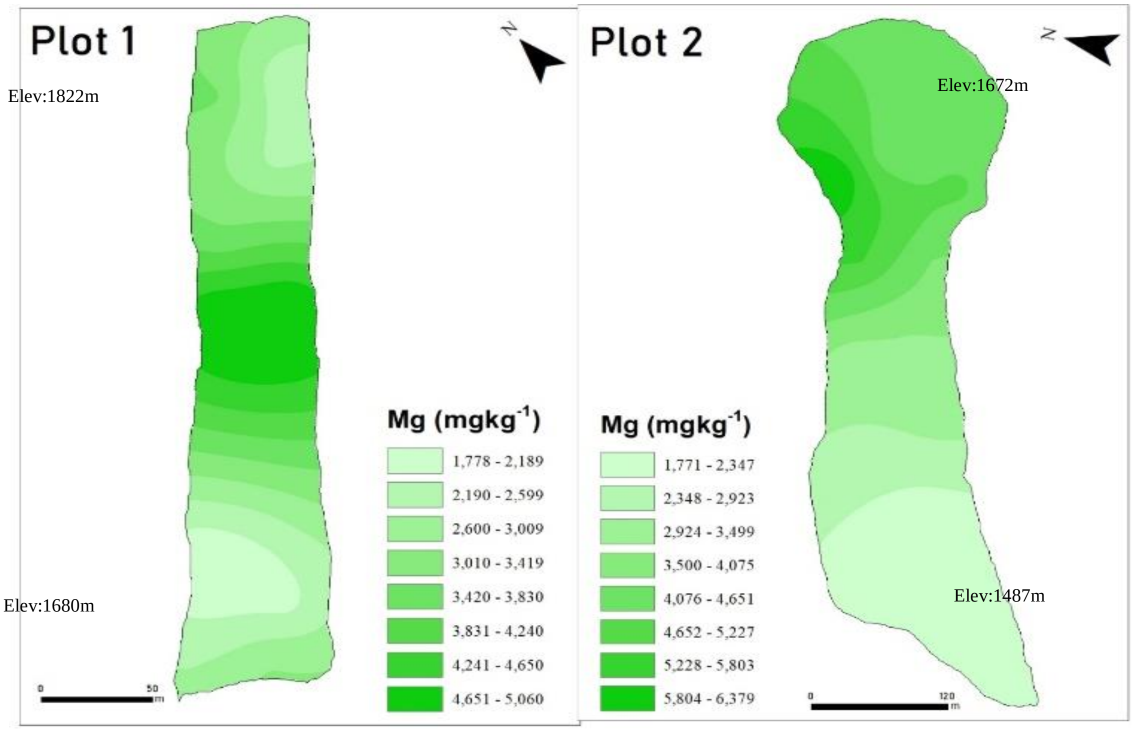

Figure 4. 20 Magnesium concentration distribution from plots 1 and 2 extracted acid from the grass plant

In plot two, magnesium in the grass was highly concentrated at the top of the plot. As indicated in Figure 22. the correlation between magnesium concentration in soil and plant for EDTA extract and acid extracts for plot one is 0.178 and 0.234, respectively.

Table 4. 5 ***Bivariate correlation between magnesium concentration of plant acid extract soil EDTA and Acid from plots 1 and 2***

Magnesium						
	Plot 1			Plot 2		
	Mg Plant	Mg EDTA	Mg Acid	Mg Plant	Mg EDTA	Mg Acid
Mg Plant	1			1		
Mg EDTA	0.178	1		0.248	1	
Mg Acid	0.234	0.672**	1	0.247	0.205	1

**. Correlation is significant at the 0.01 level (2-tailed).

4.3.8 Selenium

Selenium-rich rocks enrich the soil with selenium through weathering, which is highly absorbed in clay particles. Selenium is known to be insoluble in water. From the study, both plots' top soils were analysed for selenium.

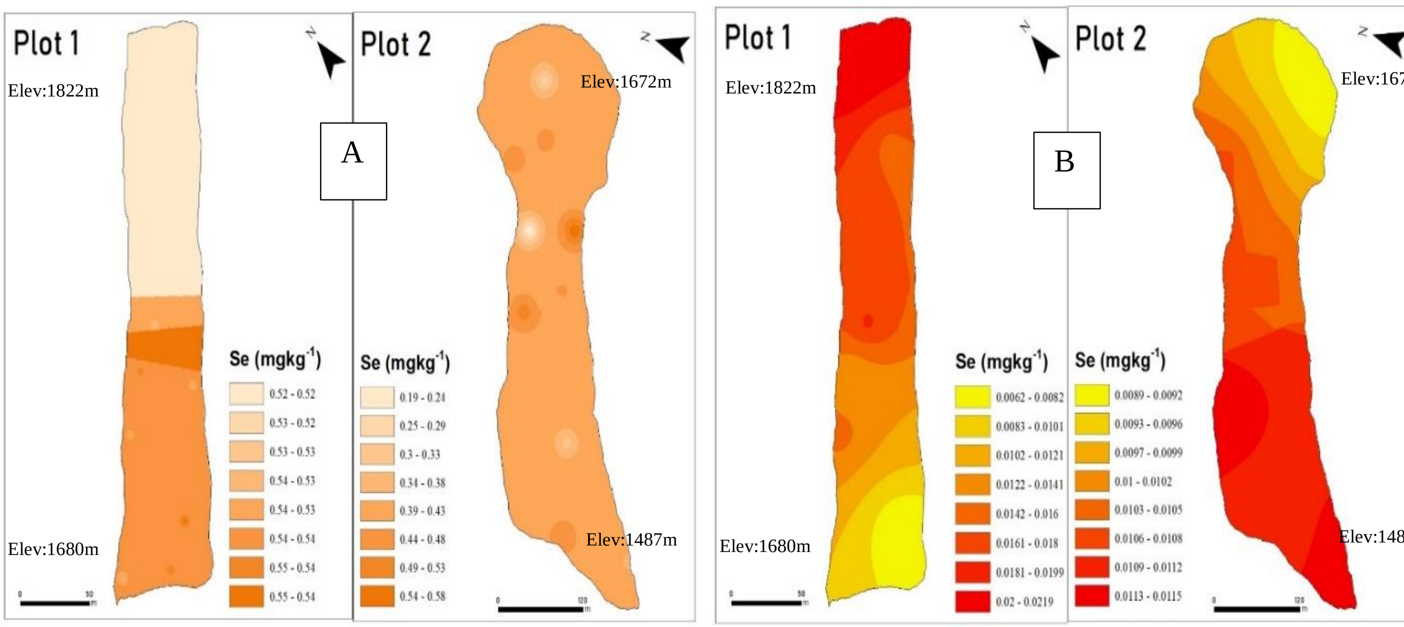

Figure 4. 21 Selenium concentration distribution from plots 1 and 2 extracted with both acid and EDTA extraction

Plot one selenium has been washed to the bottom of the plot by water erosion as it is the major agent of selenium distribution and deposition. For the available element of magnesium in both plot ranged from 0.0062 mg kg^{-1} to 0.0219 mg kg^{-1}. More concentrated at the top of plot one and bottom in plot two.

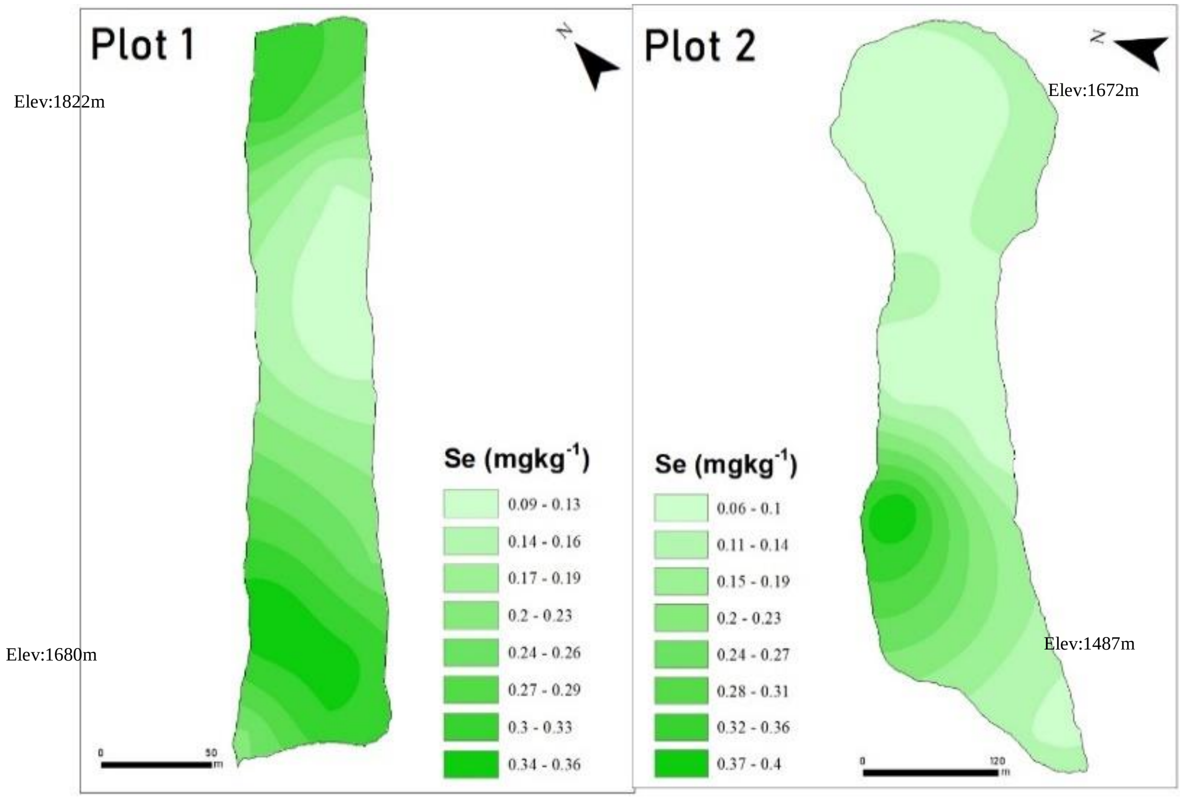

Figure 4. 22 Selenium concentration distribution from plots 1 and 2 extracted acid from the grass plant

The concentrations range from 0.52 mg kg^{-1} to 0.54 mg kg^{-1} for plot one and 0.19 mg kg^{-1} to 0.58 mg kg^{-1} for plot two, as shown in Figure 23. There is an indication of even distribution of selenium in plot two, indicating less soil erosion due to the mitigation measures applied during farming.

Table 4. 6 Bivariate correlation between selenium concentration of plant acid extract soil EDTA and Acid from plots 1 and 2.

Selenium						
	Plot 1			**Plot 2**		
	Se Plant	Se EDTA	Se Acid	Se Plant	Se EDTA	Se Acid
Se Plant	1			1		
Se EDTA	-0.118	1		-0.022	1	
Se Acid	0.329	-0.598*	1	-0.133	0.435	1

*. Correlation is significant at the 0.05 level (2-tailed).

The correlation between the EDTA extracted and acid extracted soil selenium in plants is low, as indicated in Table 8.

4.3.9 Zinc

Naturally occurring zinc in the soil is insoluble in water and is available depending on the areas parent rock.

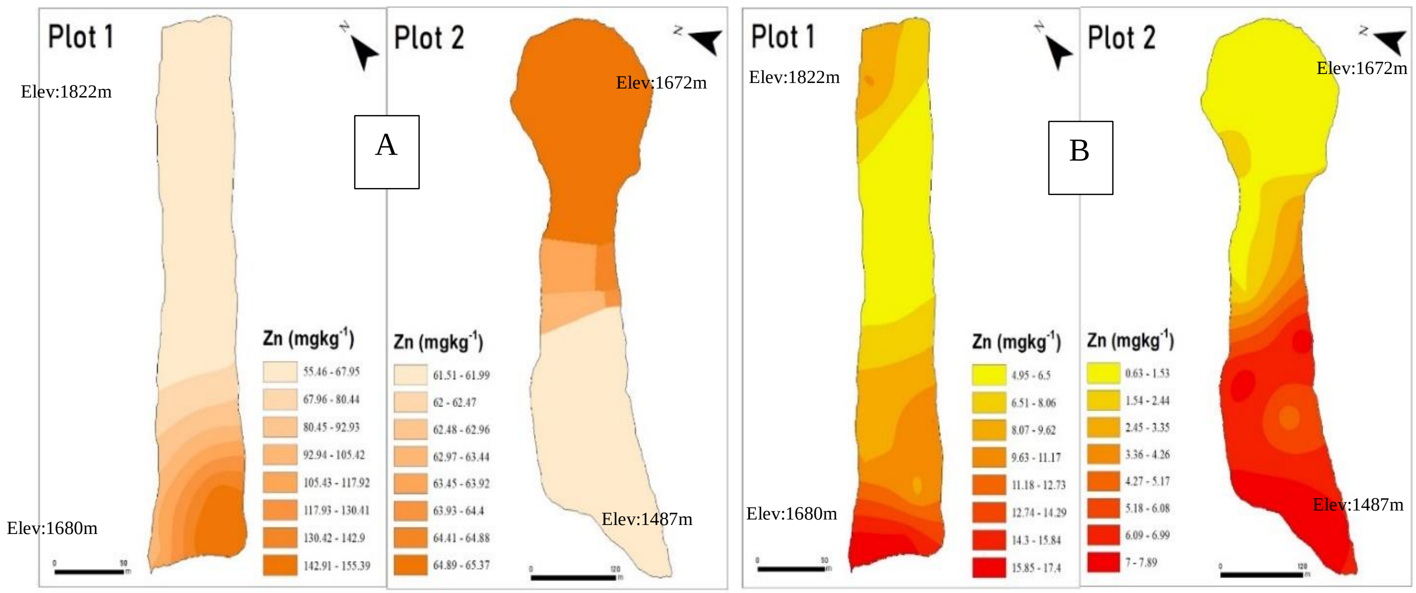

Figure 4. 23 Zinc concentration distribution from plots 1 and 2 extracted with both acid and EDTA extraction

From the analysis of the topsoil of plots one and two, zinc is highly concentrated at the plot's lower elevation compared to the higher elevation. The zinc concentration in both plots ranges from 55.46 mg kg^{-1} to 155.39 mg kg^{-1} for plot one and 61.51 mg kg^{-1} to 65.37 mg kg^{-1} for plot two, with a median of 62.4 mg kg^{-1} and 61.2 mg kg^{-1}, respectively as indicated in Figure 25.

