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**Investigation of the CO₂ Sequestration Potential of Buffel Grass
(*Cenchrus ciliaris*) in Kenyan Grasslands, Case of South Baringo
County**

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DECLARATION

I, **FRANCIS OKWATCH**, declare that this project is my original work and has not been presented as a degree thesis in any other University worldwide.

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CERTIFICATION

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DEDICATION

I sincerely dedicate this work to my lovely mother and siblings, who supported, encouraged, and prayed for me during my studies.
May God bless you all.

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Lastly, but most importantly, I would like to express my special gratitude to my family for being the strongest pillars in my academic life.

ABBREVIATION AND ACRONYMS

ASALs: Arid and Semi-Arid Lands

CO₂: Carbon (IV) Oxide

FAO: Food and Agriculture Organization

LCIPP:

UNFCCC: United Nations Framework Convention on Climate Change

RCMRD: The Regional Centre for Mapping of Resources for Development

NbS: Nature-based Solutions

SDGs: Sustainable Development Goals

VIF: Variance Inflation Factor

SOC: Soil Organic Carbon

BT: Blank titer volume

ST: Sample titer volume

SW: Sample weight

EDA: Exploratory Data Analysis

AGB: Above Ground Biomass

BGB: Below Ground Biomass

KDE: Kernel Density Estimations

TC: Textural Classes

OM: Organic Matter

TC: Total Carbon

NAPs: National Climate Action Plans

GDP: Gross Domestic Product

GHGs: Greenhouse Gases

NOAA: National Oceanic and Atmospheric Administration

ESRL: The Earth System Research Laboratories

EEA: European Economic Area

IPCC: The Intergovernmental Panel on Climate Change

CorHR: Corrected Hydrometer Reading

SOM: Soil organic matter

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ABSTRACT

This study investigates the carbon sequestration potential in Buffel grass landscapes, focusing on the influence of soil biophysical conditions and climate factors. The primary objective was to assess how soil properties, such as pH, bulk density, texture, and carbon content in above-ground biomass (AGB), below-ground biomass (BGB), and soil organic carbon (SOC), contribute to the total carbon sequestration potential. The role of climate factors, including temperature and precipitation, was also evaluated. A multiple linear regression model was developed to examine the relationships between these independent variables and total carbon (sequestered). The results showed that BGB was the strongest predictor of carbon sequestration, followed by AGB and SOC, while soil pH and texture had minimal impact. Although the model perfectly predicts carbon sequestration in Buffel grass landscapes, long-term monitoring and climate data integration is recommended for further understanding. The study suggests that adopting practices that improve below-ground biomass and maintain healthy soil organic carbon levels could enhance carbon storage in similar ecosystems. The findings highlight the importance of soil properties in optimizing carbon sequestration and inform land management practices to enhance carbon storage in grassland ecosystems and mitigate climate change.

1. INTRODUCTION

1.1 Chapter Layout

This Chapter comprises the study background, statement of the research problem, general and specific objectives, and corresponding research hypothesis. It further presents details of the study's scope, significance, limitations, and summary of the study organization.

1.2 Background Information

Grasslands encompass around 3.5 billion hectares, equivalent to 26% of the total land area, 70% of the agricultural land area, and 20% of the soil carbon reserves on Earth (Conant, 2010). The grassland resources are abundant in many nations but are threatened by the increasingly harsh climatic conditions, especially in sub-Saharan Africa. Food and forage production depends on these grassland resources, especially for the populations living in these areas. For instance, a considerable amount of the world's milk (27% of total production) and beef (23% of the total output) originate from grasslands, and around 20% of the world's original grasslands have been transformed into farmed crops (Gibson *et al.*, 2019; FAO, 2006). Because of this, grasslands are vital to the livestock sector, feeding one-third of the world's population and sustaining the livelihoods of one billion people living in the world's poorest arid and semi-arid regions (ASALs) (FAO, 2006). Roughly 14 million people in Kenya, and seventy percent of the country's cattle are found in arid and semi-arid areas (ASALs) (Yator, 2024; Mganga, 2022). With a contribution of 10.4 percent to GDP, ASALs play a crucial role in Kenya's tourist industry (Yator, 2024). The importance of these lands and the livestock sector to economic growth, as acknowledged under Vision 2030, calls for pasture production and restoration of degraded ASAL lands. A significant concern is the degradation of these natural resources; according to the United Nations, 1.2 billion hectares of land are moderately degraded, with a quarter of that landmass being in Africa (Mganga, 2022).

Environmental degradation, encompassing soil erosion and climate change, directly affects agricultural production and food security. Globally, degradation damages 6 million hectares of agrarian land yearly, with 16% impacted by soil problems (Mganga, 2022). Water erosion is the predominant factor, responsible for 56% of land degradation. Land degradation, together with other human activities, has significantly contributed to global environmental change, which has sparked widespread concern due to the increasing concentration of atmospheric greenhouse gases (GHGs) such as methane (CH₄), carbon dioxide (CO₂), and nitrous oxide (N₂O) (Nguyen *et al.*, 2023; Právělie, 2021; Hermans & McLeman, 2021). Average yearly concentration of carbon dioxide (CO₂) increased from 315.97 ppm in 1959 to 408.52 ppm in 2018, the concentration of methane (CH₄) increased from 719.01 ppb in 1750 to 1857.62 ppb in 2018 (NOAA/ESRL, 2018), and the concentration of nitrogen dioxide (N₂O) expanded from 270.00 ppb in 1750 to 328.51

ppb in 2016 (EEA & NOAA, 2019). Deforestation, agricultural practices, livestock husbandry, land-use change, transportation, and industrial developments are among the human activities in the grasslands linked to increased GHG concentrations (Hermans & McLeman, 2021). These, in turn, have contributed to the rising global mean surface air temperature and climate change over the past century, according to (EEA & NOAA, 2019).

The escalating concentrations of GHGs in the atmosphere worsen extreme events such as prolonged droughts and increased flooding intensity in the ASALs due to climate change. One of the most important ways to lessen the effects of global climate change is to achieve net-zero emissions, which is the balance between carbon absorption and emissions (Fankhauser *et al.*, 2022). According to Fankhauser *et al.* (2022), the complete transition to alternative energy sources for industry and power generation and a phase-out of fossil fuels could drastically cut greenhouse gas emissions. Furthermore, carbon-removal technology like carbon capture, utilization, and storage may help reduce harmful emissions (Shu *et al.*, 2023). Notably, natural ecosystems are essential to addressing the climate crisis because sustainable ecosystems store substantial carbon in soils, sediments, and vegetation (Rodrigues *et al.*, 2023; Hessen & Vandvik, 2022). Almost all of the main biome types in Kenya's terrestrial natural environment act as carbon sinks. The capacity of grassland ecosystems to sequester carbon is significantly reduced when degraded, but this can be reversed to accelerate carbon storage through reafforestation and restoration of degraded lands.

Many ecological restoration strategies have been implemented to slow the loss of grasslands since the 1970s. The original goal of these restoration projects was to restore individual deteriorated areas (Lyons *et al.*, 2023). Still, they have expanded to include broader objectives, such as increasing carbon sequestration, improving soil quality, and increasing biodiversity. Much research has looked into what causes grassland degradation, what restoration methods can do to help, and what detriment they can cause (Lyons *et al.*, 2023). Restoring degraded grasslands, especially to reach carbon neutrality, requires immediate attention and adopting more ambitious and coordinated strategies. Given their capacity to tackle numerous long-term issues like climate change, food insecurity, and disaster risk reduction, Nature-based Solutions (NbS) have become potent instruments in this context (Mushashu, 2023). An increasing number of countries recognize NbS as a viable solution to environmental problems, and its use is skyrocketing. These common uses were restoring vegetation, reducing soil degradation, and increasing carbon sequestration. NbS interventions, like safeguarding intact ecosystems, managing agricultural areas, and rehabilitating degraded vegetation, could avert the release of approximately 10 gigatons of CO₂ equivalent annually (Mushashu, 2023). One way to lower the levels of CO₂ in the atmosphere and, hence, reduce or mitigate climate change is to maintain and increase soil carbon. A significant strategy for reducing the impact of climate change on rangeland ecosystems is using grass pastures, which have a deep root system, a high photosynthetic capacity, and a high biomass (Halli *et al.*, 2022; Chandregowda, 2021). One such pasture grass is Buffel grass (*Cenchrus ciliaris*). The perennial tussock grass, known as Buffel grass, has deep taproots and grows in the summer (Maweu *et al.*, 2022). Its original habitats are in Africa, south of the Sahara, India, and Indonesia. The grass is the most extensively cultivated type of pasture grass in pastoral communities of Kenya and has long been acknowledged for its value in rangeland grazing systems (Maweu *et al.*, 2022).

Buffel grass, scientifically known as *Cenchrus ciliaris*, is an essential forage across dry rangelands globally, owing to its remarkable resilience to drought and heavy grazing. Buffel grass shows great promise in reducing soil erosion, increasing soil fertility, and rehabilitating damaged landscapes (Nkombe, 2016; Lebbink *et al.*, 2021). Buffel grass provides several environmental functions and societal advantages, in contrast to its possibly negative impacts on SOM buildup and overall ecosystem quality. For example, Buffel grass significantly removes carbon from the atmosphere (Okwatch & Belem, 2024). This process involves carbon sequestration, capturing and preserving carbon dioxide in carbon pools. Pasture grasses take carbon dioxide from the air and store it in their tissue above and below ground via photosynthesis. In the rangelands of Kenya, Buffel grass can help restore degraded soil and create pasture, increasing the amount of carbon these areas can sequester (Okwatch & Belem, 2024). Thus, this species' adaptability makes it an excellent option for reseeded disturbed regions, which can increase primary productivity in the affected rangelands and add to climate mitigation

1.3 Statement of the Problem

Grasslands offer the key potential for climate change mitigation through carbon sequestration because they represent 26% of global land areas and hold 20% of soil carbon stocks, according to Conant (2010). These ecosystems have lost much of their ability to store carbon since they experienced significant degradation recently. The degradation worsens because of excessive grazing activities, deforestation, and inappropriate land management methods (Maweu *et al.*, 2022). Buffel grass (*Cenchrus ciliaris*) stands out as a native perennial drought-tolerant grass that people recognize as an effective tool to stabilize soils and increase forage production while restoring degraded lands across rangeland areas. However, there is a dearth of research examining the CO₂ sequestration capacity of Buffel grass in Kenyan rangelands for effective land restoration. Buffel grass holds extensive ecological and socio-economic value and widespread usage throughout the rangeland region. Evaluating Buffel grass as a tool for nature-based solution (NbS) for climate change mitigation could establish a degraded land restoration model that effectively responds to global climate change. It is a mitigation tool because it stores carbon in dense aboveground biomass and through its substantial belowground root systems. The intended study investigates the CO₂ sequestration potential of Buffel grass ecosystems in South Baringo County to address existing knowledge gaps. Predictive models will be developed to generate the necessary data to optimize management practices for maximizing carbon sequestration across the area.

1.4 Research Objective

1.4.1 Main/Broad Objective

The study's broad objective is to quantify the capacity of three Buffel grass landscapes to sequester carbon from the atmosphere by analyzing their biophysical properties.

1.4.2 Specific Objectives

- i. To assess the edaphic and climatic conditions influencing carbon sequestration in Buffel grass landscapes.
- ii. To quantify the aboveground biomass, belowground biomass, and soil organic carbon in partially managed Buffel grass landscapes.

- iii. To develop empirical models for estimating CO₂ sequestration potential based on biophysical parameters.

Three specific objectives will guide this study:

1.5 Working Hypothesis:

Hypothesis 1: Edaphic and climatic conditions significantly influence carbon sequestration potential in Buffel grass landscapes.

Hypothesis 2: Buffelgrass landscapes exhibit varying capacities for carbon sequestration based on biomass productivity and soil characteristics.

Hypothesis 3: Using measured biophysical data, predictive models can accurately estimate CO₂ sequestration in Buffel grass landscapes.

1.6 Significance of the Research

The research addresses critical climate change and land degradation challenges that are highly important across local regions and worldwide spheres. Grasslands play an essential role in regulating carbon cycling across the Earth. The ASALs have untapped potential as carbon sinks, yet their degradation and poor management strategy prevent their full carbon storage potential from being achieved. The research studies Buffel grass (*Cenchrus ciliaris*) to redefine these ecosystems as strong carbon sinks, which creates a nature-based solution (NbS) for combating climate change and offering adaptation strategies to pastoralists. These research findings will establish solid experimental evidence on how Buffel grass improves soil carbon sequestration while sustaining ecological stability and sustainable community livestock production. The quantification of Buffel grass carbon storage ability can serve as evidence to promote its implementation in national and regional land restoration and conservation programs that support Vision 2030 and Kenya's climate initiatives. Research findings will guide environmental practitioners, local communities, and official policymakers to implement evidence-based NbS in pastoral communities. The predictive models from this study will establish recommendations to optimize carbon sequestration by balancing ecological objectives with economic and social considerations. Through these insights, communities will understand how to implement sustainable forage production practices, resulting in improved livestock production and enhanced climate risk resilience, supporting environmental conservation and poverty reduction initiatives. This research contributes to a global understanding of how grassland ecosystems can help reach net-zero emissions targets worldwide. It also demonstrates why NbS strategies should be used to fulfill environmental goals within global initiatives like the Paris Agreement and Sustainable Development Goals (SDGs).

1.7 Scope of the Study

This research focuses on quantifying the carbon sequestration potential of Buffel grass in

the context of South Baringo County, Kenya. This area provides a representative setting for evaluating the effectiveness of Buffel grass as a restoration tool in arid and semi-arid lands. The study is structured to address three key dimensions: biophysical assessments, biomass quantification, and predictive modeling. An advanced statistical model was developed to simulate CO₂ sequestration dynamics under various management conditions. These models will provide insights into how practice changes that target soil biophysical properties can enhance carbon storage, offering scalable solutions for similar ecosystems globally.

1.8 Limitations

The initial research design was a comparative investigation of the carbon sequestration potential of managed and unmanaged Buffel grass landscapes. However, this was not possible since the research fieldwork coincided with the protracted dry spell in Kenya from December to March. The fields dried up and had no vegetation cover, which limited the study to only partially managed landscapes. To address this challenge, the research design and objective were revised after consultation with the supervisor and research coordinator to investigate different biophysical conditions and model how they affect carbon sequestration. Another limitation is that while the study focuses on Buffelgrass, findings may not be directly transferable to other grass species or ecosystems without additional research. External factors such as extreme weather events, soil variability, and socio-economic constraints may also influence outcomes. Lastly, the research was limited by financial constraints and limited time allocated for research that could not allow for extensive study and analysis of a large sample size. Careful planning and budgeting were necessary to ensure that quality data was collected and the necessary parameters analyzed to produce replicable findings.

2. LITERATURE REVIEW

2.1 Introduction

This Chapter reviews available literature on the role of grasslands in carbon sequestration and how rangelands offer scalable NbS opportunities. The literature review aimed to build a deeper understanding of the issues under research. It used documents related to the work done by other researchers in reports, textbooks, online publications, and journals through definitions of concepts and terms, a theoretical literature review, an empirical literature review, and a conceptual framework. The Chapter identified and provided solutions to the gaps in previous related case studies.

2.2 Grassland Ecosystems and Degradation

Grassland ecosystems encapsulate approximately 40.5% of the Earth's landmass, excluding Antarctica and Greenland, and span 52.5 million km² (Bai & Cotrufo, 2022). Grasslands offer many cultural functions and habitats for various species of animals and plants (White, 2000; Conant, 2010). In addition to storing approximately 34% of the carbon on Earth, they play a crucial role in soil carbon sequestration by storing 90% of their carbon underground in the form of root biomass and soil organic carbon (SOC) (White, 2000). Grasslands, on the other hand, are highly susceptible to climate change and human interference (such as overgrazing and land-use conversion to agriculture) (Conant, 2010; Okwatch & Belem, 2024). Grasslands worldwide have seen a dramatic decline in SOC storage due to a loss of biodiversity and ecosystem services (Bai & Cotrufo, 2022; White, 2000). Destruction of grasslands endangers the cultural, nutritional, economic, and societal values of the hundreds of millions of people who depend on them (Lark *et al.*, 2020). Degradation of grasslands has an estimated \$6.8 billion worldwide cost to cattle output between 2001 and 2011, disproportionately negatively affecting human well-being in areas where poverty is high (Nkonya *et al.*, 2016). Since grasslands are so crucial for regulating the climate, water, and biodiversity as well as for global biogeochemical cycles, their degradation is a significant environmental problem in and of itself. Converting tropical grassy biomes to arable agriculture, for instance, threatens biodiversity since grasslands contain a vibrant species richness that is equivalent to that of forests (Nkonya *et al.*, 2016). Wildlife has suffered dramatically due to the extensive conversion of prairie grasslands brought about by expanding croplands in the US (Lark *et al.*, 2020). Overgrazing, fire, and invading species are some of the disturbances that can cause grasslands to become arable cropland, which in turn can induce significant soil carbon loss.

The above challenges have made grassland degradation a considerable obstacle that needs to be overcome to reach the critical goals of biodiversity agendas and the UN Sustainable Development Goals (SDGs) (Bardgett *et al.*, 2021). These goals include restoring and using

terrestrial ecosystems sustainably, reducing poverty and hunger, and reducing the impact of climate change significantly in the ASAL environments. Grasslands are among the many degraded ecosystems that the United Nations Decade on Ecosystem Restoration (2021–2030) has identified as critically needing restoration solutions (Bai & Cotrufo, 2022; Bardgett *et al.*, 2021). Several factors work together to degrade grasslands; these include overgrazing, eutrophication, land conversion to crops and forestry, abandonment of land, invasive species, harsh weather, and changed fire regimes due to global warming effects (Bardgett *et al.*, 2021; Conant, 2010). Some examples of socio-economic causes are changes in population density, shifting income and food alternatives, changing land ownership, and inadequate enforcement of land use rights. Also, climate change is accelerating the degradation of grasslands through increased frequency and severity of fires and droughts. Therefore, problems with sustainable development and the ecosystem services provided by grasslands have persisted due to a lack of action to stop and reverse the deterioration of grasslands worldwide (Bardgett *et al.*, 2021).

2.3 Grassland Degradation in Kenya and its Impacts

According to studies conducted in 1997, 64% of Kenya's geographical area could experience mild desertification, and 23% could face severe to highly severe desertification. Within the northern rangelands, 12.3% experienced severe land degradation, 52% moderate land degradation, and 33% were slightly vulnerable to degradation (Kenya Land Alliance, n.d.). According to Kenya Land Alliance (n.d.), the second study found that degradation in ASALs could be a sign of widespread desertification. Thirty percent of Kenya was impacted by severe land degradation in the early 2000s (Mwaura, 2019), and twelve million people, or one-third of Kenya's population, relied directly on that land (Bai *et al.*, 2008). Soil deterioration and decreased food production per capita were both hastened by the droughts between 1970 and 2000 (Mwaura, 2019). Land degradation is becoming worse and more widespread, according to newer research that extrapolates from local findings of spatial and temporal patterns. Degradation affects more than 20% of all cultivated areas, 30% of forests, and 10% of grasslands (Muchena 2008). Areas with diminishing net primary production and rain-use efficiency made up 17% of the country and 30% of its cropland, according to a 2006 pilot study. Much of this degradation is attributable to the spread of farming into marginal regions. According to Bai and Dent (2006), the areas seeing the most drastic loss include the marginal farmland in Eastern Province and the drylands surrounding Lake Turkana.

Poverty and food insecurity are intimately associated with land degradation and desertification, which reduces the productivity of crops, pastures, fuelwood, and non-timber forest products (Bai & Dent, 2006). Reduced biodiversity, ecosystem services, and economic repercussions result from soil degradation, habitat loss, water scarcity, and siltation (Kenya Land

Alliance, n.d.). Grasslands, in particular, are also crucial for the global carbon balance as they act as large carbon pools both in aboveground plant material and in the carbon content of the soil. Shrub and herbaceous biomass in grassland areas fix atmospheric CO₂ through photosynthesis while developing deep roots; this helps accumulate carbon in the deep bottom soil profile. However, overgrazing, deforestation and poor resource management reduce the extent to which grasslands are helpful in sequestering carbon. Reduced ability in grasslands implies a decline in plant cover, soil compaction, loss of organic materials, and the emission of stored carbon back into the atmosphere. The annual transfer of approximately 0.8 Mg of soil carbon to the atmosphere is primarily attributable to cultivating natural grasslands (Conant, 2010). There is substantial and well-documented evidence of soil organic matter losses due to cultivating natural grasslands. Not only does this continue climate change, but it also reduces the functions and values of these ecosystems, making the restoration and proper use more critical. Significant human-controlled variables impacting grassland production and contributing to soil carbon stock depletion include the removal of substantial amounts of aboveground biomass, perpetual heavy stocking rates, and other ineffective grazing management practices (Conant, 2010). However, effective grassland management can retrieve soil carbon losses in the past and even increase soil carbon sequestration.