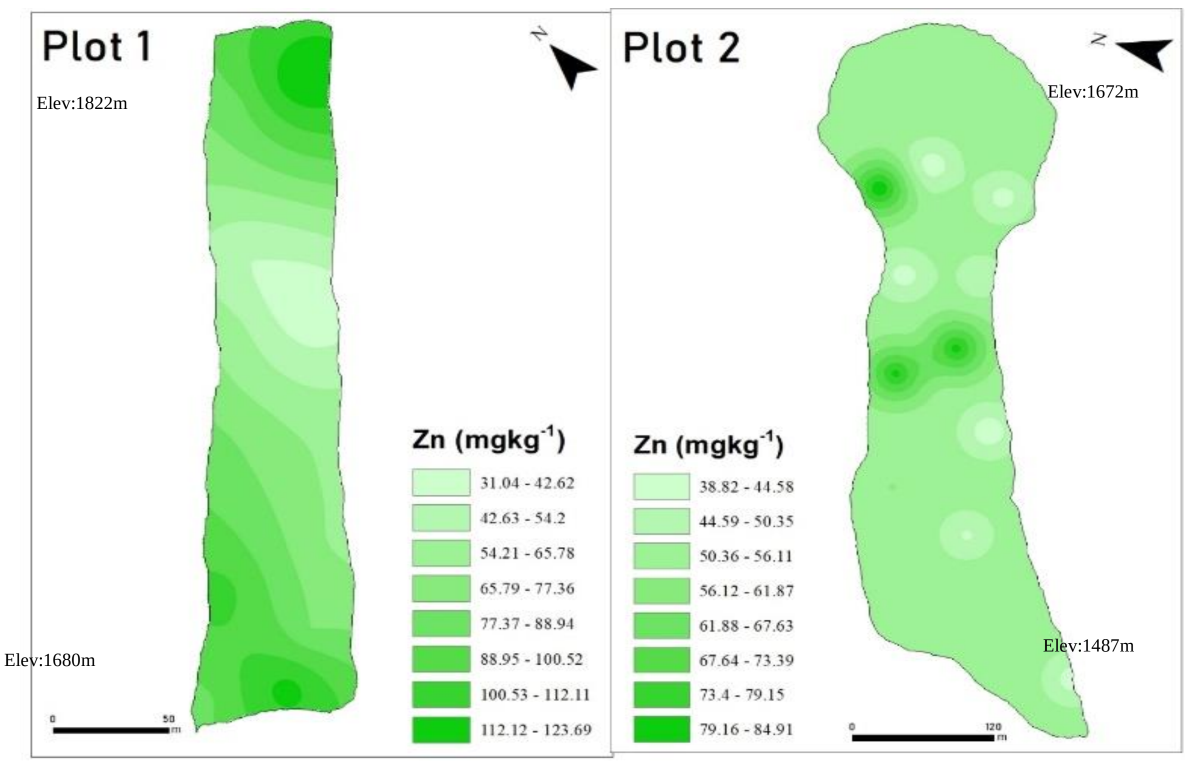

Figure 4. 24 Zinc concentration distribution from plots 1 and 2 extracted acid from the grass plant

For the readily available zinc for plants uptake, there is a high concentration at low altitudes, with the total concentration of plots one and two ranging from 4.95 mg kg^{-1} to 17.4 mg kg^{-1} and 0.63 mg kg^{-1} to 7.89 mg kg^{-1}, respectively as shown in Figure 15b.

Table 4. 7 Bivariate correlation between zinc concentration of plant acid extract soil EDTA and Acid from plots 1 and 2.

Zinc						
	Plot 1			Plot 2		
	Zn Plant	Zn EDTA	Zn Acid	Zn Plant	Zn EDTA	Zn Acid
Zn Plant	1			1		
Zn EDTA	0.424	1		-0.022	1	
Zn Acid	0.326	0.851**	1	-0.342	-0.282	1

**. Correlation is significant at the 0.01 level (2-tailed)

There was a positive correlation for zinc concentration in grass plants obtained from the plot with acid extracted and EDTA extracted soils of 0.424 and 0.326, respectively. The concentration in plot one is evenly distributed, ranging from 31.04 mg kg^{-1} to 123.69 mg kg^{-1}, as shown in Figure 26. for plot two, the correlation was negative of -0.022 and -0.342 between grass and EDTA and acid extracted concentrations from the soil. The concentration in plot two ranges from 38.82 mg kg^{-1} to 84.91 mg kg^{-1}, and zinc is concentrated at the plot's low altitude.

4.3.10 Molybdenum

Molybdenum is an essential element highly required for symbiotic nitrogen fixation by rhizobia bacteria. It is soluble in water as a compound of other elements.

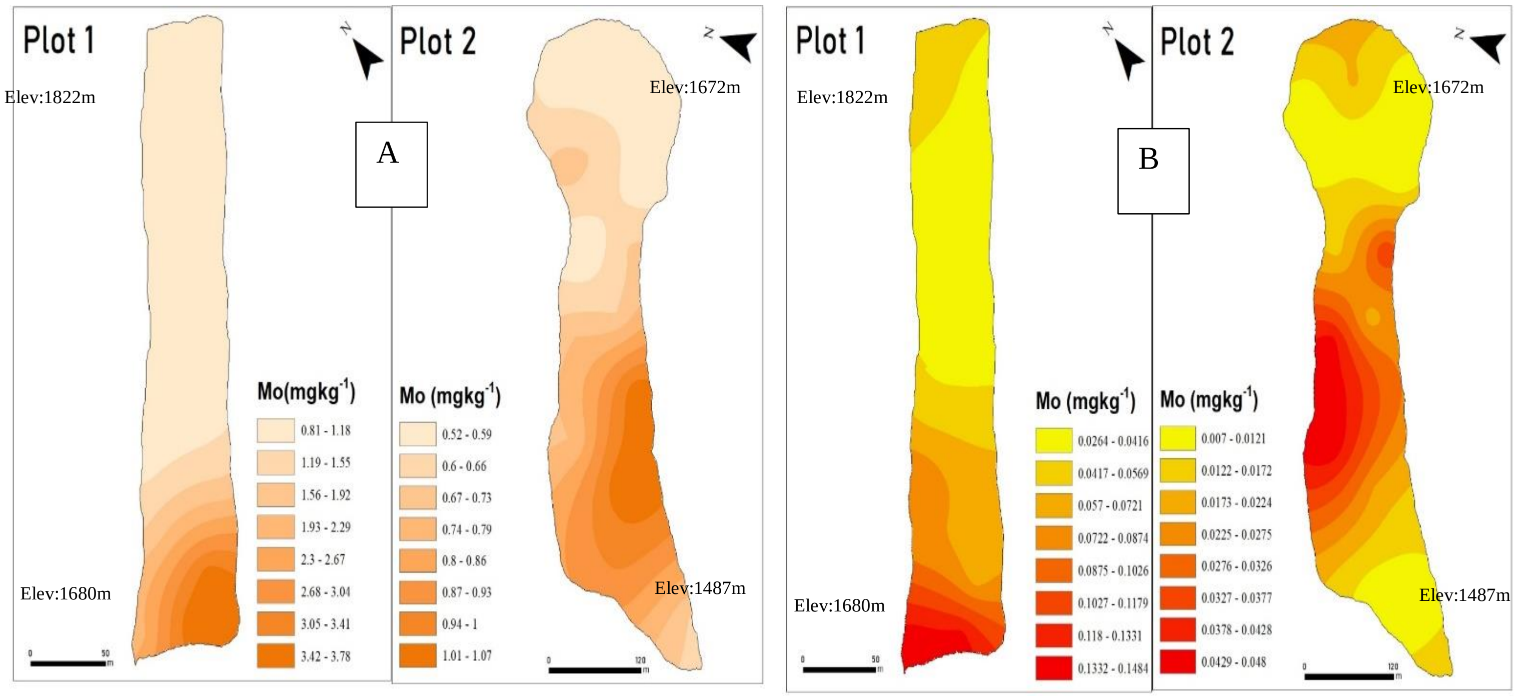

Figure 4. 25 Molybdenum concentration distribution from plots 1 and 2 extracted with both acid and EDTA extraction

For plots one and two, the element molybdenum is concentrated at the lower elevation.

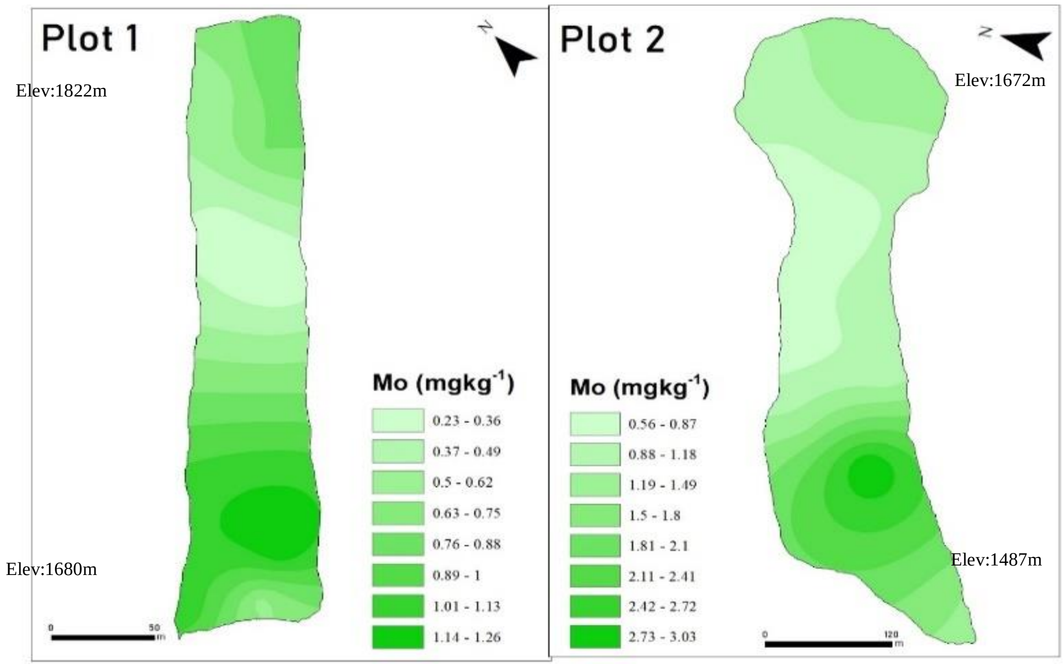

Figure 4. 26 Molybdenum concentration distribution from plots 1 and 2 extracted acid from the grass plant

The amount of molybdenum is more in plot one than in plot two, with a p-value of <0.05. The median for plot one is 0.94 mg kg^{-1}, and two is 0.66 mg kg^{-1}, as shown in Figure 27a.

Table 4. 8 Bivariate correlation between molybdenum concentrations of both plant acid extract soil EDTA and Acid from plots 1 and 2

Molybdenum						
	Plot 1			**Plot 2**		
	Mo Plant	Mo EDTA	Mo Acid	Mo Plant	Mo EDTA	Mo Acid
Mo Plant	1			1		
Mo EDTA	0.483	1		0.551	1	
Mo Acid	0.255	0.872**	1	0.364	0.696**	1

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 27b shows the EDTA extraction of molybdenum from the soils of both plots, and the result shows a high concentration of the same element at low altitudes. Total concentration ranges between 0.007 mg kg^{-1} to 0.1484 mg kg^{-1}. Molybdenum in grass plants was also concentrated at the bottom of both plots, with a total concentration ranging from 0.23 mg kg-1 to 3.03 mg kg-1.

4.3.11 Phosphorous

Phosphorous is used by plants in the storage and transfer of energy produced by photosynthesis for growth. It is slightly soluble in water. Both plots' topsoil samples were analysed for total phosphorous and available amount for plant uptake.

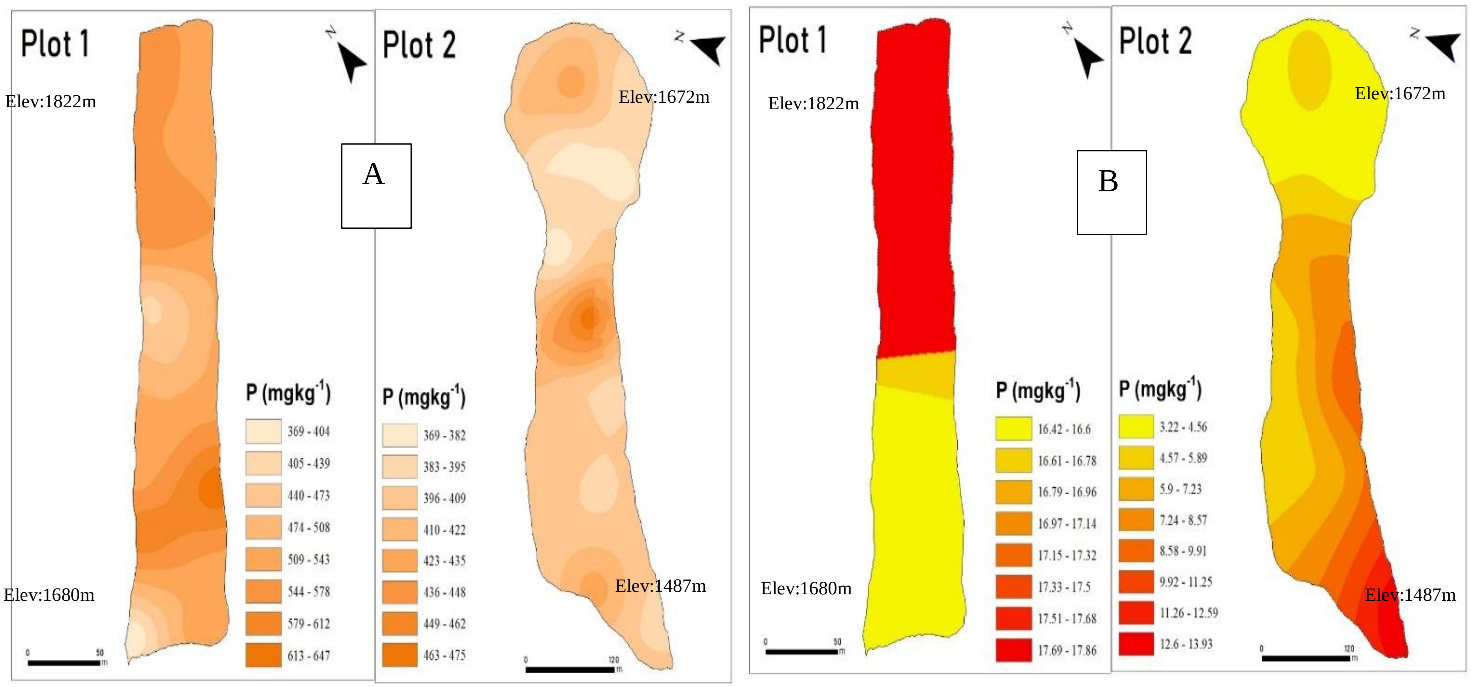

Figure 4. 27 Phosphorous concentration distribution from plots 1 and 2 extracted with both acid and EDTA extraction

The element is evenly distributed in both plots, with the minimum concentration ranging between 369 mg kg^{-1} to 647 mg kg^{-1}. Plot one contains a higher concentration than the two, with a median of 523.43 mg kg^{-1} and 367.59 mg kg^{-1}, respectively. For EDTA extraction, phosphorous was highly concentrated at the top of plot one while at the bottom of plot two. The total concentration from both plots ranged from 3.22 mg kg^{-1} to 17.86 mg kg^{-1}, as shown in Figure 29b. Grass concentration of phosphorous shows that the grass from the bottom of both plots was enriched with phosphorous concentration compared to that of high altitude. Figure 30 shows the distribution of phosphorous concentration in plots one and two, with the concentration ranges between 940 mg kg^{-1} to 4,418 mg kg^{-1}.

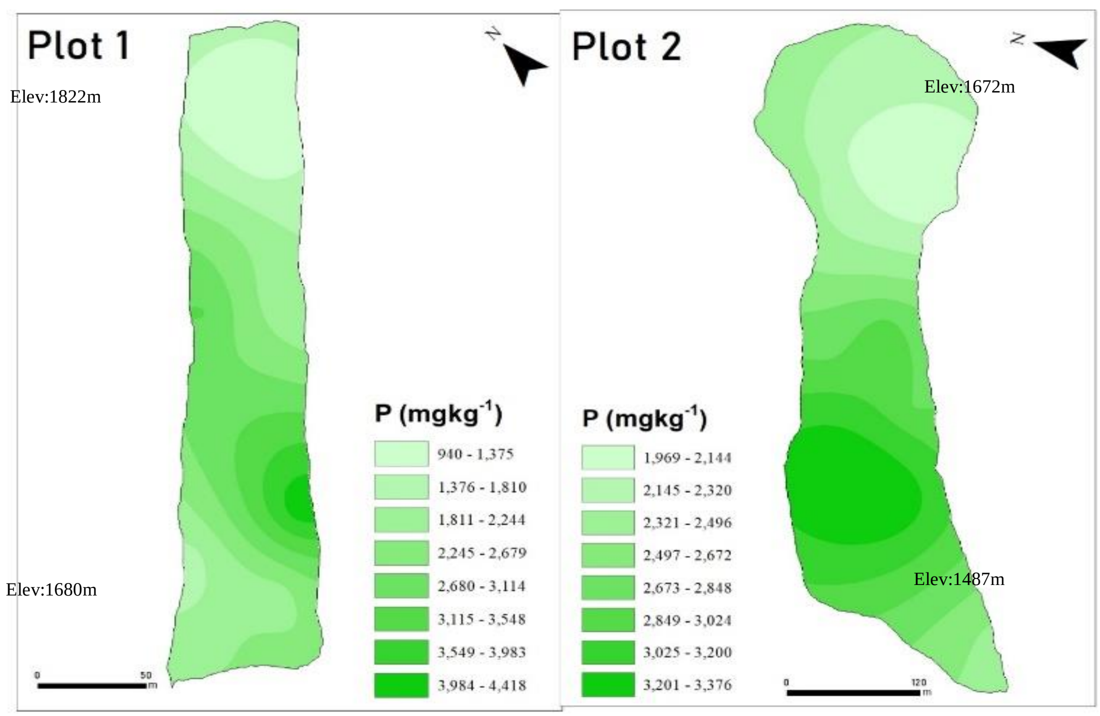

Figure 4. 28 Phosphorous concentration distribution from plots 1 and 2 extracted acid from the grass plant

Table 4. 9 Bivariate correlation between the phosphorous concentration of plant acid extract soil EDTA and Acid from plots 1 and 2

Phosphorous						
Plot 1				Plot 2		
	P Plant	P EDTA	P Acid	P Plant	P EDTA	P Acid
P Plant	1			1		
P EDTA	0.558	1		0.408	1	
P Acid	0.157	0.742**	1	0.221	0.429	1

**. Correlation is significant at the 0.01 level (2-tailed).

Both correlations between plant and soil are positive in that plant and EDTA soil extracted phosphorous is the highest with .558, as shown in Table 11.

4.3.12 Potassium

Table 4. 10 Bivariate correlation between potassium concentration of plant acid extract soil EDTA and Acid from plots 1 and 2.

Potassium						
Plot 1				Plot 2		
	K Plant	K EDTA	K Acid	K Plant	K EDTA	K Acid
K Plant	1			1		
K EDTA	0.012	1		0.554	1	
K Acid	0.030	-0.483	1	0.288	-0.088	1

In plots one and two, potassium concentrations are fairly distributed across the whole area, reducing in areas constantly under cultivation at high altitudes.

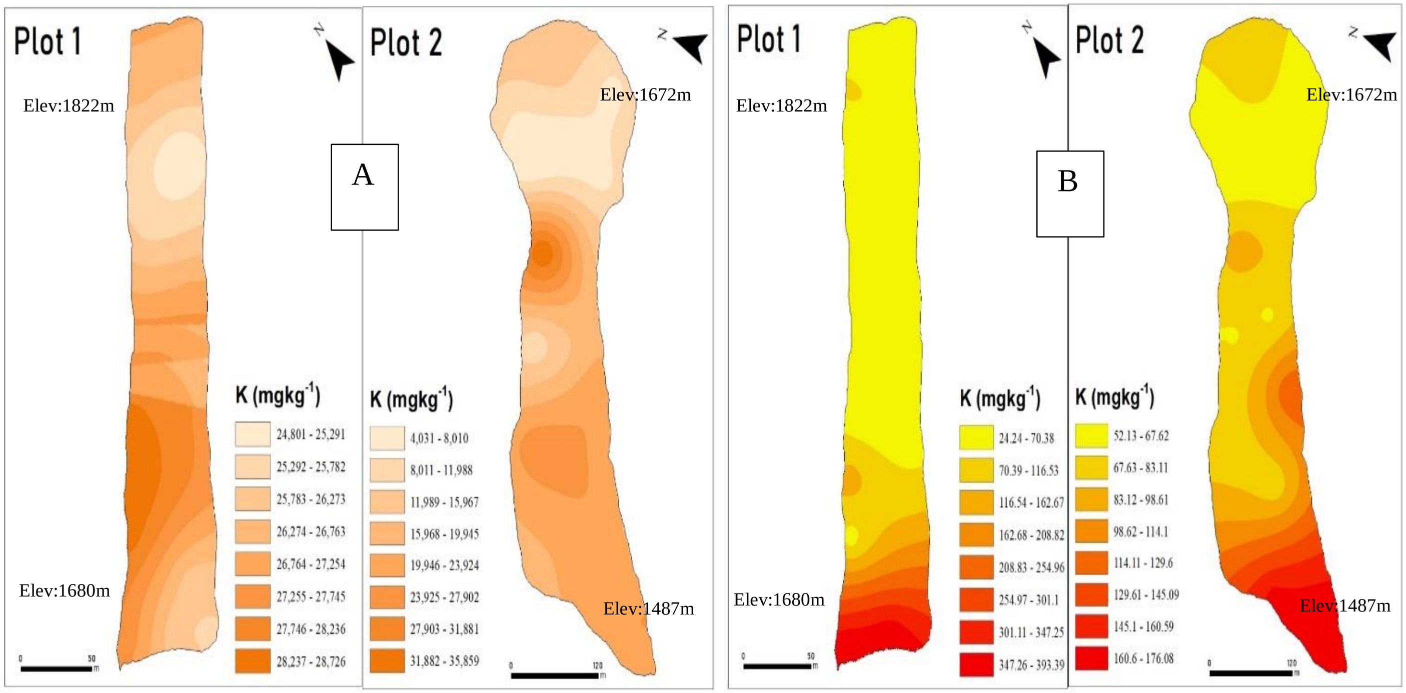

Figure 4. 29 Potassium concentration distribution from plots 1 and 2 extracted with both acid and EDTA extraction from soil.

The lowest detected concentration in both plots is 4,031 mg kg^{-1}, and the highest is 35,859 mg kg^{-1}, with a median of 29,758 mg kg^{-1} and 16,715 mg kg^{-1} for plots one and two, respectively. Plot one contains a high potassium concentration compared to plot two, with a significant value of 0.002.

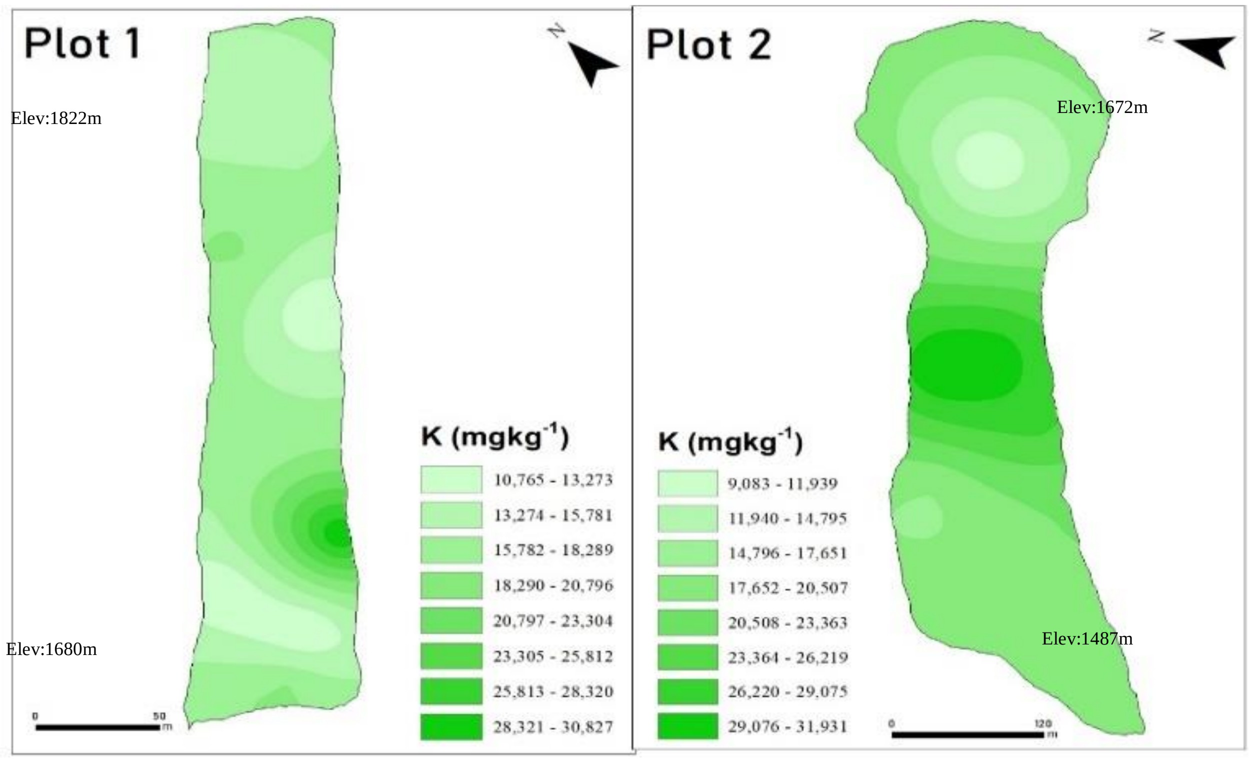

Figure 4. 30 Potassium concentration distribution from plots 1 and 2 extracted acid from the grass plant

EDTA extracted soil measured potassium as distributed in the plots shows that in all the two plots, the concentration is higher at low altitudes than at high altitudes. As shown in Figure 31, the concentration range is 24.24 mg kg^{-1} to 393.39 mg kg^{-1}, as the highest concentration was detected at the no mitigation plot. The grass was analysed, and the concentration in Figure 32 ranges from 9083 mg kg^{-1} to 31,931 mg kg^{-1} from both plots. Correlation of the concentration between soil and plants in which the relationship between grass and EDTA concentrations was the highest with 0.554, as shown in Table 12.