2.4 Nature-Based Solutions (NbS)

Several researchers have pointed out that additional interventions are urgently needed to remove the existing from the atmosphere and achieve net zero by mid-century. Although natural grasslands offer a variety of environmental goods and services, such as carbon (C) storage, temperate grasslands are known to play a significant role in fodder and livestock production, as well as taking huge amounts of carbon from the atmosphere (Valkó *et al.*, 2022; Sun *et al.*, 2024). Developing ways to sequester carbon to combat climate change using nature has garnered considerable attention due to the increasing quantities of carbon dioxide in the atmosphere and the corresponding rises in average temperatures. There has been a surge in interest in carbon cycling within grassland systems, thanks to the vast amount of land they cover, rising concerns about global warming, and the possibility that grasslands could store carbon (Sun *et al.*, 2024). According to Jones and Donnelly (2004), the amount of carbon that is stored in temperate grasslands is determined by subtracting the amount of carbon that is released through harvest, fire, heterotrophic respiration, and changes in soil organic carbon stocks from the amount of carbon that is taken in by net primary production. Because soils hold over two times as much carbon as the atmosphere, they play a crucial role in the storage of vast quantities of carbon (Tanwar *et al.*, 2019). As in other terrestrial ecosystems, soil carbon sequestration is the primary mechanism by which increased carbon inputs

naturally cause grassland systems to sequester carbon (Conant, 2010). Because as much as 97 percent of soil carbon is kept below ground, where it is relatively shielded from short-term disturbances like fire, which would otherwise release carbon in above-ground vegetation, perennial grasslands are significant sinks for carbon storage (Conant, 2010; Abberton *et al.*, 2010). As a result of the slow underground carbon turnover in this very stable soil environment, significant accumulations of soil organic matter are present.

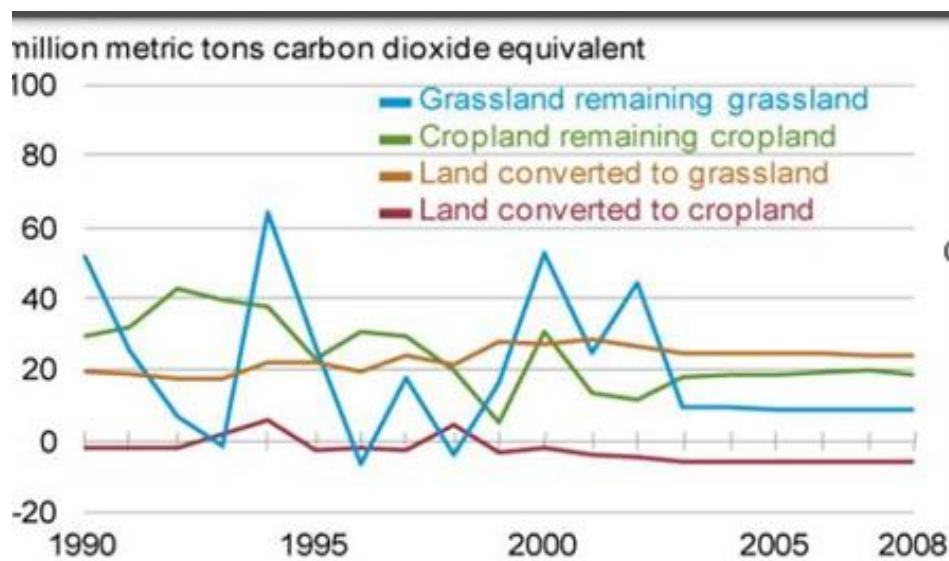


Figure 1: Carbon sequestration in US Croplands and Grasslands (U.S. Energy Information Administration - EIA - independent statistics and analysis, 2011)

Figure 1 above shows how much carbon is sequestered in grasslands in the US between 1990-2008. Grasslands are shown to sequester higher amounts of carbon than croplands (U.S. Energy Information Administration - EIA - independent statistics and analysis, 2011). The capacity of temperate grasslands to sequester carbon is finite (Abberton *et al.*, 2010). Native grasslands, forests, and agroecosystems are examples of carbon sinks since they absorb more carbon than they release. When looking at the world's carbon stock, grasslands account for around 34%, forests for about 39%, and agroecosystems for about 17% (World Resources Institute, 2000). It is the soil, not the plants, that stores the vast majority of carbon in

grasslands, in contrast to forests. Therefore, the arid and semi-arid areas, which make up around 26% of the world's landmass (Qader *et al.*, 2021), have the potential to significantly contribute to the fight against climate change through reseeding severely damaged public grasslands and agroforestry on agricultural land, which may increase tree and grass cover thereby increasing carbon sequestration. For instance, Jonnes and Donnelly (2004) state that carbon sequestration rates in temperate grasslands can vary between zero and over eight million metric tons per hectare. According to a review of empirical studies on the topic by Éco Resources Carbonne (Norfolk, 2011), the rates of soil organic carbon change during the transition from annual crops to perennial cover varied from 0.23 to 1.40 Mg C/ha/yr in the Canadian Prairies. Boehm *et al.* (2004) used the Century model to determine that converting farmland to permanent cover added 18 Mg C/ha to the Brown soil zone and 66 Mg C/ha to the Black and Gray soil zones of the Canadian Prairies regarding cumulative soil organic carbon stock changes. Soil organic carbon stocks are predicted to rise by 25 Mg C/ha when arable land is converted to natural grasslands, and 0.8 Mg C/ha/yr is the yearly sequestration rate (IPCC 2000). However, statistical evidence is necessary to back up these projects to effectively restore degraded grasslands or convert croplands to grasslands for NbS projects, especially in the Kenyan rangelands.

2.5 Carbon Sequestration Potential of Buffel Grass

Grasslands covered with Buffel grass may be found worldwide within 45 degrees of latitude and longitude from the Equator (Veitch & Clout, 2002). Buffel grass has extreme drought tolerance and can endure severe grazing, making it extensively cultivated in tropical and subtropical dry rangelands worldwide (Mansoor *et al.*, 2019). Outside of its native habitat, Buffel grass may quickly spread to other areas, displacing native species and changing the way wildfires are managed. It can even overrun roadsides and urban settings (Marshall *et al.*, 2012). The exceptional nutritional content, drought endurance, heavy grazing tolerance, deep stabilizing root structure, and rapid rainfall response of Buffel grass make it ideal for pasture grass and land restoration.

According to studies Buffel grass generates substantial aboveground biomass across different management approaches. The input of nitrogen fertilizer resulted in increased aboveground biomass yields of Buffel grass in Mandera County, Kenya, throughout the short and long rain seasons. Appropriate nutrient management practices have been shown to increase the productivity of Buffel grass when used in Kenyan rangelands. Buffel grass exhibits exceptional survival in arid environments through its effective root system (Basharat *et al.*, 2024). Buffel grass presents long root systems that create substantial contributions to soil organic

carbon (SOC) levels because of their extensive penetration into the ground. Research demonstrates that Buffelgrass exhibits strong survival capabilities under harsh conditions and robust belowground biomass production for preserving soil stability and carbon-locking capabilities (Basharat *et al.*, 2024). The ability of Buffel grass to improve SOC levels demonstrates its significant impact on soil conditions. Research into grassland management has revealed that Buffelgrass produces notable increases in SOC levels in managed spaces when compared to unmanaged areas. Researchers in the Sonoran Desert discovered Buffel grass establishment elevated nitrogen alongside soil organic carbon measurements that are critical for soil well-being and fertility (Fariás *et al.*, n.d). Buffel grass exhibits effective capability to restore land and enhance soil quality across Kenyan rangelands.

2.6 Management Effects on Carbon Sequestration

Recent research has shown that grassland ecosystems benefit from improved nitrogen cycling and increased development of herbaceous plants when grazing is appropriately done. According to LeCain *et al.* (2000), compared to ungrazed prairie/exclosures, grazed mixed-grass prairie showed increased early-season photosynthesis. Evidence shows that grazing has a similar effect, increasing tillering and rhizome production and aboveground output (de Vries *et al.*, 2019). Also, the rate of root exudation and root respiration may be increased by grazing. In several cases, it has been discovered that when grasslands lacked nitrogen and when fertilized with nitrogen, they showed signs of enhanced productivity and water-use efficiency. In such cases, increased soil C storage results from fertilizer-induced litter formation. A 1.6 Mg/ha increase in soil C resulted from nitrogen fertilizer treatment, which enhanced plant output in the tall grass prairie (Rai *et al.*, 2003). Research conducted by Rai *et al.* (2013) found that natural pasture soil organic carbon (TOC) content and dry fodder production significantly increased with an application of 40 kg N/ha.

Restoration of degraded grasslands through reseeding with Buffel grass and other native species can enhance carbon sequestration. Biomass production may be enhanced by introducing or promoting improved and beneficial forage species that are more suited to the local climate, more resistant to grazing and drought, and can improve soil fertility (Tulu *et al.*, 2023). Increasing productivity results in more carbon inputs and sequestration. Fire management may change the density or invasion of woody species in certain grasslands, affecting the amount of carbon stored in biomass. Some grassland soils may contain a substantial amount of charcoal, a relatively inert form of carbon produced by burning biomass. After 10 years of yearly fire and grazing on tallgrass prairie, soil C storage increased by 2.2 Mg/ha, or 0.22 Mg/ha/year, according to Ghosh and Mahanta (2014). The following flow chart shows some beneficial and negative management practices for carbon management in grasslands.

2.7 Conceptual Frameworks

While the reviewed literature provides thorough information on the role of grasslands in carbon sequestration, there is limited documented work that quantifies the specific role of Buffel grass in absorbing and storing carbon from the atmosphere. Most of the available literature covers carbon dynamics in grasslands and explores the role of Kenyan grasslands in climate change action. Additionally, other scholars have focused on the suitability of Buffel grass in desert restoration and as a forage for the pastoralist communities. These researchers provide a crucial foundation for quantifying carbon stored and sequestered over time under different management regimes and environmental conditions. This study quantifies carbon sequestration by examining amounts of carbon stored in the above-ground biomass, below-ground biomass, and soil organic carbon with the goal of understanding how various biophysical factors, such as soil properties and vegetation characteristics, interact with climatic factors (temperature and precipitation) to affect carbon storage in soils and vegetation. This framework will be the basis of Total Carbon (TC) modeling and will guide recommending solutions to optimize carbon sequestration efforts.

The conceptual framework builds the foundation to demonstrate how soil biophysical factors and climatic factors interact with biomass accumulation to determine carbon sequestration in Buffel grass ecosystems. This framework relies on two significant independent variables: soil biophysical factors and climatic factors. Ecosystem carbon sequestration capacity depends on these variables because they influence plant growth and soil organic carbon storage (Ahirwal *et al.*, 2021). All the characteristics of soil biophysics, including texture, bulk density, and moisture levels, pH levels, and organic carbon concentrations, determine a soil's potential to nurture plant growth and store carbon (Lal, 2022). The soil texture controls how much water it holds and aeration levels because it influences roots' ability to penetrate the soil and microbial functioning (Jha *et al.*, 2023). The compaction of soils due to bulk density affects root development and water infiltration rates, influencing organic matter buildup (Jhaa *et al.*, 2023; Lal, 2022). The pH of soil controls the release of fundamental nutrients to plants and affects the breakdown of organic matter through microorganisms. The breakdown of organic matter, nutrient release, and organic carbon stabilization depend on microbial activity, which reduces at higher pH levels (Lal, 2022). Soil fertility improves when organic carbon is high, enhancing the soil's capability to store carbon.