4.4 Transfer factor

Metals transfer from soil to plant based on elements biochemistry, in which the ratio determines the rate at which the plants can take in elements(Jolly *et al.*, 2013). The transfer factor of the EDTA ratio of extracted elements shows a high ratio in which the micronutrients analysed for the plants' uptake are increased. The element with the highest transfer factor was phosphorous in plot two, 337.79 ± 104.05, while the lowest was calcium in plot two at 2.80 ± 0.65 from the EDTA extracted soils. Also, the highest transfer factor based on the total elements in the soil as extracted using acid protocol was phosphorous at 6.50 ± 1.33, while the lowest was iron at 0.09 ± 0.02.

Table 4. 11 Transfer factor and standard error of the mean for plants acid extract soil EDTA and Acid from plots 1 and 2

	EDTA Extraction		Acid Extraction	
Plot	P1	P2	P1	P2
Mg	28.88 ± 6.99	19.75 ± 4.99	1.39 ± 0.32	0.40 ± 0.12
P	135.11 ± 103.21	337.79 ± 104.05*	4.14 ± 1.00	6.50 ± 1.33
K	172.18 ± 69.91	226.53 ± 67.11	0.61 ± 0.13	1.24 ± 0.44
Ca	4.70 ± 1.18	2.80 ± 0.65	0.81 ± 0.33	0.29 ± 0.07
Fe	9.01 ± 2.77	18.45 ± 9.03	0.10 ± 0.04	0.09 ± 0.02
Cu	8.38 ± 5.80	6.54 ± 2.02	1.21 ± 0.55	0.58 ± 0.33
Zn	8.80 ± 2.11	19.58 ± 14.54	0.97 ± 0.26	0.85 ± 0.20
Se	15.69 ± 5.25	18.10 ± 4.51	0.45 ± 0.11	0.42 ± 0.13
Mo	12.11 ± 2.96	55.53 ± 17.43	0.51 ± 0.20	1.60 ± 0.35

4.4.1 Correlation between element in the soil concentration to that in plants

Table 4. 12 R^2 of log-transformed element concentrations in the relationship between the element in the soil to that in plants. Graphs for the best line of fit are in appendix 1

	PLOT 1		PLOT 2	
ELEMENT	**ACID**	**EDTA**	**ACID**	**EDTA**
Magnesium	0.0624	0.029	0.2228	0.0207
Phosphorous	0.0741	0.0161	0.0986	0.0492
Potassium	0.0074	0.1023	0.3729*	0.2151*
Calcium	0.0007	0.0528	0.1283	0.0269
Iron	0.2411*	0.0169	0.2984*	0.4316*
Zinc	0.1061	0.1617	0.0014	0.0006
Copper	0.0136	0.0362	0.0151	0.0002
Selenium	0.0575	0.0035	0.0001	0.1376
Molybdenum	0.054	0.2097*	0.1485	0.0724

The relationship between the concentration and the best line of fit indicated how much the concentration in soil is related to that in plant samples (grass). Iron in soil extracted with EDTA contains the highest relationship in plants, with r^2 of 0.4316. The lowest r^2 is the relationship between selenium extracted by acid in the soil to that in plants of 0.0001.

4.4.2 Prediction of factors affecting the uptake of elements by plants

Different elements in the soil are affected by various factors in the uptake by plants. The table below shows the effects of soil properties, pH, and organic matter on the uptake of different essential elements. Each factor affects the uptake either positively or negatively, as indicated in Table 15 occurrence of one element also hinders the uptake of the other element. The presence of molybdenum in the soil enhances the uptake of calcium in soil by a variance of 2.07, as indicated from soil analysed by EDTA extraction. Magnesium also suggests that it reduces the uptake by a variance of -1.67, as shown in Table 15 from the elements readily available for plants' uptake.

Table 4. 13 The percentage of crop element concentration variation in the dependent variable by soil regression models. Estimates are computed on log-transformed element concentrations from multiple linear regression models. Significant (P<0.05) predictors are marked by (*). Unless otherwise marked (-), the directions of correlation are positive

Acid extracted soil predictor									
PREDICTOR	***Mg***	***P***	***K***	***Ca***	***Fe***	***Cu***	***Zn***	***Se***	***Mo***
pH	*-0.63*	*-0.11*	*0.27*	*-0.67*	*-0.25*	*0.76*	*-0.36*	*-0.43*	*1.17*
LOI	*1.11*	*-1.57*	*-0.94*	*-0.67*	*-0.92*	*-0.88*	*0.48*	*-0.68*	*-1.39*
Mg_acid	*0.76*	*0.07*	*0.09*	*-2.08*	*1.21*	*-2.73*	*-0.70*	*0.86*	*0.10*
P_acid	*-0.74*	*0.74*	*0.12*	*0.57*	*0.24*	*-1.30*	*0.65*	*0.17*	*0.66*
K_acid	*1.35*	*-0.71*	*1.81*	*-2.17*	*0.07*	*-0.53*	*0.35*	*0.39*	*-2.99*
Ca_acid	*-2.38*	*1.80*	*1.44*	*3.85*	*-0.91*	*4.39*	*-2.04*	*0.63*	*1.60*
Fe_acid	*2.29*	*0.69*	*1.53*	*-2.02*	*-0.34*	*-1.28*	*0.34*	*-1.39*	*-1.70*
Cu_acid	*0.86*	*-2.95*	*-1.43*	*-1.08*	*0.57*	*-3.18*	*2.27*	*-0.01*	*-3.15*
Zn_acid	*-0.97*	*0.23*	*1.09*	*0.82*	*0.77*	*3.98*	*-0.73*	*1.30*	*1.40*
Se_acid	*0.08*	*0.30*	*0.71*	*-0.34*	*-0.52*	*0.40*	*-1.13*	*-0.37*	*-0.17*
Mo_acid	*-3.32*	*-0.51*	*-1.62*	*2.21*	*0.21*	*-0.34*	*0.43*	*1.28*	*0.58*
TOTAL VARIANCE	*14.47*	*9.67*	*11.06*	*16.49*	*6.01*	*19.76*	*9.48*	*7.51*	*14.90*
EDTA extracted soil predictor									
PREDICTOR	***Mg***	***P***	***K***	***Ca***	***Fe***	***Cu***	***Zn***	***Se***	***Mo***
Mg_EDTA	*-0.44*	*-0.03*	*0.77*	*-0.99*	*-1.67**	*0.07*	*-1.45*	*0.64*	*0.13*
P_EDTA	*0.35*	*0.62*	*0.56*	*0.18*	*-0.14*	*-1.26*	*-0.71*	*0.33*	*-0.80*
K_EDTA	*-0.06*	*-0.03*	*1.49*	*-0.66*	*0.66*	*-0.61*	*0.57*	*-1.47**	*0.49*
Ca_EDTA	*0.60*	*-0.42*	*-1.28*	*1.41**	*1.11*	*0.23*	*1.51*	*-0.54*	*-0.12*
Fe_EDTA	*-0.37*	*-1.24*	*0.01*	*-0.54*	*-0.55*	*-1.76*	*0.87*	*-0.02*	*-1.87**
Cu_EDTA	*-0.94*	*-0.08*	*0.91*	*-0.44*	*-0.24*	*0.66*	*0.66*	*-0.40*	*0.81*
Zn_EDTA	*-1.77*	*-0.48*	*-1.24*	*-1.32*	*-0.91*	*2.20*	*-0.74*	*0.44*	*2.15*
Se_EDTA	*0.35*	*-0.29*	*1.15*	*0.14*	*-0.58*	*-0.03*	*-0.14*	*-0.60*	*-0.34*
MO_EDTA	*0.18*	*1.53*	*0.35*	*2.07**	*0.29*	*1.48*	*1.39*	*1.51**	*0.11*
TOTAL VARIANCE	***5.05***	***4.74***	***7.75***	***7.74***	***6.14***	***8.29***	***8.05***	***5.95***	***6.81***

CHAPTER FIVE

DISCUSSION

5.1 RUSLE Assessment

The study aimed to investigate the essential element movement from the soil into the food chain as it is affected by land use management and soil erosion. The investigation was carried out on the slopes and valleys of Nandi hill, which are prone to erosion. The study aimed at mapping the movement and loss of essential elements. First, the study estimated the extent of soil erosion to which the study area is subjected through water erosion. The study employed the RUSLE equation to calculate the soil erosion trend at the Kibos river catchment.

The RUSLE model (Chuma *et al.*, 2022; Humphrey *et al.*, 2022b) implemented in the GIS tool was utilized in this study to analyze and quantify soil erosion hazards using remote sensing data. The model employed a land use/land cover map, rainfall, slope length/steepness, soil types and properties, and management practices. The method's parameters were measured from the study site and use of secondary data in which they were integrated with GIS for the analysis (Wynants *et al.*, 2019). This model was adopted because it is known to describe and estimate erosion in the basins (Zerihun *et al.*, 2018).

The rainfall factor is the key factor in the model for determining the risk of erosion. In the study, area rainfall was analysed in which it was ranging from 1310-2268 MJ mm ha^{-1} h^{-1} $month^{-1}$. Is the smallest amount of rain received and the highest in the Kibos river catchment, as shown in Figure 3. The rainfall factor directly correlates to the erosion of the study area; a study carried out at the Winam Gulf of Kenya indicated that rainfall seasons directly affect the model. Most rainfall is experienced in April yearly (Humphrey *et al.*, 2022b; Nearing, Mark, *et al.*, 2017). Different years receive an additional amount of rain hence an annual change in the amount of soil erosion

(Su *et al.*, 2022), as shown in Figure 4. Also, there has been an increase in annual rainfall, which depicts high erosion, as shown in Figure 4 mean rainfall in the years 2017, 2018 and 2019 is less than 2021, which is a result of climate change and change in regular weather patterns (D. Otieno *et al.*, 2022). The slopes of Nandi hills experience the most precipitation, as depicted in Figure 3.

High mountains and low land areas characterize the area; hence the K factor is more experienced in the slopes of Nandi hills, in which the highest recorded is 0.031 t ha h ha^{-1} MJ^{-1} mm^{-1}. The area's topography has greatly influenced the overall soil erosion of the site. The erosion factor of the study area ranged from 0.013-0.031 t ha h ha^{-1} MJ^{-1} mm^{-1}, varying the degree of erosion along the Kibos river catchment.

The slope of the study area ranges from 0m as the lowest altitude to 929.672 meters as the highest altitude, in which the lower basin of the catchment is almost zero, as shown in Figure 6. The upper part of the catchment is the hill part of Nandi hills, in which a steep slope ring separates the mountainous and lower parts. The vertical areas are around the Nandi hills slopes and along the river channels of river Kibos. LS comprises the slope and steepness of the area, which is proportionate to soil erosion due to runoff buildup on downslopes (Magesh & Chandrasekar, 2016). An increase in precipitation at steep slopes, as categorized in Figure 6, increases the movement of loosely packed soil through erosion in mostly farmed areas (Martín-Moreno *et al.*, 2016)

The land protective capacity of the study area increased from 0 to 0.35, as shown in Figure 7. The highest value indicates no crop or pares land at the catchment, while the lowest value indicates the ground with much thick cover. The land cover also increases with the increase in rainfall. From December to January, the amount of rain is reduced to the minimum, as shown in Figure 4. the catchment is situated at the east-north of the Winam Gulf, which is along the equator; hence the amount of sunlight received in this region is relatively high, increasing the ambient temperatures of the catchment. When the rainfall is low, the plant around the catchment dries up, increasing the C factor. Also, when the rain is high during the month of April to September, the plants grow, reducing the C factor. After the harvest, the farmers clear land for the following seasons, increasing the C factor values(Yan *et al.*, 2020). This seasonal clearing and planting change the pattern of erosion sequence in the catchment, which depends on the cover and compactness of the topsoil. Ploughing affects the topsoil firmness hence increase in erosion.

Conservation measures indicate the mitigation taken place to curb soil erosion. The study contains almost 80% of the land subjected minimal amount of mitigation, and others are entirely not mitigated. As shown in figure 8, most parts of the study area are subjected to some mitigation measure, lowering the p-value to 0.8. These measures are agroforestry; contour farming is mainly done on the slopes of Nandi hills, intercropping, and terracing (Kumawat *et al.*, 2020; Nyilitya *et al.*, 2020).

Soil erosion was calculated after computation of all the factors outlined above using the RUSLE model as formulated in equation 1, from the soil prediction was estimated to range between <1 to >50 t ha^{-1} yr^{-1} as calculated annually. The steep mountains of Nandi hill and its environments show a high risk of soil erosion ranging between 6 to >50 t ha^{-1} yr^{-1}. as shown in Figure 9. The increased risk of erosion on the steep slopes of Nandi hill is associated with the area's topography, which is so steep, dropping from 929.7 meters as the highest region to 0m the lowest altitude, as shown in Figure 6. (Ghomash *et al.*, 2019). Most studies show that the slope type affects the water movement rate, especially the convex hillslope. The erosion rate is most significant in the center of the hillslope and decreases toward the bottom of the hillslope. The most considerable soil loss occurred near the bottom of the hillslope (Lu *et al.*, 2020; Sabzevari & Talebi, 2019).

Crop management is also key in this model, contributing to increased soil erosion risk. From Figure 7, crop management at the estimated high-risk zones ranges from 0.088-0.175, indicating that anthropogenic activities have invaded the area, removing crop cover and exposing the soil to water agents (Nearing, Xie, *et al.*, 2017). Poor cultivation practices and lack of steep land use management increase soil erosion along the Nandi hills. The risk of soil erosion is also seen, as in Figure 9, on the river banks. This is estimated from the steep unprotected riverbanks and water terraces that channel water to the rice farms and the lake. These river banks are not protected with crop covers, and the soils are loosely packed; hence high risk of erosion is estimated to be 6-10 t/ha/yr. (Barman, 2016). The cultivation process up to the river banks also increases the risk of river bank erosion.

Knowledge of land use/land cover has become critical in addressing the issues of biogeochemical cycles, biodiversity loss, worsening of environmental quality, loss of agricultural lands, destruction of wetlands, and loss of fish and animal habitat. Rapid population expansion, rural-to-urban migration, reclassification of rural regions as urban areas, lack of valuing of ecological services, poverty, misunderstanding of biophysical constraints, and usage of ecologically incompatible technology are the primary causes of LU/LC shifts (Mallupattu & Sreenivasula Reddy, 2013). Figure 10 shows maps of land use changes from different periods, that is, 2013, 2016, 2019, and 2022. Statistically, as shown in Table 3, agriculture, settlement, and wetland are the land uses that have indicated a positive increase. The settlement increase is due to the rural-urban movement to Kisumu city and its environment (Fusilli *et al.*, 2014). Increased agricultural activities have primarily increased due to the commercialization of two cash crops in the study area, rice (Niemeijer *et al.*, 1994) and sugarcane (Jamoza, 2005). Bare land, forest, and vegetation have reduced, as shown in Table 3, in which 62%,14%, and 49% of the land are used, as shown in

Figure 11. An increase in agricultural activities loosens the topsoil and increases rainfall, as demonstrated in Figure 4, increases the rate of soil erosion, as shown in Figure 9, and this increases the nutrients in the river and lake Victoria (Fusilli *et al.*, 2013). The increase in Kenya's population led to the use of agricultural products as the primary sources of income and food, hence an increased land change to agricultural land at a steep slope of Nandi hills, similar to that of North-East Turkey (Reis, 2008).

5.1. Land use land cover in Kibos Valley

Due to the increased population in Kenya, a developing country with limited resources, land use has changed to agricultural activities, as in Ethiopia (Hans Hurni *et al.*, 2005). Most of the land on the steep topography has been converted into agriculture; hence, the study investigates the distribution of essential elements in two differently managed pilot plots and the impact on the move into the food chain. Plot one contains no mitigation measures against soil erosion and has been farmed for over ten years. Plot two includes mitigation measures, farmers at this plot practice terrace farming to prevent soil erosion. Terracing is an agricultural process that involves rearranging cropland or converting hills into agriculture by building particular ridged platforms. Terrace farming is an effective and sometimes the only solution for steep farmlands. Terrace farming has far-reaching implications beyond cultivating sites that would otherwise be unsuitable for agriculture. Terrace farming also helps conserve soil by preventing erosion (Mylona *et al.*, 2020). Plots 1 and 2 descends from elevation 1822 m and 1672 m to 1680 m and 1487 m above sea level, respectively.

Topsoil collected randomly from both plots was analysed for soil pH and organic matter. Plot one was more acidic with a fairly distributed across the plot, ranging between 5.4 to 5.95 hence fairly acidic. Plot two is pH was acid, although more basic than plot one, which ranged from 5.8 to 6.11.

plot two at the top is more basic compared to the bottom, with a significant difference of <0.05, as shown in Figure 12, which shows that most ionic elements have been swept to the bottom of the plot. For example, the accumulation of Al^{+} either increases or reduces the pH as the parent pH from the bedrock(Matsumoto *et al.*, 2018).

Both plots' organic matter content, as described in Figure 13; the top of the plots is higher than that at the bottom. The percentage of loss of ignition that is used to measure organic matter ranges between 5.42 to 11.12 and 5.99 to 7.82 for plots one and two, respectively. The organic matter at the top of both plots is increased by piling the agricultural produce, for example, maize stacks. Also, in plot one, the upper part of the land is grazing land; hence the organic matter increases with the excretion from animals like cows.

5.2 Spatial distribution and loss of essential elements in soils from two different land use management

Iodine is a trace element that is required for the creation of thyroid growth hormones in both humans and animals. As a result, the World Health Organization (WHO) advises a daily iodine dosage of roughly 150 g for adults. Inadequate or excessive iodine consumption has been linked to various disorders, including goiter and hypo- and hyperthyroidism. Miscarriages, endemic cretinism, and other conditions can also be caused by iodine shortage(Gorstein *et al.*, 2020). Iodine is an essential trace element that plays a critical role in the normal functioning of the thyroid gland. The thyroid gland produces hormones that regulate the body's metabolism and energy production. Iodine is an essential component of these hormones, and without adequate iodine, the thyroid gland cannot produce enough hormones, leading to a condition called hypothyroidism(Zimmermann, 2009). The total iodine available ranged from 3.68 mg kg^{-1} to 12.12 mg kg^{-1}, as shown in Figure

14. plot one total concentration of iodine was relatively higher than plot 2, with a significant difference of <0.05.

In both plots, the iodine is concentrated at the bottom compared to the top, indicating loss of iodine through soil erosion. The soil pH affects the presence and binding of iodine in the soil. Acidic soil traps iodine more easily. When the pH of the soil solution is less than 6, inorganic forms of iodine can be trapped more quickly in the soil environment on positively charged surfaces of iron, aluminum, manganese (oxo)hydroxides, and clay minerals (Ledwożyw-Smoleń *et al.*, 2020). Both plots contain a pH average below six, 5.6, and 5.9 for plots 1 and 2, respectively. Because the surface of these oxides and hydroxides is positively charged under acidic circumstances, the mobility of inorganic iodine species diminishes with lowering soil pH. This is because iodide and iodate are entirely dissociated at ordinary soil pH, allowing them to be electrostatically pulled to diverse positively charged surfaces (Kaplan *et al.*, 2000; Um *et al.*, 2004). The ideal pH for iodine binding is 3.7(Emerson *et al.*, 2014).

Nonetheless, iodine in plot two had a slightly higher concentration than in plot one despite the pH difference as also indicated by (Duborská et al., 2021) that in some cases, iodine is more in alkaline that acid areas. Elemental iodine is poorly soluble in water, with one gram dissolving in 3450 ml at 20 °C and 1280 ml at 50 °C (Cicconi *et al.*, 2019) but highly binds to acidic soil; hence due to soil erosion, iodine is more concentrated at the lower elevation of both plots as seen in Figure 14.

Essential elements were digested with two different methods, namely acid digestion to determine the total elements available in the topsoil obtained from the plots (Hamilton *et al.*, 2015) and the EDTA (Ethylenediaminetetraacetic acid) extraction, which extracts the elements in the soil that are readily available for the plant uptake (Okalebo *et al.*, 2002).

Calcium is an essential mineral that plays a vital role in many physiological functions of the human body, including: Building and maintaining strong bones and teeth, Muscle function, Nerve function, Blood clotting and Hormone secretion. Deficiency of calcium leads to a range of health problems: Osteoporosis, Muscle cramps, Numbness and tingling, Weakness, and Abnormal heart rhythms(Hidalgo *et al.*, 2008). Due to its health implications, it is recommended by the WHO that, an adult to consume between 1,000-1,200 mg daily, depending on age (Beto, 2015; Pravina *et al.*, 2013). Acid-extracted calcium from both plots ranged between 2,848 mg kg^{-1} to 24,431 mg kg^{-1}, while that which EDTA has extracted ranges between 945 mg kg^{-1} to 4,363 mg kg^{-1}, as shown in Figure 15. The concentration of Calcium for both available by plants and the total in soil ranged between the recommended concentration for the human. Total calcium is highly concentrated at the top of the plots, while EDTA extracted calcium is concentrated at the top and bottom of plot two. Calcium in plants was extracted using microwave-assisted digestion using an acid. From the results in Figure 16, the distribution of calcium in the grass was even across the plots where the concentrations ranged between 3,000 mg kg^{-1} to 11,072 mg kg^{-1}. This indicated high amount of concentration between the available calcium and that in plants. Bio concentration of calcium in the plants indicates the sufficient amount of calcium consumed by the cows grazing at the valley along the plots. The relationship between the available calcium in soil for plant uptake versus the total element to concentration in soil indicated a positive correlation in plot one of 0.307 and 0.167 against plot two, which indicated a negative correlation of -0.492 and -0.104, as seen in Table 4. The pH of the soil affects the availability and uptake of calcium by plants. In general, calcium uptake is better in soils that are slightly neutral (pH 6.0 to 7.0). When the pH of the soil is too low (acidic), calcium ions are bound to other positively charged ions such as hydrogen ions, aluminum ions, and manganese ions, making them less available to the plant roots (Ruan *et al.*, 2004). This can result in calcium deficiency in plants, which can cause several problems, such as reduced growth, poor root development, and blossom end rot in fruits like tomatoes and peppers. On the other hand, when the pH of the soil is too high (alkaline), calcium ions can form insoluble compounds with other negatively charged ions like phosphate ions, making them less available to the plant roots. This can also lead to calcium deficiency in plants, even if there is an adequate amount of calcium in the soil (Neina, 2019).

Copper is an essential mineral that plays a critical role in many physiological functions of the human body, including: Iron metabolism, Connective tissue, formation Energy that is the production of ATP, which is the primary energy source for the body's cells, production Nervous system function and Antioxidant defense which is important component of the antioxidant enzyme superoxide dismutase, which helps to protect cells from damage caused by free radicals (Osredkar & Sustar, 2011). Deficiency of copper leads to a range of health problems, Anemia, Weak bones, Neurological problems, and Immune system dysfunction (Scheiber *et al.*, 2013). Depending on the age the human body required a daily intake of copper as children ranging from 4 to 18 years are required to take 440-890 micrograms per day. Adults are recommended to take more than 900 micrograms per day as the main source of copper is from the food chain which comprises of soil (Angelova *et al.*, 2011). Copper concentration, as a measure in this study from acid digestion, ranges between 9.24 mg kg^{-1} to 54 mg kg^{-1}, and that of EDTA ranges from 0.97 mg kg^{-1} to 6.5 mg kg^{-1}. Plant copper ranges from 8 mg kg^{-1} to 48 mg kg^{-1}, as shown in Figures 4.15 and 4.16. concentration increase in the plant analysed for copper indicates bio concentration which in other hand shows a correlation between the soil concentration and that in plants resulted in a negative correlation, as shown in Table 5 for acid extracted, But shows a positive correlation to that of EDTA extraction. In addition to playing vital functions in photosynthesis, respiration, and the electron transport chain, copper also serves as a cofactor in numerous enzymes and is a structural element of genes involved in defense. Excessive Cu impacts plants' growth and productivity (Yruela & Inmaculada, 2009). The solubility of copper is 4 mg l^{-1} at a pH of 6.5, which differs from the change in pH (Palmer *et al.*, 2004; Reddy *et al.*, 1995). Dissolved copper from the soil in water is swept down the gradient in soluble form. But it is trapped by the plant roots, as shown by the EDTA extracted copper distribution map. The density of plant growth in the areas indicates high copper concentration which also (Yruela & Inmaculada, 2005) confirms in his study.

Iron is highly recommended for the proper function of the human body, this functions include; Oxygen transport: Iron is a critical component of hemoglobin, which is the protein in red blood cells that carries oxygen from the lungs to the body's tissues (Gupta & K., 2014). Energy production, Immune system function and Cognitive development (Abbaspour *et al.*, 2014). Deficiency of iron can lead to a range of health problems, Anemia, impaired immune function, impaired cognitive function in which Iron deficiency leads to impaired cognitive function, particularly in infants and young children, and can affect learning and behavior. However, excessive intake of iron can also have adverse health effects, including gastrointestinal distress, liver damage, and oxidative stress (Duck & Connor, 2016). The recommended daily intake of iron for adults is 18 mg per day for women and 8 mg per day for men (Abbaspour *et al.*, 2014). According to the results shown in Figure 19, EDTA extracted iron is more concentrated at the bottom of the plots. As shown in Figure 20, plant iron concentration is concentrated at the top in plot two and the bottom in plot 1. Both relationships are positive with iron from acid extracted in the soil of 0.716 with a significant value of 0.05. Iron composition affects water's solubility; ferrous iron (Fe2+) is soluble, while ferric iron (Fe3+) is not (Yang *et al.*, 2022). Fe is abundant in soil but only marginally soluble in aerobic environments, particularly in high-pH and calcareous soils

(Kobayashi & Nishizawa, 2012). Hence, plants use a reduction– or chelation-based mechanism to regulate the uptake of iron (Kim & Guerinot, 2007); hence a high relationship between total iron and plant concentration is compared to that in EDTA extraction as tabulated by the R2 in table 14 that is 0.2411 and 0.2984 for plot one acid and EDTA extracted respectively while 0.0169 and 0.4316 for plot two.