The process of carbon sequestration depends heavily on two climatic elements: precipitation and temperature. Soil moisture availability depends on precipitation levels, directly impacting plant growth and microbial activity (Malla *et al.*, 2022). The biomass quantity and carbon stored in soils of arid and semi-arid regions with Buffel grass populations

varies because of precipitation changes. Temperature controls both photosynthetic rates and the pace of organic matter decomposition (Nie *et al.*, 2023; Lal, 2022). The rate at which microorganisms work increases with warmer conditions which speeds up the natural breakdown of natural organic compounds and may result in carbon loss (Ahirwal *et al.*, 2021; Malla *et al.*, 2022). Under favorable environmental conditions, Buffel grass rapidly grows while producing abundant biomass that increases carbon storage levels. For the purposes of this project, it is assumed that the three study sites have similar climatic conditions. Even though micro-climatic conditions could have effects, this is assumed to cause minor variations in the final total carbon stored in the whole ecosystem. Therefore, the scope of this research will remain to examine the impacts of biophysical conditions on carbon sequestration.

The developed conceptual framework uses above-ground biomass, below-ground biomass, and soil organic carbon as the intervening variables indicating the linkage between carbon sequestration and the soil biophysical conditions. Above-ground biomass consists of grasses and other plant materials above the ground level that extract carbon from the air to create biomass via photosynthesis (Malla *et al.*, 2022). Below-ground biomass elements, such as root systems, exist below the ground level and function as long-term carbon storage agents by breaking down into the soil. Soil organic carbon is formed by decomposed plant matter accumulating in the soil as a stable carbon reservoir over extended periods. Soil properties influence the carbon pool accumulation process by impacting biomass development and decomposition rates (Rodrigues *et al.*, 2023). Ultimately, Total carbon sequestration is the dependent variable in this conceptual framework. The total storage of carbon in Buffel grass ecosystems forms through the combined effects of soil attributes and biomass output quantities. More biomass allows greater carbon amounts to enter the soil, increasing its sequestration effectiveness. However, soil degradation, altered precipitation patterns, prolonged droughts, and amplified decomposition rates because of global warming accelerate the release of carbon (iv)oxide into the atmosphere, exacerbating global climate change (Rodrigues *et al.*, 2023). This framework, therefore, provides a holistic understanding of the processes governing carbon sequestration in Buffel grass ecosystems, emphasizing the need for proper land and climate management strategies to enhance carbon storage and mitigate climate change.

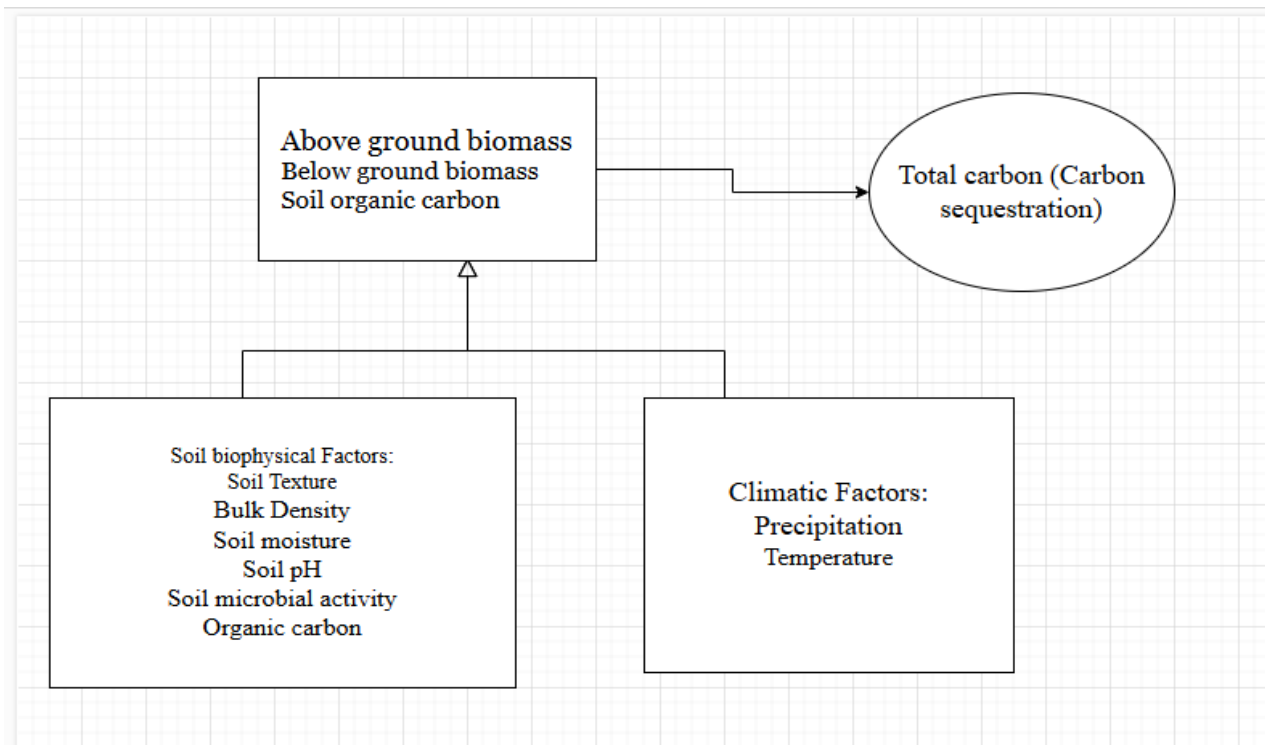


Figure 2: Conceptual Frameworks

3. MATERIALS AND METHODS

3.1 Introduction

This Chapter covers all data collection and analysis methods and explains the study area in depth.

3.2 Study Area

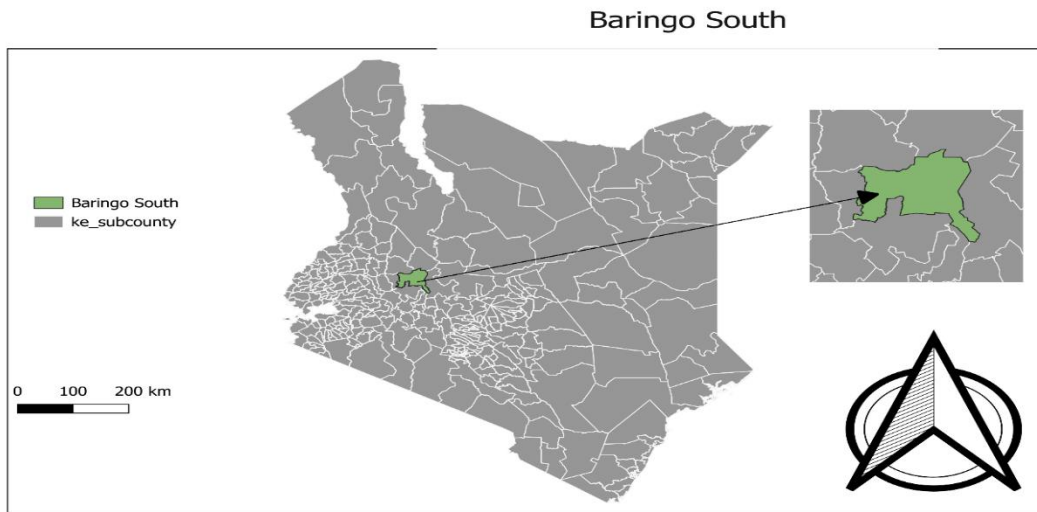


Figure 3: Study Area Map

The study was conducted in South Baringo County, Kenya, an area characterized by a combination of arid and semi-arid ecosystems, making it a critical site for evaluating the carbon sequestration potential of Buffel grass (*Cenchrus ciliaris*). This region is situated within Kenya's Arid and Semi-Arid Lands (ASALs), a vast expanse comprising around 89% of the country's land area. ASALs are crucial to Kenya's agricultural economy, particularly livestock farming, the primary livelihood activity for many rural communities. South Baringo Sub-County lies within the Great Rift Valley, one of Kenya's most geologically and ecologically diverse regions. The area has a relatively flat terrain with intermittent hilly areas and a climate ranging from hot and dry in the lowlands to more temperate conditions at higher altitudes. The climate of South Baringo is classified as semi-arid to arid, characterized by low and erratic rainfall. Average annual precipitation ranges from 500 mm to 900 mm, with significant seasonal variations and frequent droughts.

Temperatures in the region range from 25°C to 35°C, with higher temperatures during the dry seasons. The area experiences extended dry periods, exacerbating the already limited water resources, making the vegetation and soil highly sensitive to climatic conditions. The climatic stress on vegetation makes it particularly relevant to study the CO₂ sequestration potential of Buffel grass, known for its drought tolerance and resilience in harsh environments. The primary vegetation in South Baringo is dominated by grasslands, shrublands, and acacia woodlands, with vegetation cover varying in density depending on altitude and water availability. Grasslands in this region are of great importance to the local communities, providing forage for livestock and acting as important carbon sinks. Buffel grass (*Cenchrus ciliaris*), introduced in the region for pasture rehabilitation, is widely prevalent. Buffel grass thrives in arid conditions, as it has a deep

root system and is drought-resistant, making it suitable for rangeland management. Buffel grass has also been shown to play a role in soil stabilization, reducing erosion, and improving soil fertility, particularly in degraded areas.

3.2.1 Study Sites

The study focused on three key areas in Baringo South, which were chosen for their ecological importance and the presence of Buffel grass. The Marigat region in Kenya's Baringo County is the research site. There are distinct patterns of precipitation and temperature that define the semi-arid climate that this region experiences. Its tropical weather is a result of its proximity to the equator. Typically, the region's warmest months—December through March—see temperatures ranging from 28 to 35 degrees Celsius. The region has seen an increasing tendency for the average temperature to rise over time due to a warmer global climate. During the dry seasons, temperatures rise the most. Prolonged heat spells caused by this high-temperature impact the area's fodder production and lower carbon sequestration. Precipitation has also historically followed a bimodal distribution pattern. The region experiences two distinct rainy seasons annually. The first, which runs from March to May, is characterized by heavy rains, while the second, from October to December, is characterized by shorter rainfall. Nonetheless, these rain patterns show much variation and unpredictability in the past. Annual precipitation in the region typically ranges from 500 to 700 mm, though this can vary greatly depending on one's location. There has been a shift in the traditional rainfall pattern in recent years, with rain falling at unpredictable times. On top of that, there are strong downpours every so often interspersed with longer dry intervals throughout the region. The varying amounts of precipitation hinder the carbon sequestration process in those areas. These areas represent a range of environmental conditions typical of South Baringo's rangeland ecosystems. The study sites include Chuinee, Nasinya, and Kiborgoch Conservancies.