Potassium is an essential mineral that plays a critical role in many physiological functions of the human body: Fluid balance where by Potassium helps to regulate the balance of fluids in the body, which is essential for maintaining healthy blood pressure and preventing dehydration. Nerve and muscle function, Bone health, and Kidney function where by Potassium is involved in the proper functioning of the kidneys, including the regulation of salt and water balance in the body and Blood sugar control: Potassium helps to regulate blood sugar levels, which is important for individuals with diabetes (Bellows *et al.*, 2013; Lanham-New *et al.*, 2012). Deficiency of potassium leads to a range of health problems that is Muscle weakness, Irregular heartbeat, and High blood pressure. However, excessive intake of potassium increases the chance of kidney damage (Aburto *et al.*, 2013).The recommended daily intake of potassium for adults is 2,500-3,000 mg per day (Binia *et al.*, 2015). Acid-extracted total potassium is evenly distributed, while EDTA potassium is highly concentrated at the bottom of both plots, as seen in Figure 31. Figure 32 shows the even distribution of plant potassium for both plots. Compounds made of potassium may dissolve in water. Readily available potassium for plants uptake (EDTA extracts) has been swept to the bottom of plots because Increased soil moisture promotes availability and facilitates potassium transport to plant roots. According to research, potassium fertilization often produces higher results in dry years (Sustr *et al.*, 2019; Wang *et al.*, 2018; Zörb *et al.*, 2014). The concentration for total potassium in soil ranged between 4031 mg/kg to 35859 mg/kg for acid extracted while that of EDTA which is available for plant uptake ranged between 24.24 mg/kg to 176.08mg/kg. the total concentration in plant was more as compared to that in soil for EDTA extraction ranging as from 10,765 mg/kg - 30827 mg/kg and 9083 mg/kg -31931 mg/kg for plot one and two respectively showing the bioaccumulation in plants. The ranges inserted into the food chain and the bio accumulation criteria shows that the amount of potassium available in both the plots despite the erosion which is reducing the concentration is within the recommended ranges.

Magnesium is crucial in involving over 300 enzymatic reactions, including energy metabolism, protein synthesis, and DNA synthesis. The health implications of magnesium are, Bone health: Magnesium is important for developing and maintaining healthy bones. It helps regulate calcium levels in the body and aids in the formation of bone tissue. Magnesium is essential for maintaining a healthy heart. It helps regulate heart rhythm, blood pressure, and cholesterol levels. Muscle function: Magnesium is necessary for proper muscle function, including the contraction and relaxation of muscles. Nervous system function: Magnesium is important for the proper functioning of the nervous system. It helps regulate neurotransmitters, which are essential for communication between nerve cells. Energy production: Magnesium plays a key role in energy production. It helps convert food into energy that the body can use. Blood sugar regulation: Magnesium helps regulate blood sugar levels and can improve insulin sensitivity. Mood regulation: Magnesium has been shown to have a calming effect on the body and may help reduce symptoms of anxiety and depression. Migraine prevention: Magnesium supplementation may help prevent migraines and reduce the frequency and severity of migraine headaches (De Baaij *et al.*, 2015). Some of the symptoms of magnesium deficiency include muscle cramps, fatigue, and irregular heartbeat. Therefore, it's important to ensure that you're getting enough magnesium in your diet or through supplementation. Daily intake of magnesium for adults 19-51+ years is 400-

420 mg daily for men and 310-320 mg for women. Pregnancy requires about 350-360 mg daily and lactation, 310-320 mg (De Baaij *et al.*, 2015; Jahnen-Dechent & Ketteler, 2012). Magnesium was highly concentrated at the top of plots except in plot two 2 for the EDTA concentrations, which are highly concentrated at the bottom of the plot, as seen in Figure 21. Plot 1 is concentrated in the middle of the plot, while plot two is concentrated at the top, as shown in Figure 22. Both correlations are positive, as shown in Table 5. Different compounds of magnesium dissolve in water differently. Magnesium hydroxide dissolves in water at a rate of 12 mg l^{-1}. Other magnesium molecules, like magnesium carbonate (600 mg l^{-1}), are more water-soluble (Kohlstedt *et al.*, 1996). The amount, concentration, and activity of magnesium in the soil solution and the soil's ability to replenish magnesium in the soil solution all influence how much magnesium plants can absorb. The activity or proportion of Mg concerning the soluble and exchangeable levels of K, Ca, Na, Al, and Mn determines the availability of Mg (Mayland & Wilkinson, 1989; Senbayram *et al.*, 2015). K, Ca, Al, H, Mn, and NH4 limit plants' ability to absorb magnesium in acidic soils. For maximum crop output, acid soils require a greater Mg concentration than neutral soils (Havlin, 2020; A. Läuchli & Grattan, 2012).

Selenium is an essential trace mineral important for several bodily functions, including , Selenium is a potent antioxidant that helps protect cells from damage caused by free radicals. This can help reduce the risk of chronic diseases such as heart disease and cancer(Kiełczykowska *et al.*, 2018). Selenium plays a critical role in thyroid hormone metabolism and helps regulate thyroid function. This is important for maintaining a healthy metabolism, immune function, and overall health. Immune system: Selenium is important for proper immune function and helps prevent viral and bacterial infections. Selenium may help prevent cognitive decline and improve memory and overall cognitive function. Fertility: Selenium is important for both male and female fertility, and can help improve sperm quality and reduce the risk of miscarriage. Selenium may help reduce the risk of heart disease by reducing inflammation and oxidative stress (Fairweather-Tait *et al.*, 2011). Excess consuming of selenium causes selenosis; the recommended amount to consume per day is 400micrograms per day. Plot one selenium has been washed to the bottom of the plot by water erosion as it is the major agent of selenium distribution and deposition. For the available element of selenium in both plot ranged from 0.0062 mg kg^{-1} to 0.0219 mg kg^{-1}. More concentrated at the top of plot one and bottom in plot two. In nature, selenium is not quickly reduced or oxidized and is not soluble in water. In acidic soils, selenium is typically found as selenite bonded to iron and aluminum oxides in compounds of very poor solubility; in alkaline soils, selenium is present as water-soluble selenate and is available to plants (Fernández-Martínez *et al.*, 2009; Organization, 2003). Higher plants use the high-affinity sulfate permease to absorb Se as selenate selectively. Agricultural crops are generally considered safe for human and animal consumption even when grown on moderately high Se soils because their contents are typically less than 1 mg kg1. Numerous plant species are prevented from absorbing selenate by sulfate salinity (Läuchli, 1993; Lima *et al.*, 2018; White, 2016). Hence the indication of low selenium content in the soil is not affected by soil movement due to it is state of occurrence.

Health implications of zinc for the body functions are: Immune system, Wound healing, Growth and development, Taste and smell receptors, Mental health, Reproductive health, blood sugar regulation: Zinc helps regulate blood sugar levels by assisting in the production and release of insulin(Choi *et al.*, 2018). Human body take an average of 43mg per day as the recommended intake according to WHO in which excess intake can cause nausea, vomiting, and diarrhea. Zinc in both plots is concentrated at the lower elevation except in acid extracted for plot two. the concentration for acid extracted ranges between 55.46 mg kg^{-1} to 155.39 mg kg^{-1} while that of

EDTA ranges between 0.63 mg kg^{-1} to 17.4 mg kg^{-1}. plant extracted zinc is evenly distributed, as shown in Figure 26. relationship between zinc in plants and on soil for plot one is positive, while plot two contains a negative correlation, as illustrated in Table 9. Zn is not available to plants in whole soil; instead, it depends on the soil's physico-chemical characteristics, the activity of plant roots and the rhizosphere's microbiota, among other non-edaphic variables. Zn in soil can be found as exchangeable adsorbed form or as insoluble complexes to some extent. Another portion, nevertheless, is present in a water-soluble state and is freely available to plants. Through ion exchange and the production of organic acids and other substances, root activity also partially makes exchangeable form available for uptake. More than 90% of soil Zn is insoluble and unavailable to plants, but exchangeable Zn ranges from 0.1 to 2 gZn g1soil.(N. Gupta *et al.*, 2016; Majumdar *et al.*, 1999).

Molybdenum is an essential trace mineral that is required in small amounts for many biological processes in the body. It is necessary for the proper functioning of enzymes involved in the metabolism of carbohydrates, fats, and proteins. Molybdenum is also important for the health of the nervous system and the formation of red blood cells (Schwarz *et al.*, 2013). However, excessive intake of molybdenum can have negative health effects. High levels of molybdenum in the body can lead to gout-like symptoms, including joint pain and swelling. In severe cases, it can also cause seizures, coma, and even death (Novotny, 2011). Long-term exposure to high levels of molybdenum can also cause liver and kidney damage. This is a concern for people who work in industries where they may be exposed to high levels of molybdenum, such as mining or metal working (Battogtokh *et al.*, 2014). The recommended daily intake of molybdenum for adults is 45 micrograms per day. In both plots, molybdenum is highly concentrated at the bottom of all plots regardless of the extraction process, as seen in Figure 27. likewise, in plants, it also is concentrated at the base of the plots. The correlation between the soil extracts and the grass was positive, with grass and EDTA extraction soil being the strongest correlation of 0.551, as shown in Table 10. Water does not dissolve molybdenum or molybdenum disulfide. Both phosphomolybdic acid and ammonium molybdate are soluble in water (Braithwaite & Haber, 2013).

Phosphorous is required for the formation and maintenance of strong bones and teeth and for the production of DNA, RNA, and ATP, which is the primary energy source for cells (Gropper & Smith, 2012). However, excessive intake of phosphorus can have negative health effects. High levels of phosphorus in the blood can lead to a condition called hyperphosphatemia, which is associated with an increased risk of cardiovascular disease, kidney disease, and osteoporosis (d'Haese *et al.*, 2019). High intake of phosphorus can also interfere with the absorption of other important minerals, such as calcium, leading to deficiencies that can weaken bones and teeth. People with kidney disease or other conditions that affect their ability to excrete excess phosphorus are particularly at risk for these negative health effects. In these cases, limiting phosphorus intake through diet or medication may be necessary. The recommended daily intake of phosphorus for adults is 700 mg to 1250 mg per day, depending on age and sex. Most people can meet their phosphorus needs through a well-balanced diet that includes sources such as dairy products, meat, fish, nuts, and whole grains (Lambers, 2022). Acid extracted phosphorous is evenly distributed in both plots, while the EDTA extracted is concentrated at the top for plot one and at the bottom for plot 2. The concentration for acid extraction ranges from 369 mg kg^{-1} to 647 mg kg^{-1} while that of EDTA extraction ranges from 3.22 mg kg^{-1} to 19.86 mg kg^{-1} as shown in Figure 29. In both plots, plant phosphorous is concentrated at the bottom. And ranges between 940 mg kg^{-1} to 4,418 mg kg^{-1}. the correlation between plant phosphorous and soil phosphorous is positive. Phosphates in soil are largely sorbed to soil particles or absorbed into the organic content of the soil. The geology, soil composition, air temperature, precipitation, hydrological condition, pH, and other factors all play a role in releasing and exporting phosphorus from untamed soil. Depending on the conditions in the soil or sediments, sorption-desorption or precipitation-dissolution events influence the solubility of phosphates. The amount of orthophosphate in the solution is mostly determined by sorption-desorption processes in soil and sediments with significant concentrations of iron and aluminum hydrous oxides (Holtan *et al.*, 1988).

Continuous cultivation changes the land cover of the plots from season to season hence different times of rainwater exposure to the surface of the soil. Through the physical and mechanical effects of rainfall and aggregate destruction, poor land cover causes soil erosion. In turn, this causes the soil surface to seal off, decreasing infiltration while increasing runoff and soil loss(McHugh *et al.*, 2007). Different compositions of essential elements in the soil are then moved differently from one point of the plot to another, depending on the binding to the soil particles and solubility. This erosion affects the distribution of elements in the two study plots. Generally, EDTA extracted essential elements were influenced by erosion in both plots, in which copper, iron, magnesium, zinc molybdenum, and potassium elements were highly concentrated at the lower altitude of plots one and two. This is attributed to elemental solubility, which leads to the loss of nutrients through leaching, denitrification runoff, and volatilization (Klaus *et al.*, 2018; Rusu & Moraru, 2021).

Descriptive statistics in Table 13 contains the transfer factor calculated from both EDTA and acid-extracted soils. The transfer factor of the EDTA ratio of extracted elements shows a high percentage in which the micronutrients analysed for the plant's uptake are increased. The element with the highest transfer factor was phosphorous in plot two, 337.79 ± 104.05, while the lowest was calcium in plot two at 2.80 ± 0.65 from the EDTA extracted soils. While the highest transfer factor based on the total elements in the soil as extracted using acid protocol was phosphorous at 6.50 ± 1.33, while the lowest was iron at 0.09 ± 0.02. for the transfer, Many cationic elements are soluble in acidic solutions (desorption from surface sites at pH values below 5) but insoluble in weakly acidic to slightly alkaline solutions (adsorption maximum between pH 5 and 8). Acidification improves the solubility of the adsorbent materials like Al^-, Fe^-, and Mn^- oxides/hydroxides, hence driving element release into the solution (Nguyen *et al.*, 2020).

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

Essential elements are majorly obtained through the food chain in which it is channeled through soil, plants and animals. Erosion leads to soil essential elements depletion. The high risk of erosion in Kibos area is contributed by the topography and precipitation factors. Nandi hill contributes much to the erosion of the study area.

The increasing population in the country depending on farming for substances has increased land use along the high risked erosion region. Most of the land has been converted to agriculture due to the increase in population hence demand of food. Increased cultivation leads to loosening of top layer leading to erosion and also clearing the land covers.

Different elements have different solubility factors which leads to different mobility responces. Different Elements have shown different responses to the gradient in terms of distribution and how they are affected by soil erosion. Generally, iron and selenium show the importance of soil erosion mitigation measures as they indicate the slow sweeping of the elements down the slope.

Readily available elements for plant uptake were the most affected concentration compared to erosion's total elements available in the soil. The amount of elemental concentration largely correlates to the EDTA extracted concentration in soil, which showed a high transfer rate from soil to plants compared to that of acid extracted.

Depending on the co-occurrence of different elements, they hindered the movement of elements either positively or negatively from soil to plants in both study plots. This is mainly affected by the location of the bedrock rich with that particular element, hence describing the element's distribution along that gradient. Plant uptake of each element depends on the capacity and the ability of the plant to absorb that particular element. For example, selenium is more absorbed by high plants due to its toxicity as compared to low plants.

6.2 Recommendation

Health implication for the essential elements is at risk as they are slowly washed down on the study plots hence smart agriculture is recommended on the study plots to mitigate the loss of top soil by rain erosion (water erosion)

High terrain and steep land topography should be avoided from agricultural activities to prevent clearing of the areas hence reducing the rain contact to the surface of the land or planting crops that do not need clearing in every season of plant like tea.

Different land management systems to prevent runoffs and deep-rooted plants at the terracing edges to slow down the rate of runoff should be encouraged hence reducing the loss of essential elements.

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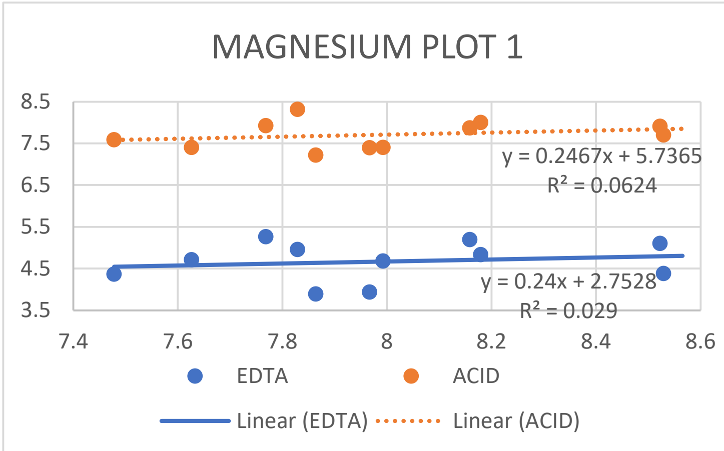
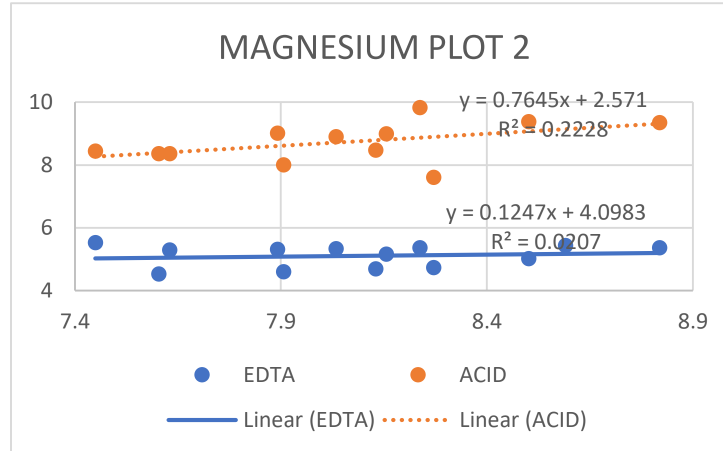
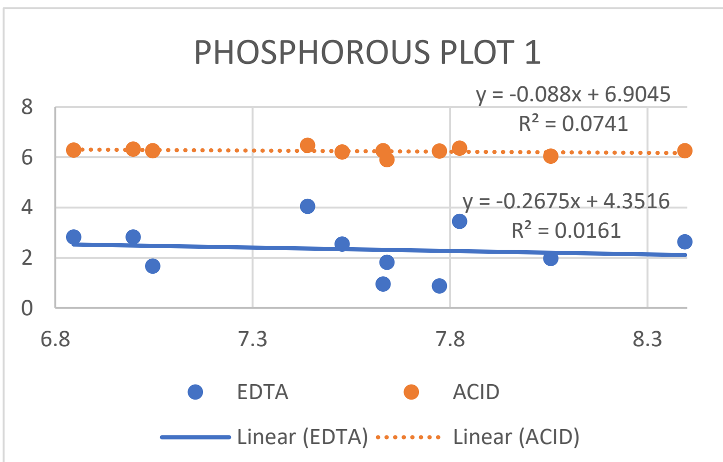
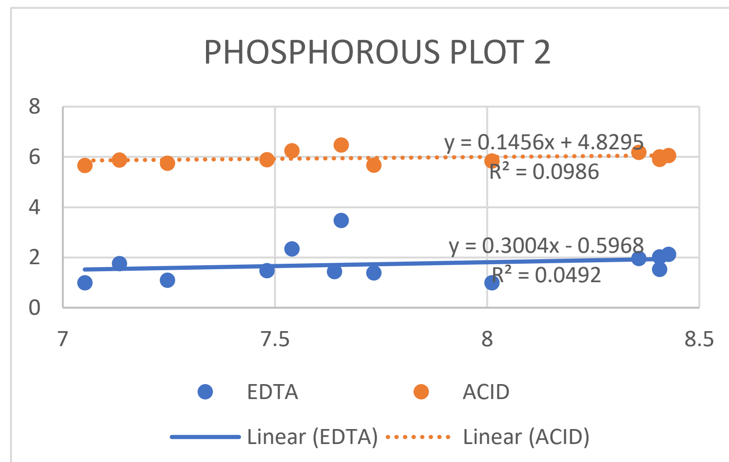
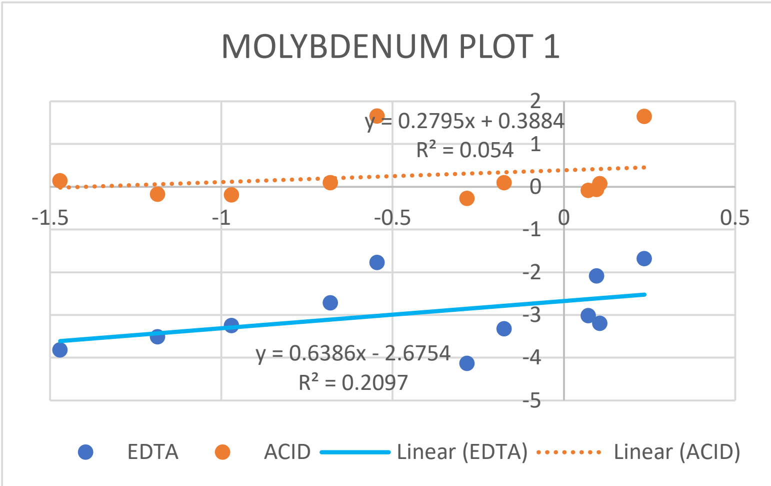
Appendix I

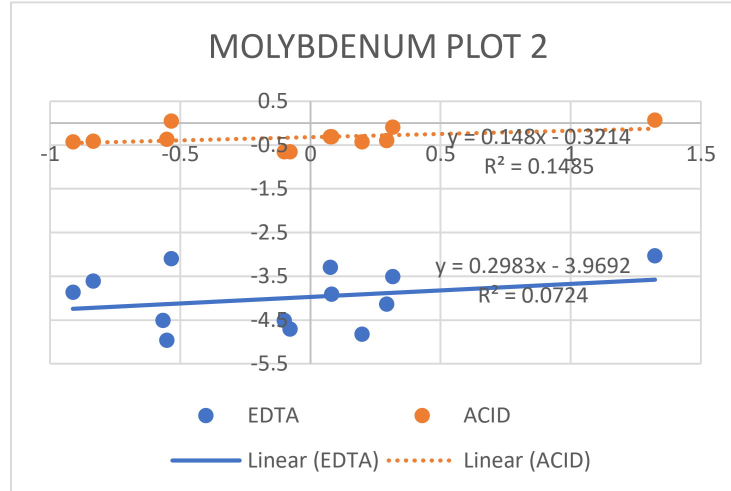

MAGNESIUM PLOT 1
y = 0.2467x + 5.7365
R² = 0.0624
y = 0.24x + 2.7528
R² = 0.029
8.5
7.5
6.5
5.5
4.5
3.5
7.4
7.6
7.8
8
8.2
8.4
8.6
EDTA
ACID
Linear (EDTA)
Linear (ACID)

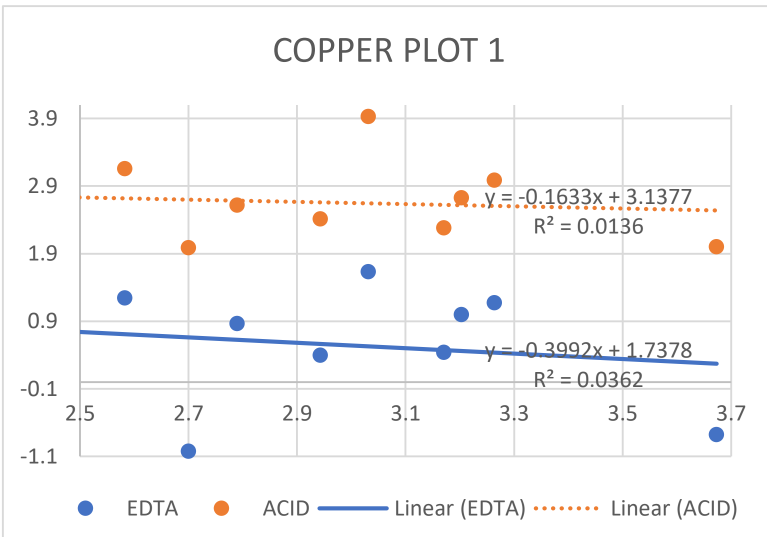

MAGNESIUM PLOT 2
y = 0.7645x + 2.571
R² = 0.2228
y = 0.1247x + 4.0983
R² = 0.0207
10
8
6
4
7.4
7.9
8.4
8.9
EDTA
ACID
Linear (EDTA)
Linear (ACID)

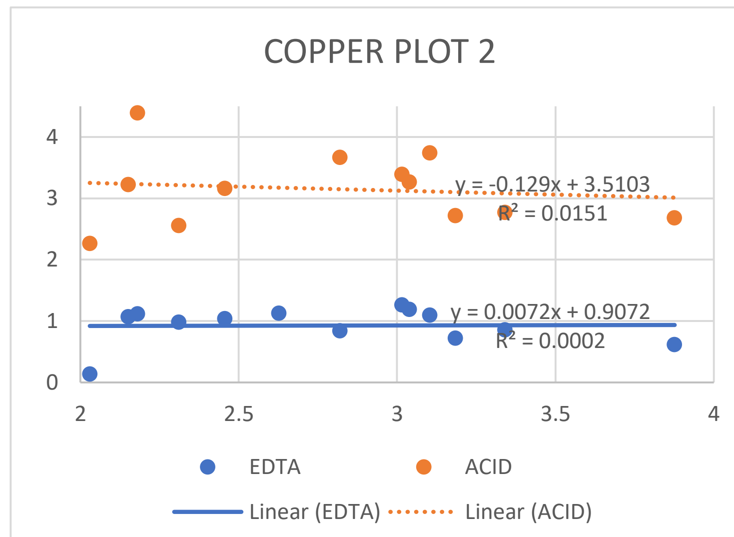

PHOSPHOROUS PLOT 1
y = -0.088x + 6.9045
R² = 0.0741
y = -0.2675x + 4.3516
R² = 0.0161
8
6
4
2
0
6.8
7.3
7.8
8.3
EDTA
ACID
Linear (EDTA)
Linear (ACID)

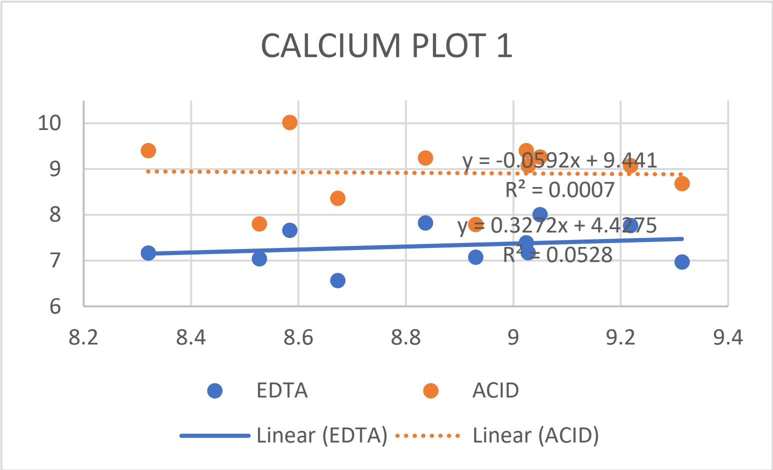

PHOSPHOROUS PLOT 2
y = 0.1456x + 4.8295
R² = 0.0986
y = 0.3004x - 0.5968
R² = 0.0492
8
6
4
2
0
7
7.5
8
8.5
EDTA
ACID
Linear (EDTA)
Linear (ACID)

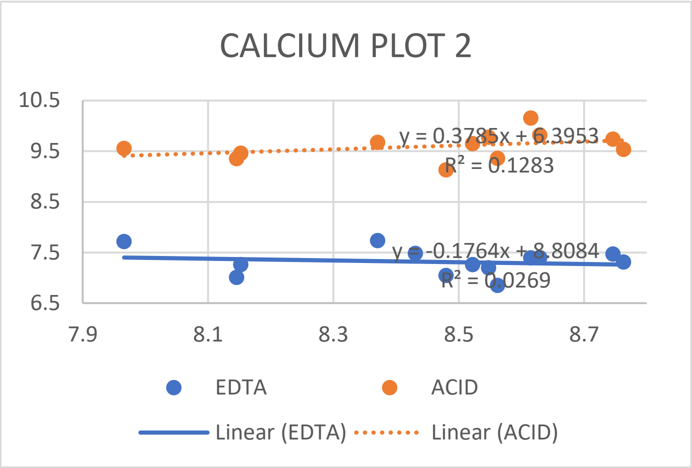

MOLYBDENUM PLOT 1
y = 0.2795x + 0.3884
R² = 0.054
y = 0.6386x - 2.6754
R² = 0.2097
2
1
0
-1
-2
-3
-4
-5
-1.5
-1
-0.5
0
0.5
EDTA
ACID
Linear (EDTA)
Linear (ACID)