In addition to being significant grazing lands for livestock, the grasslands in these areas are used for pastoralism and agriculture. Overgrazing, unsustainable farming practices, and deforestation have contributed to land degradation in the region. In response, increasing efforts have been made to restore degraded areas by introducing Buffel grass and other drought-resistant species. This restoration is intended to improve soil fertility, reduce erosion, and enhance carbon sequestration. The study areas have been selected to reflect both well-managed and less-managed ecosystems, making them ideal for understanding the dynamics of carbon sequestration under varying land management practices.

3.3 Research Design

The study adopted a correlational research design to evaluate the carbon sequestration potential of Buffel grass fields by examining how biophysical factors influence the total carbon of three

landscapes. It will involve stratified random sampling to develop three study sites within the same hydroclimatic zone, random sampling to collect samples and laboratory analyses.

3.4 Sampling Methods

A stratified random sampling method was used to identify three study sites: Chuinee Conservancy, Kiborgoch Community Conservancy, and Nasinya Women Group Pasture Project. The stratification will ensure that comparisons are made between fields with similar environmental conditions to eliminate external variability. Twelve sample sites were randomly taken at a distance of six meters apart for above-ground biomass, below-ground biomass, and soil organic carbon for each study site. In each sample site, composite samples for aboveground biomass, belowground biomass, and soil organic carbon (SOC) will be taken randomly. The samples were collected and stored in clean, airtight Ziplock bags. The samples were then carried out and stored in a cool box to preserve the moisture content and taken to the laboratory for analysis.

3.5 Data Collection Methods

According to IPCC (International Panel on Climate Change) (2006), carbon in land area is accumulated in five main pools: above-ground biomass, below-ground biomass, deadwood (dead organic matter), litter (dead organic matter), and soil organic carbon. According to the IPCC, dead organic matter (deadwood and litter) is not a priority pool for the grassland land-use category since carbon accumulation is negligible. Therefore, three carbon pools were considered for the project area's carbon inventory: 1. Above-ground biomass, 2. Below-ground biomass, and 3. Soil organic carbon. After selecting the sampling plots, the soil harvesting method was used to collect field data (above-ground biomass). Soil coring was used (extract soil cores to quantify root biomass) for below-ground biomass. For soil organic carbon (SOC), the study collected soil samples at a depth of 30 cm for laboratory analysis (using standard methods, the Walkley-Black titration method). Thirty-six soil samples were collected from all fields to analyze edaphic properties, including texture, pH, bulk density, and soil organic matter. A soil auger with a diameter of 5 cm was used, and soil samples were taken to a depth of 30 cm. Therefore, the sampled area in each site is given by:

$$\text{Cross-sectional area: } A = \pi r^2$$

Where:

- r = radius of the auger = $5/2.5 = 2.5$ cm
- $\pi = 3.1416$

$$A = 3.1416 \times (2.5)^2 = 19.635 \text{ cm}^2$$

Thus, the cross-sectional area of the soil sample is 19.64 cm².

There was no functioning hydrometeorological station in the area. Therefore, the Kenya Meteorological Department obtained gridded (interpolated station and satellite data) hydroclimatic data for the study area.

3.6 Sample Analysis

3.6.1 Soil Characteristics

To assess soil characteristics, soil samples were collected from the three study sites to analyze edaphic properties, including texture, pH, bulk density, and soil organic matter. Standard soil analysis methods will be used. Soil texture was determined using the Bouyoucos Hydrometer Method to measure the sand, silt, and clay proportions in a soil sample. The samples were air-dried, grounded, and sieved using a fine mesh to remove large particles. 50 g was weighed of the air-dried soil and transferred into a 1000 mL beaker where 100 mL of distilled water was added, followed by 10 mL of sodium hexametaphosphate to disperse the particles. The mixture was stirred for two minutes using a stirrer. The beaker was filled with water up to about 1000 ml. The soil suspension was plunged for two minutes, and then a hydrometer reading for the sand content (at the 40-second mark) and temperature reading were immediately taken. The soil suspension was plunged for two minutes and allowed to rest for two hours. The second reading was taken and recorded for temperature and hydrometer readings. The sand, clay, and silt proportions are given by:

$$\% \text{Sand} = (50 - \text{CorHR} / 50 \text{g/l}) 100$$

$$\% \text{Clay} = (\text{CorHR} / 50 \text{g/l}) 100$$

$$\% \text{Silt} = 100 - (\% \text{sand} + \% \text{clay})$$

Where CorHR is the corrected hydrometer reading.

Calculating corrected hydrometer reading:

1. For each degree above 20 °C, add 0.36 g L⁻¹ to the hydrometer reading; for each degree below 20 °C, subtract 0.36 g L⁻¹ from the hydrometer reading. This was done for each sample (soil checks and blanks included) at both time intervals.



Figure 4: Adding sodium hexametaphosphate solution

3.6.2 Soil pH Determination (Using a pH Meter)

10g of the fine air-dried soil was weighed and placed in a clean beaker. 20 mL of distilled water was added to the soil, mixing it to form a slurry. The mixture was stirred for 30 minutes to ensure proper suspension of soil particles. The electrode was immersed in the soil slurry using a pH meter and recorded the pH value.

3.6.3 Aboveground Biomass

Grass within a 1 m² quadrat was clipped at ground level for each sample site. The grass biomass density was high, and it was enough to harvest just 0.25 m² area. The sample was taken inside a Ziplock bag and kept in a cool box for transportation to the laboratory. The samples were weighed to obtain fresh-weight biomass. Then, the samples were dried at 65°C for 72 hours to a constant weight to determine dry biomass. Based on IPCC guidelines, carbon content was estimated by assuming 47% of the dry biomass weight is carbon.

Aboveground Biomass (g/m²) is calculated as:

$$\text{AGB (g/m}^2\text{)} = \text{Dry weight of biomass (g)} / \text{Area sampled (m}^2\text{)}$$

Estimating Carbon Content of Aboveground Biomass:

$$\text{Carbon in AGB (g C/m}^2\text{)} = \text{Dry weight of AGB (g/m}^2\text{)} \times 0.47$$

3.6.4 Belowground Biomass

The soil core method was used to estimate the below-ground biomass because it is the most appropriate for grassland vegetation. Soil cores of 30 cm depth were extracted at each sample site using a soil auger and placed inside a Ziplock bag. Roots were separated from the soil using a fine mesh sieve, dried for seventy in the oven at 65 degrees, and weighed to estimate root biomass. This ensures that the weight measured is purely from the root biomass and not influenced by water content. The weight of the dried roots represents the belowground biomass (BGB). Like aboveground biomass, carbon content was estimated at .47 of the dry biomass.

Belowground Biomass (g/m²) can be expressed as:

$$\text{BGB (g C/m}^2\text{)} = \text{Dry weight of roots (g)} / \text{Area sampled (m}^2\text{)}$$

Estimating Carbon Content of Belowground Biomass:

Carbon in BGB (g C/m²) = Dry weight of roots (g/m²) × Carbon fraction (0.47)

The results were then extrapolated to per hectare in tones.

3.6.5 Soil organic matter and Soil Organic Carbon (SOC) (the Walkley-Black titration method)

Soil analysis was conducted from one sample for the following analysis: 1. Soil organic matter (SOM) and soil organic carbon (SOC) for carbon stock inventory and soil pH. Soil samples were collected at a depth of 30 cm using a soil auger. Samples were then spread out in an open space, air-dried for 72 hours, and ground to fine particles. The particles were sieved and analyzed in the laboratory for SOC using the Walkley-Black titration method, which was selected after consultation with soil experts. 0.3g of each sample was weighed into a beaker, and 10 ml of potassium dichromate (oxidizing agent) was added. 20 ml of concentrated sulfuric acid (H₂SO₄) was added to the mixture. This results in an exothermic process that oxidizes the organic carbon in the soil. The mixture was allowed to stand for 30 minutes and then diluted with 200 ml of distilled water inside a conical flask. After oxidation, 85% orthophosphate (phosphoric acid, H₃PO₄) is added. This step helps to stabilize the reaction and neutralize excess potassium dichromate and sulfuric acid, preventing the formation of unwanted side products. Diphenylamine was then added as an indicator to detect the presence of excess dichromate. When the sample is in excess dichromate, the solution will appear violet-blue due to the formation of a diphenylamine-chromium complex. The sample is then titrated with 0.5 M ferric ammonium sulfate (FeNH₄(SO₄)₂) solution, which reacts with the remaining excess dichromate. The titration is conducted until the color changes from violet-blue to green, indicating the endpoint. The iron (Fe³⁺) in the ferric ammonium sulfate has reduced all the excess dichromate. The titer volume was recorded. The amount of ferric ammonium sulfate used in the titration correlates with the reduced dichromate, which reflects the amount of organic carbon in the soil sample. The difference in the initial and final concentrations of dichromate is used to calculate the organic carbon content. The soil organic carbon (SOC) percentage was calculated using the following formula.

$$\%SOC = 10(BT-ST)/BT * (0.003/SW)100$$

Where:

BT is the blank titer volume

ST is the sample titer volume

SW is the sample weight

3.7 Data Analysis

3.7.1 Exploratory Data Analysis

A comprehensive exploratory data analysis (EDA) was conducted to understand the dataset's characteristics. The EDA included distribution analysis, where histograms and Kernel

Density Estimations (KDE) were generated for continuous variables such as pH, Above Ground Biomass (AGB), Below Ground Biomass (BGB), Soil Organic Carbon (SOC), and Carbon. Mean and median values were annotated on the plots, and the Shapiro-Wilk test was used to assess normality. For categorical variable analysis, boxplots were created to examine the distribution of carbon across different study sites and textural classes. Correlation analysis was performed by computing Pearson correlation coefficients among key numerical variables, and a heatmap was generated to visualize relationships, with the significance of correlations evaluated using p-values. Scatterplot analysis was conducted by constructing regression plots to assess relationships between Carbon and continuous predictors, including pH, AGB, BGB, and SOC. Pearson correlation coefficients and significance levels were annotated on each plot.

3.7.2 Outlier Detection and Removal

Outliers were identified using the Z-score method to enhance data quality. Data points with Z-scores greater than 2.5 were flagged as potential outliers. A boxplot visualization was used to inspect the outlier presence visually. Observations classified as outliers were removed from the dataset to prevent them from influencing the model results.

3.8 Statistical Modeling

A multiple linear regression model was developed to examine the impact of predictor variables on Carbon content. The model was implemented using the `sklearn.linear_model.LinearRegression` module/library in Python, with Carbon as the dependent variable and pH, Above Ground Biomass (AGB), Below Ground Biomass (BGB), Soil Organic Carbon (SOC), and the dummy variables for textural classes (TC) as independent variables. The model was evaluated using several metrics, including the coefficient of determination (R^2) to assess the proportion of variance explained by the model, mean squared error (MSE) to evaluate prediction accuracy, and statistical significance, where individual predictors were assessed using p-values from the regression output. To ensure the model's reliability, assumptions such as linearity, homoscedasticity, and independence of residuals were examined. The variance inflation factor (VIF) was computed to detect potential multicollinearity issues among independent variables.

3.9 Data Visualization and Interpretation

Results from the statistical models were visualized using Seaborn and Matplotlib libraries. Scatterplots with fitted regression lines, boxplots, and heatmaps were used to present findings effectively. All figures were saved in high resolution for inclusion in the final report.

4. RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the study's results and the discussion derived from them. The results are presented in tabular and graphical methods for straightforward interpretation and inference. The Chapter also discusses and compares results obtained from similar studies.

4.2 Climate Data

Weather impacts every stage of the carbon storage process. Soil organic carbon increases with more rain and lower temperatures. Rising temperatures speed up the decay of soil organic matter, releasing carbon into the atmosphere. Carbon sequestration relies heavily on these climatic factors. This investigation utilized hydroclimatic data from Stateline stations from 1993 to 2023, covering 30 years. These climatic factors are crucial in understanding the edaphic conditions influencing Buffel grass (*Cenchrus ciliaris*) growth, productivity, and carbon sequestration potential. The results of the study's research questions and hypotheses are discussed. The results are presented and discussed in the following sections. Marigat is 1024.24 meters (3360.37 feet) above sea level and has a Tropical wet and dry or savanna climate. The region's annual temperature is 19.8°C, which is 2.7% lower than the average for Kenya. The warmest month is February (27.98°C / 82.36°F), while the coldest is June (11.07°C / 51.93°F). Marigat generally experiences approximately 230.32 millimeters (9.07 inches) of precipitation and records 264.52 rainy days (72.47% of the year) yearly. The wettest Month is April, with a precipitation of about 377.19mm, while the driest Month is February, with a precipitation of 60.0mm. The area has a humidity of about 76.39%.

4.2.1 Monthly and Annual Temperature Patterns

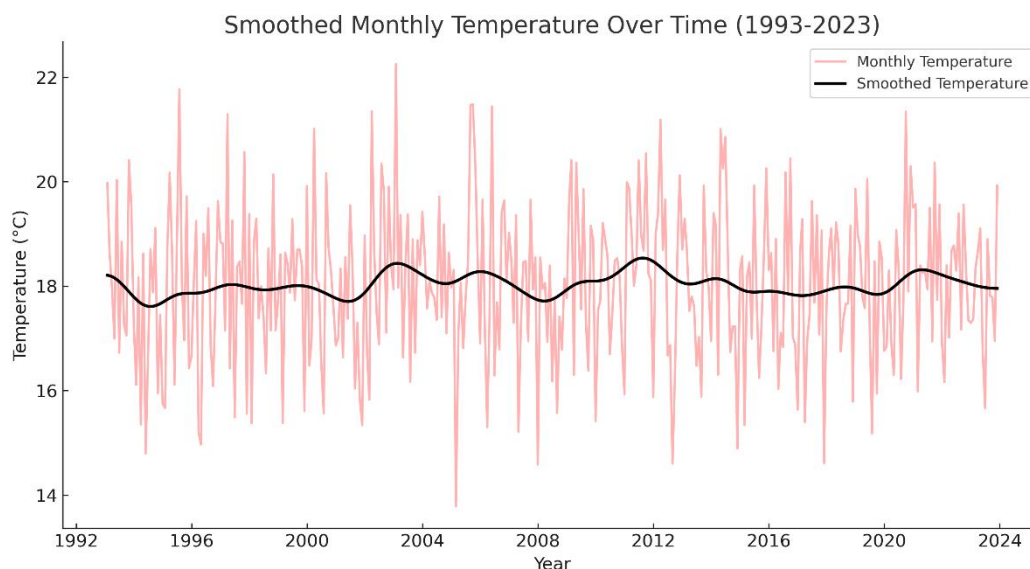


Figure 5: Smoothed monthly temperature over time (1993-2023)

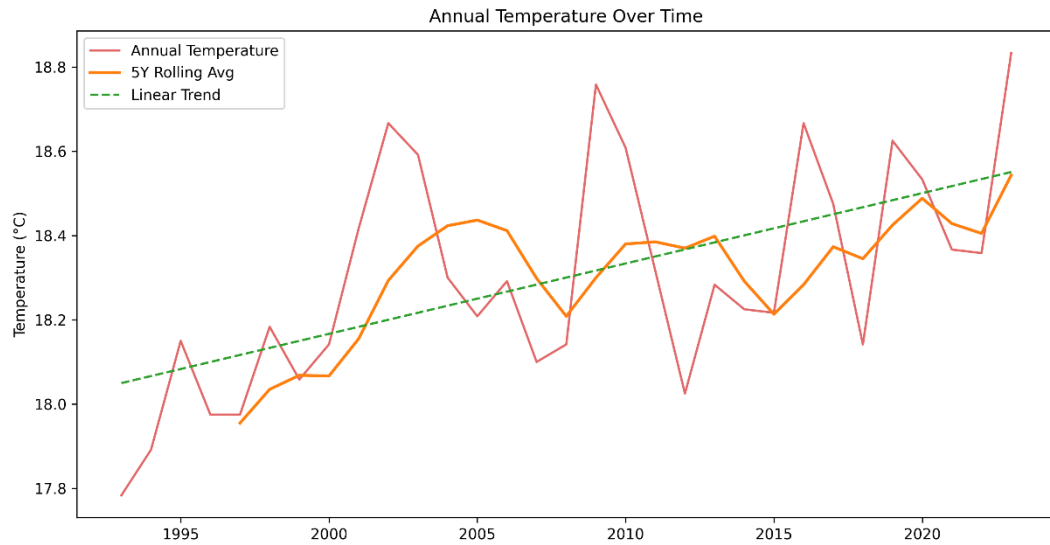


Figure 6: Annual temperature over time

The recorded monthly temperatures present recurring warm and cool intervals because of seasonal shifts. Maximum temperatures typically occur in the dry months, while temperatures remain lower during the wet months. A six-month rolling average was used to eliminate temporary fluctuations and show the underlying trend accurately. The elevated dry season temperatures increase plant respiratory processes and evapotranspiration rates, resulting in increased soil water loss and diminished plant productivity influencing aboveground and belowground carbon dynamics. However, Buffel grass can endure high temperatures due to its well-adapted nature. Nonetheless, severe hot conditions will affect its photosynthetic functions, decreasing biomass production, according to Farrell *et al.* (2022). Also, soil organic matter decomposes more quickly under elevated temperature conditions, which generates additional CO₂ emissions and reduces the capability of carbon sequestration over time. On the other hand, periods of reduced temperature in the wet season will decrease the metabolic activity of plants and soil microorganisms, decreasing respiration while raising organic carbon accumulation in the soil. Furthermore, seasonal shifts trigger short-term growth stresses on Buffelgrass plants through abrupt temperature changes within brief time windows, as per Ward *et al.* (2006). Temperature stability proves fundamental for Buffel grass landscapes to sustain continuous carbon sequestration rates.

4.2.2 Monthly and Annual Precipitation Variability

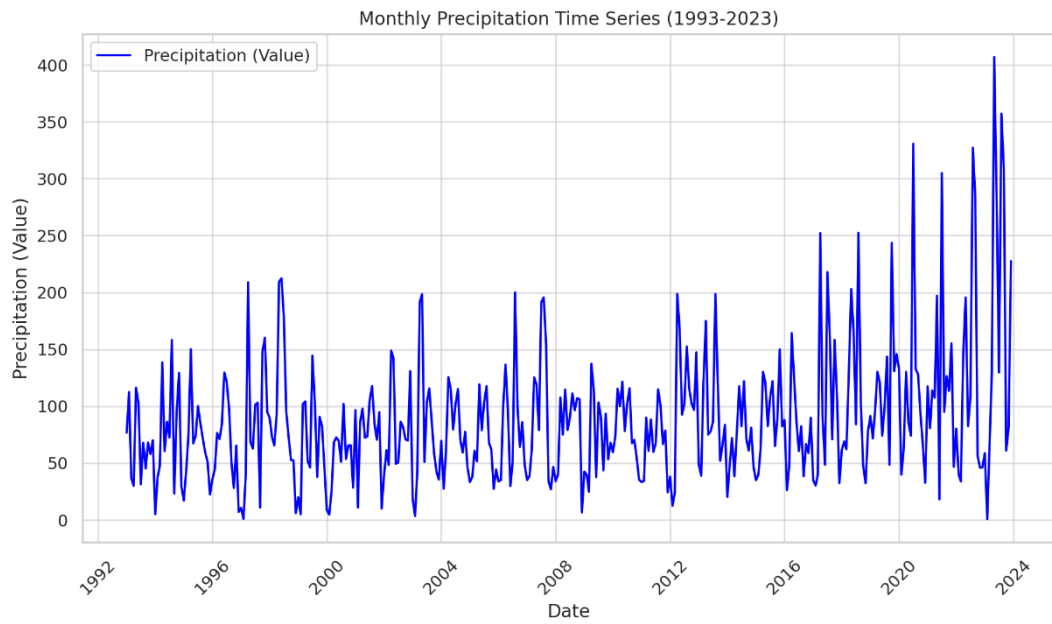
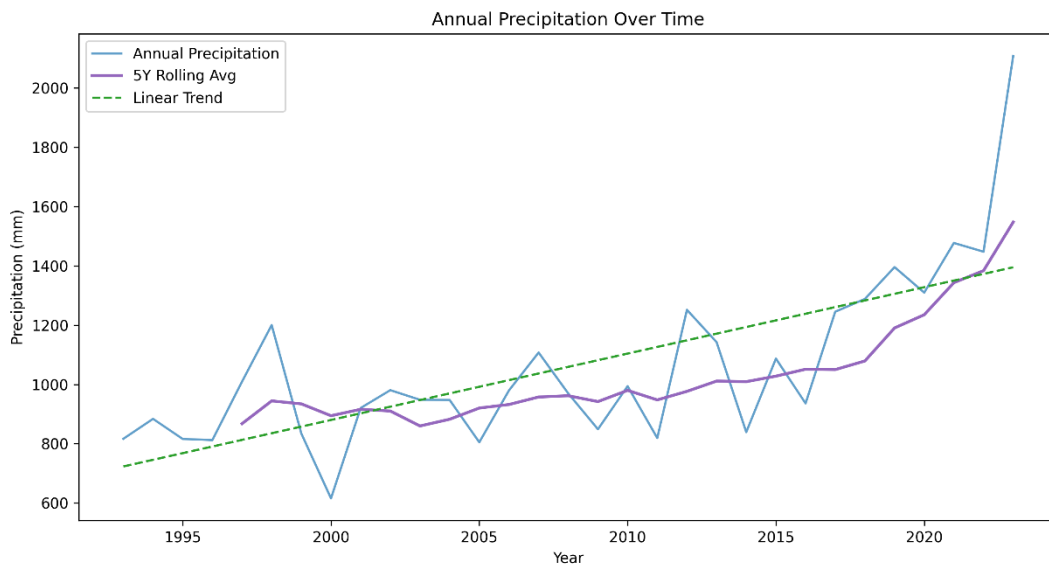


Figure 7: monthly precipitation time series (1993-2023)



The precipitation time series shows robust seasonal rainfall variations that produce distinct wet and dry seasons in Baringo South. The data shows intense precipitation during peak months, and the dry season presents practically no rainfall. The rolling average trend removes short-term fluctuations to reveal the area's primary rainfall distribution pattern. Soil moisture levels depend heavily on precipitation patterns, directly influencing Buffel grass productivity and growth. For instance, higher rainfall during the wet season strengthens soil moisture retention levels, leading to better plant growth and helps increase carbon sequestration by enhancing biomass growth. Higher water availability stimulates microbial processes that accelerate soil organic matter decomposition

and nutrient cycling mechanisms, leading to sustained land fertility and increased carbon storage.