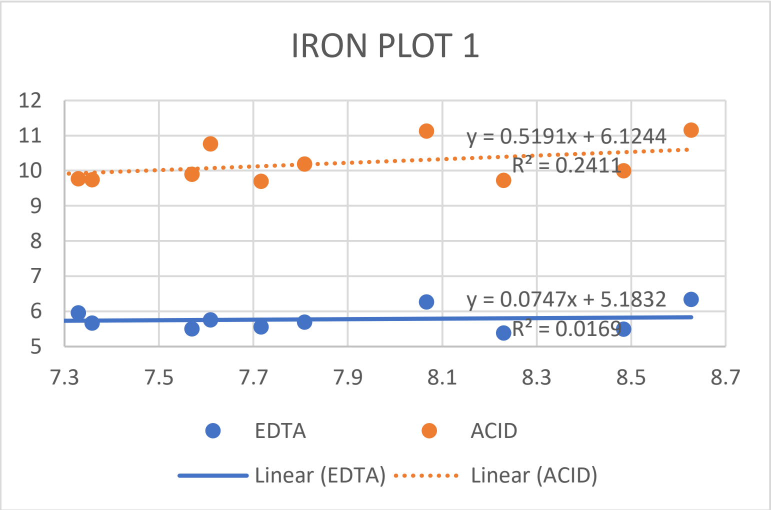

MOLYBDENUM PLOT 2
y = 0.148x - 0.3214
R² = 0.1485
y = 0.2983x - 3.9692
R² = 0.0724
0.5
-0.5
-1.5
-2.5
-3.5
-4.5
-5.5
-1
-0.5
0
0.5
1
1.5
EDTA
ACID
Linear (EDTA)
Linear (ACID)

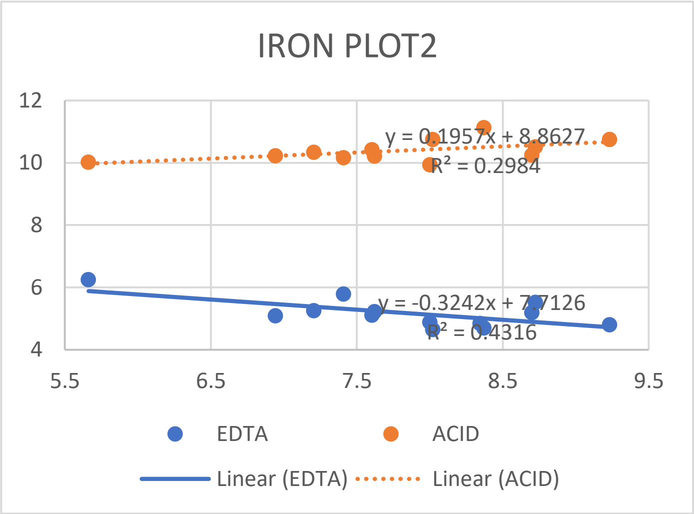

COPPER PLOT 1
y = -0.1633x + 3.1377
R² = 0.0136
y = -0.3992x + 1.7378
R² = 0.0362
3.9
2.9
1.9
0.9
-0.1
-1.1
2.5
2.7
2.9
3.1
3.3
3.5
3.7
EDTA
ACID
Linear (EDTA)
Linear (ACID)

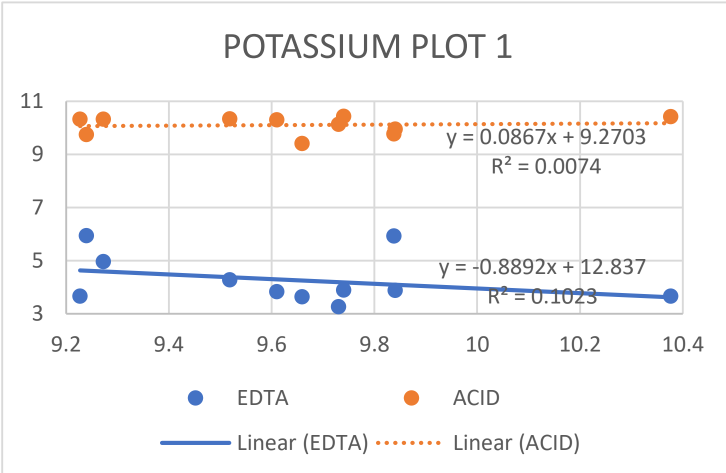

COPPER PLOT 2
y = -0.129x + 3.5103
R² = 0.0151
y = 0.0072x + 0.9072
R² = 0.0002
4
3
2
1
0
2
2.5
3
3.5
4
EDTA
ACID
Linear (EDTA)
Linear (ACID)

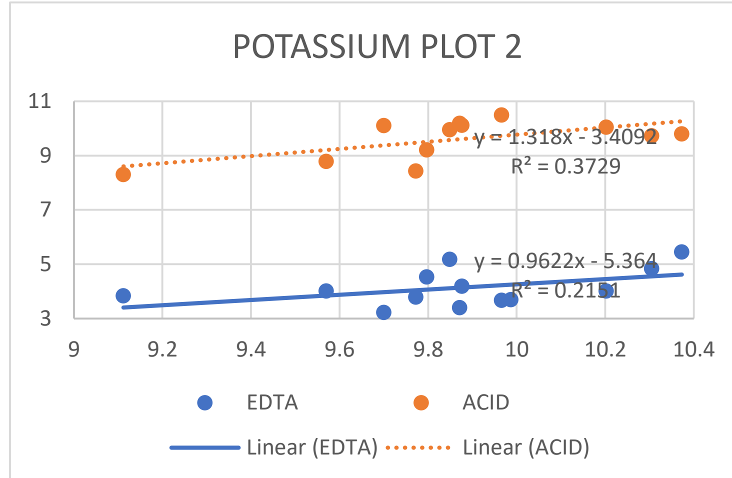

CALCIUM PLOT 1
y = -0.0592x + 9.441
R² = 0.0007
y = 0.3272x + 4.4275
R² = 0.0528
EDTA
ACID
Linear (EDTA)
Linear (ACID)

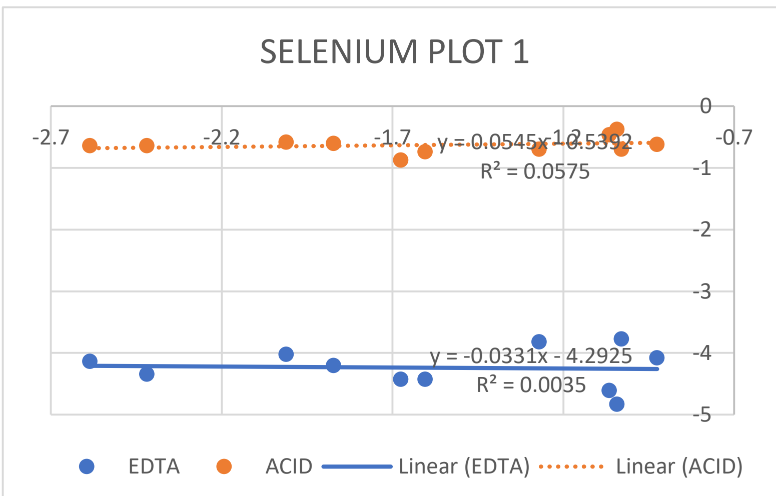

CALCIUM PLOT 2
y = 0.3785x + 6.3953
R² = 0.1283
y = -0.1764x + 8.8084
R² = 0.0269
EDTA
ACID
Linear (EDTA)
Linear (ACID)

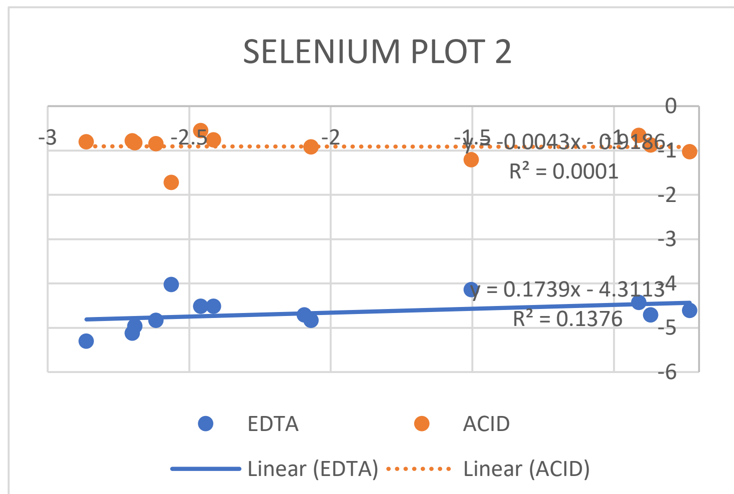

IRON PLOT 1
y = 0.5191x + 6.1244
R² = 0.2411
y = 0.0747x + 5.1832
R² = 0.0169
EDTA
ACID
Linear (EDTA)
Linear (ACID)

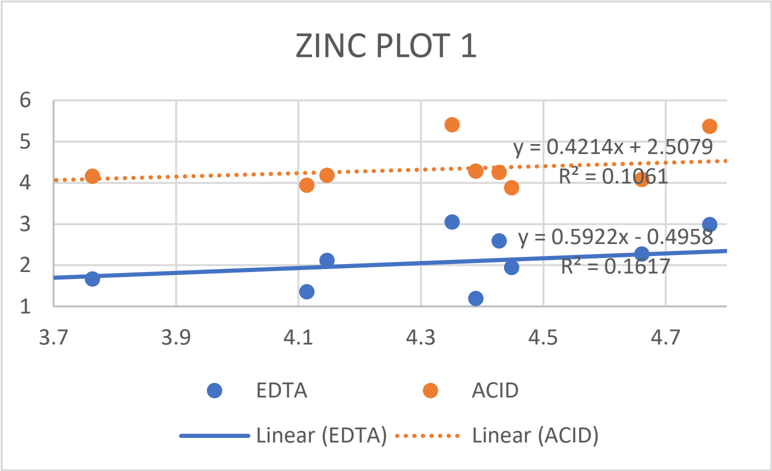

IRON PLOT2
y = 0.1957x + 8.8627
R² = 0.2984
y = -0.3242x + 7.7126
R² = 0.4316
EDTA
ACID
Linear (EDTA)
Linear (ACID)

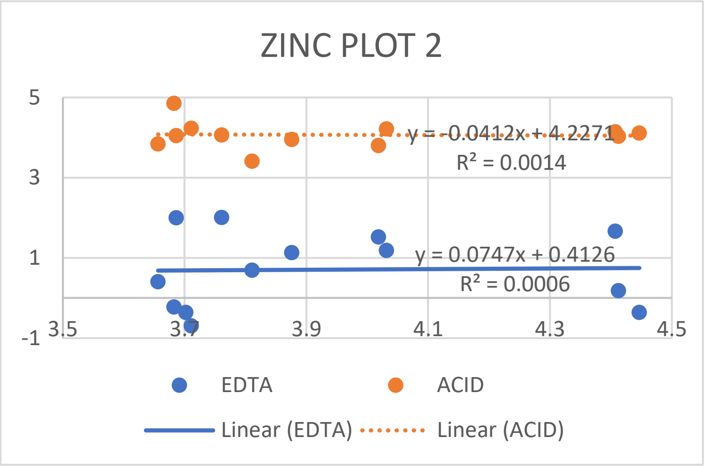

POTASSIUM PLOT 1
y = 0.0867x + 9.2703
R² = 0.0074
y = -0.8892x + 12.837
R² = 0.1023
EDTA
ACID
Linear (EDTA)
Linear (ACID)


POTASSIUM PLOT 2
y = 1.318x - 3.4092
R² = 0.3729
y = 0.9622x - 5.364
R² = 0.2151
EDTA
ACID
Linear (EDTA)
Linear (ACID)


SELENIUM PLOT 1
y = 0.0545x - 0.5392
R² = 0.0575
y = -0.0331x - 4.2925
R² = 0.0035
EDTA
ACID
Linear (EDTA)
Linear (ACID)


SELENIUM PLOT 2
y = -0.0043x - 0.9186
R² = 0.0001
y = 0.1739x - 4.3113
R² = 0.1376
EDTA
ACID
Linear (EDTA)
Linear (ACID)


ZINC PLOT 1
y = 0.4214x + 2.5079
R² = 0.1061
y = 0.5922x - 0.4958
R² = 0.1617
6
5
4
3
2
1
3.7
3.9
4.1
4.3
4.5
4.7
EDTA
ACID
Linear (EDTA)
Linear (ACID)


ZINC PLOT 2
y = -0.0412x + 4.2271
R² = 0.0014
y = 0.0747x + 0.4126
R² = 0.0006
5
3
1
-1
3.5
3.7
3.9
4.1
4.3
4.5
EDTA
ACID
Linear (EDTA)
Linear (ACID)

Appendix II: Similarity Report

University of Eldoret

Certificate of Plagiarism Check for Synopsis

Author Name	Isaboke Job SENV/EBH/M/001/19
Course of Study	Type here...
Name of Guide	Type here...
Department	Type here...
Acceptable Maximum Limit	Type here...
Submitted By	titustoo@uoeld.ac.ke
Paper Title	Availability, mobility, and health implications of essential elements along the gradient of pilot plots of Oroba Valley, Winam Gulf
Similarity	6%
Paper ID	978967
Submission Date	2023-09-21 21:16:21

Signature of Student

Signature of Guide

Head of the Department

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