Conversely, prolonged dry intervals create significant obstacles to carbon sequestration. First, there is restricted availability of water, which lowers plant water content in certain months and triggers stress-related damage to photosynthetic capabilities. Drought conditions that persist too long cause plants to die naturally alongside reduced biomass, impairing their ability to take up and store carbon. This was observed during the field visits as many landscapes had dried up with no observable vegetation. Also, arid conditions were seen to cause extensive soil degradation, exposing the soil to wind erosion, which is prevalent in these areas, decreasing the land's total carbon storage capacity. These substantial variations require flexible land management strategies to sustain these Buffel grass landscapes and optimize carbon sequestration. The combination of biochar amendments and half-moon structures offers effective soil moisture preservation techniques to fight against dry periods through better water storage in soil.

4.2.3 Implications for Carbon Sequestration

The dual effects of rising temperature and reduced precipitation affect carbon sequestration opportunities in Buffel grass locations and create specific challenges. Short-term plant growth benefits from warming exist, but these advantages will be counteracted by faster decomposition rates that decrease long-term soil carbon storage potential. The reduced levels of rainfall create conditions that reduce Buffel grass productivity, which hinders its ability to capture atmospheric carbon effectively. Practical adaptive management systems need to be adopted as they will optimize carbon sequestration under these climate conditions. Using biochar and practices for soil moisture preservation and regulated grazing operations helps maintain soil stability and carbon sequestration levels. The future forecasts of climate conditions must be incorporated into predictive modeling designs to predict future impacts on Buffelgrass ecosystems. By creating effective carbon sequestration models, land managers can maximize the progress of their ecosystem restoration in degraded areas and contribute to carbon uptake from the atmosphere.

4.3 Soil Texture and pH Analysis

Soil texture fundamentally affects the physical aspects of soil, along with its chemical properties, which control water retention while regulating drainage and providing nutrients. Also, the soil's pH value is a primary factor determining nutrient accessibility and microbial performance levels. The three study locations recorded alkaline soil conditions and pH level variations. Soil texture at Nasinya, Chuinee, and Kiborgoch showed different patterns that impacted both carbon storage in soil and the productivity of Buffelgrass.

Nasinya: The results for soil texture classification and PH for the Nasinya study site are shown in Table 1 below. The Nasinya soil samples predominantly belong to Clay Loam textural categories except for NT2, which is the Clay textural class. Combining sand, silt, and clay in clay

loam soils creates medium water absorption and appropriate air circulation. The high 49.28% clay composition of NT2 leads to poor drainage and higher susceptibility to soil compaction that limits root growth while reducing oxygen availability. Conversely, NT9 shows good drainage because it contains 42% sand while having the lowest clay content (6%). The pH measurement of the soil samples falls between 8.06 and 8.9, where NT9 maintains the highest pH value at 8.9, and NT2 presents the lowest at 8.06. Soils with high pH levels reduce the nutrient availability of phosphorus, iron, and zinc, impacting plant growth and carbon sequestration.

Table 1: Nasinya Samples Textual Class and PH measurements

Nasinya Samples	%Sand	%Clay	%Silt	Textual Class	pH
NT1	33.44	29.28	37.28	Clay Loam	8.7
NT2	26.72	49.28	24	Clay	8.06
NT3	29.44	34.56	36	Clay Loam	8.2
NT4	31.44	37.28	31.28	Clay Loam	8.3
NT5	24.72	39.28	36	Clay Loam	8.09
NT6	26.72	32.56	40.72	Clay Loam	8.1
NT7	25.44	35.28	39.28	Clay Loam	8.4
NT8	34.72	38.56	26.72	Clay Loam	8.87
NT9	42	34.56	23.44	clay loam	8.9
NT10	28.72	34.56	36.72	Clay Loam	8.08
NT11	26.72	35.28	38	Clay Loam	8.35
NT12	30.72	34.56	34.72	Clay Loam	8.08

Chuinee: The results of a textual class and PH analysis for Chuinee samples are shown in Table 2 below. Chuinee's soil texture includes sandy clay, clay loam, and clay types. Sandy Clay soils form the dominant soil type, with six samples exhibiting high sand and clay percentages with low silt levels, leading to quick drainage and possible compacting problems. Five samples (CT5, CT6, CT7, CT9, and CT11) show Clay Loam soil textures based on the particle size analysis and, therefore, retain moisture better than the poorly draining CT8 soil in the Clay category. Chuinee soil samples show pH values between 8.45 and 9.0, as most demonstrate alkaline conditions. CT9 has the maximum pH reading of 9.0 among all samples, while CT7 registers a minimum reading

of 8.45. The pH readings indicate insufficient nutrient availability, affecting Buffel grass production levels and carbon storage beneath the surface.

Table 2: Chuinee Samples Textual Class and PH measurements

Chinese Samples	% Sand	% Clay	% Silt	Textual Class	pH
CT1	47.44	40	12.56	Sandy Clay	8.68
CT2	47.44	40	12.56	Sandy Clay	8.96
CT3	42.72	40	17.28	Sandy Clay	8.62
CT4	42.72	40	17.28	Sandy Clay	8.78
CT5	37.44	40	22.56	Clay Loam	8.76
CT6	41.44	39.28	19.28	Clay Loam	8.7
CT7	38.72	37.28	24	Clay Loam	8.45
CT8	36.72	42	21.28	Clay	8.98
CT9	36.72	33.28	30	Clay Loam	9
CT10	45.44	36	18.56	Sandy Clay	8.65
CT11	42.72	38	19.28	Clay Loam	8.79
CT12	47.44	36	16.56	Sandy Clay	8.79

Kiborgoch: Soils from Kiborgoch have the highest clay composition, resulting in predominant Clay and Silty Clay classifications. The samples KT1, KT3, KT4, and KT12 show Silty Clay properties that retain significant water but drain poorly, so these soils tend to compact. KT5 represents the highest clay category with a measured clay content of 72%. Kiborgoch shows the highest recorded pH levels between 8.79 and 10.07 throughout the three sites. KT11 presents the highest alkalinity level at pH 10.07, indicating that severe nutrient deficiencies may hinder microbial decomposition and lead to consequential carbon sequestration rates.

Table 3: Kiborgoch Samples Textual Class and PH measurements

Kiborgoch Samples	% Sand	% Clay	% Silt	Textual Class	pH
KT	8.72	49.28	42	Silty Clay	9.39
KT2	14.72	49.72	36	Clay	9.14

KT3	12	46	42	Silty Clay	9.51
KT4	10	46	44	Silty Clay	9.52
KT5	12	72	16	Clay	9.32
KT6	13.28	50	36.72	Clay	9.4
KT7	14	56	30	Clay	9.6
KT8	14.72	54.72	30.56	Clay	8.79
KT9	14.72	52	33.28	Clay	9.23
KT10	15.44	52	32.56	Clay	9.59
KT11	14.72	48.56	36.72	Clay	10.07
KT12	14.72	42.46	42.72	Silty Clay	9.72

The belowground carbon sequestration rate in Buffel grass landscapes depends on the texture and pH of the soil. Clay-rich soils retain large amounts of water but restrict root growth and microbial processes, which impacts organic carbon storage rates. Conversely, faster organic matter breakdown and diminished water retention lead to decreased carbon sequestration potential in sandy-type soils, which were present in certain Chuinee and Nasinya samples.

4.4 Soil Bulk Density Analysis

The three research sites of Chuinee, Nasinya, and Kiborgoch present varying bulk densities, which depend on their specific soil textures. The Chuinee and Kiborgoch sites primarily feature Sandy Clay and Clay textures with bulk densities that typically measure from 1.2 to 1.3 g/cm³. Sandy Clay samples at Chuinee exhibited the lowest bulk density, reaching 1.2 g/cm³, and Kiborgoch Clay samples, alongside Nasinya Clay Loam samples, displayed the highest bulk density at 1.3 g/cm³. Bulk density measurements from Nasinya's Clay Loamy and Clay textures produced uniform results at 1.3 g/cm³. Samples of Silty Clay from Kiborgoch demonstrated a 1.2 g/cm³ density, matching Sandy Clay's levels at Chuinee. Results from the physical properties analysis will contribute to a better understanding of how these properties affect carbon sequestration potential at each study site.

Table 4: Bulk density measurements

Sample	Study Site	Textual Class	Bulk Density (g/cm³)
C1	Chuinee	Sandy Clay	1.2
C2	Chuinee	Sandy Clay	1.2
C3	Chuinee	Sandy Clay	1.2
C4	Chuinee	Sandy Clay	1.2
C5	Chuinee	Clay Loam	1.3
C6	Chuinee	Clay Loam	1.3
C7	Chuinee	Clay Loam	1.3
C8	Chuinee	Clay	1.3
C9	Chuinee	Clay Loam	1.3

C10	Chuinee	Sandy Clay	1.2
C11	Chuinee	Clay Loam	1.3
C12	Chuinee	Sandy Clay	1.2
N1	Nasinya	Clay Loamy	1.3
N2	Nasinya	Clay	1.2
N3	Nasinya	Clay Loamy	1.3
N4	Nasinya	Clay Loamy	1.3
N5	Nasinya	Clay Loam	1.3
N6	Nasinya	Clay Loam	1.3
N7	Nasinya	Clay Loam	1.3
N8	Nasinya	Clay Loamy	1.3
N9	Nasinya	Clay Loam	1.3
N10	Nasinya	Clay Loamy	1.3
N11	Nasinya	Clay Loam	1.3
N12	Nasinya	Clay Loamy	1.3
K1	Kiborgoch	Silty Clay	1.2
K2	Kiborgoch	Clay	1.3
K3	Kiborgoch	Silty Clay	1.2
K4	Kiborgoch	Silty Clay	1.2
K5	Kiborgoch	Clay	1.3
K6	Kiborgoch	Clay	1.3
K7	Kiborgoch	Clay	1.3
K8	Kiborgoch	Clay	1.3
K9	Kiborgoch	Clay	1.3
K10	Kiborgoch	Clay	1.3
K11	Kiborgoch	Clay	1.3
K12	Kiborgoch	Silty Clay	1.2

4.5 Quantification of Above and Below Ground Biomass (AGB) and Below Ground Biomass (BGB)

The results for the above-ground biomass for the three sites are summarized in Table 5 below. The biomass is presented in terms of carbon content which was calculated by multiplying the dry weight of the samples by .47 according to IPCC guidelines. The three study sites demonstrate different aboveground biomass production patterns due to soil properties, including texture, pH value, water availability, and climate conditions. Kiborgoch shows the minimum average aboveground biomass of 0.7533 tons/ha because its clay-rich soil and high alkalinity reduce nutrient accessibility. Nasinya presents maximum aboveground biomass (1.0620 tons/ha) due to its clay loam soil structure that maintains effective water retention with suitable aeration conditions. Chuinee maintains intermediate levels of biomass growth between the other two locations.

Table 5: Bulk density measurements

Study Site	Min(tons/ha)	Max(tons/ha)	Range (tons/ha)	Average (tons/ha)	Variance	SD
Chuinee	0.7450	1.1887	0.4437	0.9115	0.019230	0.1130
Nasinya	0.9413	1.1543	0.2130	1.0620	0.0052	0.0721
Kiborgoch	0.5048	1.1818	0.6770	0.7533	0.0256	0.1600

4.5.1 Above Ground Biomass: Nasinya

The results for above-ground biomass for Nasinya are presented in the histogram below (Figure 7). According to the results, the carbon content in the aboveground biomass in Nasinya ranges between 0.9413 and 1.1543 tons per hectare. Aboveground biomass carbon accumulation rates display uniformity across sampling points with an average value of 1.0620 tons/ha and a standard deviation of 0.0721 tons/ha. The site demonstrates consistent sequestration levels based on the median value, which is significantly higher than the other sites. Data shows that the Nasinya site delivers a reliable system for Buffel grass to store carbon in its aboveground parts. The observed high sequestration values can be attributed to favorable microclimatic conditions, fertile soil, and abundant grass cover at this site. The pH levels measured at these sites ranged from 8.06 to 8.87 and showed the lowest level of alkalinization among the three locations. The site possesses a moderate base level that aids microbial processes and decomposition rates, which affect how carbon is transformed.

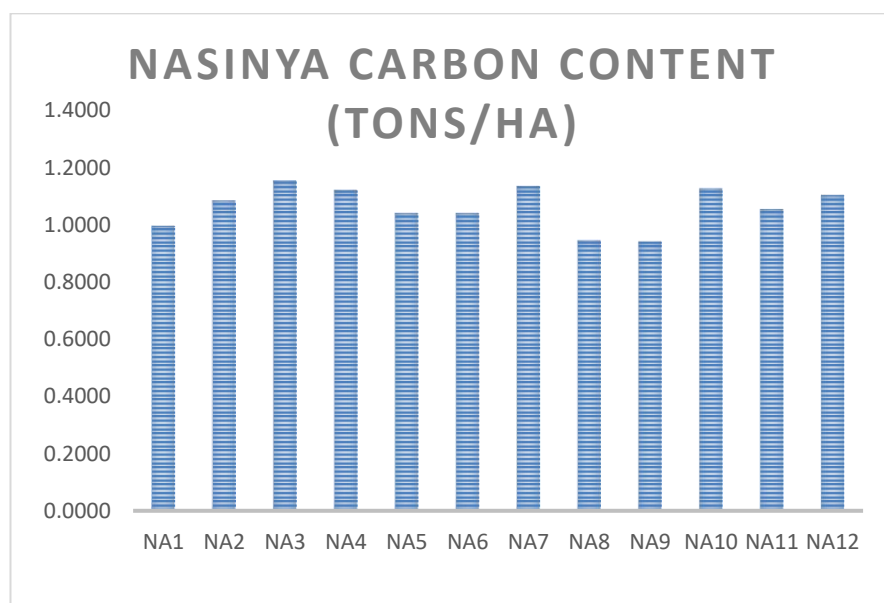


Figure 8: Nasinya Carbon content (tons/ha)

4.5.2 Above Ground Biomass: Chuinee

As shown in Figure 8, the carbon content in biomass at the Chuinee site demonstrated

moderate variability ranging from 0.7450 to 1.1887 tons/ha. The average carbon content measurement of 0.9115 tons/ha indicates good potential for carbon sequestration with optimized management practices. The standard deviation demonstrates a typical pattern of variability in the samples. Local environmental conditions promote more significant biomass growth because one sample (CA12) exhibited 1.1887 tons/ha carbon content. This area consists of primarily sandy clay and clay loam soil types, which contain between 36% and 42% clay content. The overall carbon stabilizing ability remains consistent, but higher sand composition leads to accelerated organic matter breakdown and reduced carbon storage potential. The alkaline environment can help reduce microbial decomposition but only allows moderate quantities of carbon storage.

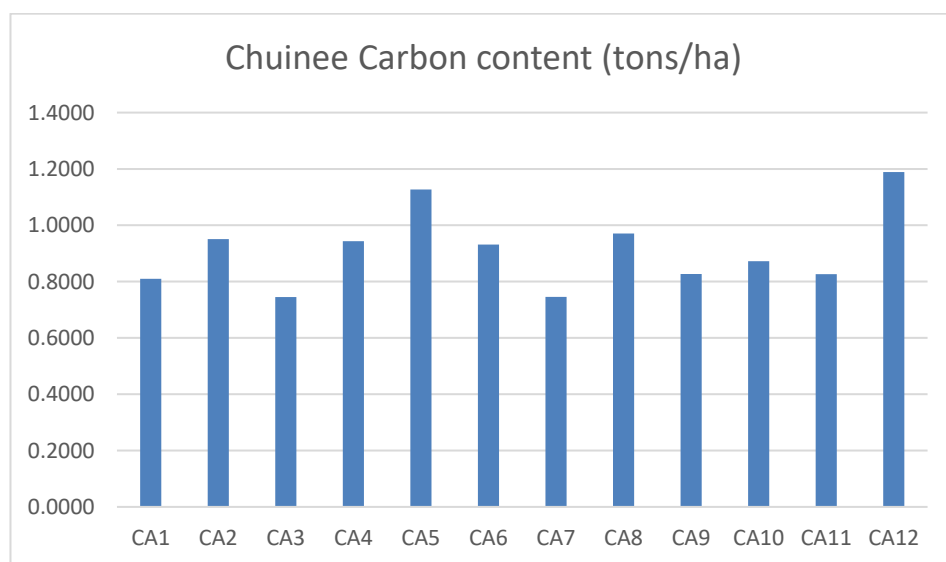


Figure 9: Chuinee Carbon content

4.5.3 Above Ground Biomass: Kiborgoch

The Kiborgoch site displays the most significant carbon content variation between 0.5048 to 1.1818 tons/ha in the AGB, as seen in Figure 9. These sites demonstrate the minimum average carbon content (0.7533 tons/ha) when compared to the other sites, indicating reduced biomass production. Most carbon content samples at Kiborgoch exhibit lower values, as shown by the lower quartile limit (0.6961 tons/ha) and the median value (0.7230 tons/ha). Site-specific elements such as soil degradation, soil conditions, and microclimatic factors are attributed to the wide variability in results. This site primarily consists of silty clay and clay soils where clay content measures from 42% up to 72%. The clay content strongly enhances soil carbon stabilization potential because these fine particles effectively bind organic matter, causing decomposition rates to decrease. The pH measurements show strongly alkaline characteristics in this site, fluctuating between 9.14 and 10.07. The site lies next to a wetland that links to Lake Bogoria, which is alkaline. These conditions have created strong alkaline conditions that impact the decomposing efficiency of microbes, which influences the potential for carbon storage in the soil.

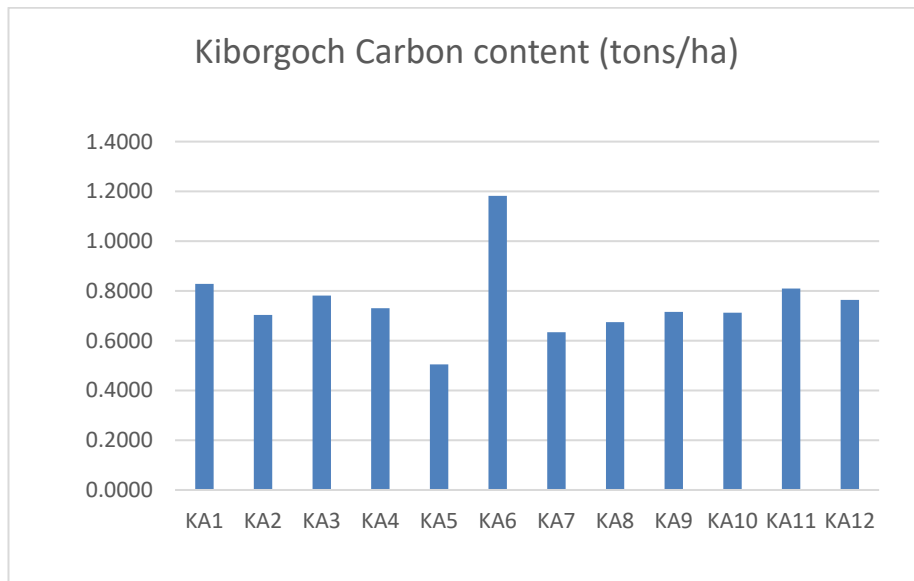


Figure 10: Kiborgoch Carbon content

4.5.4. Below Ground Biomass (BGB)

The BGB measurements produced distinct results between Chuinee Nasinya and Kiborgoch, indicating contrasting carbon sequestration abilities that result from site-specific environmental conditions, including soil characteristics and vegetation distributions. The belowground biomass carbon content of Chuinee measured between 17.04 and 27.90 T/Ha, having an average of 20.38 T/Ha. The maximum carbon content was observed in CB1 (27.90), while CB4 displayed the minimum value (17.04). Results indicate moderate variability across the sample sets because their standard deviation is 2.86. The 19.96 T/Ha median shows that belowground carbon levels were distributed proportionately throughout the study area, though half the samples measured above this value, as shown in Figure 10 below. The results demonstrate that Chuinee's belowground carbon storage falls within an average range, but distinct soil and vegetation compositions affect sequestration rates.

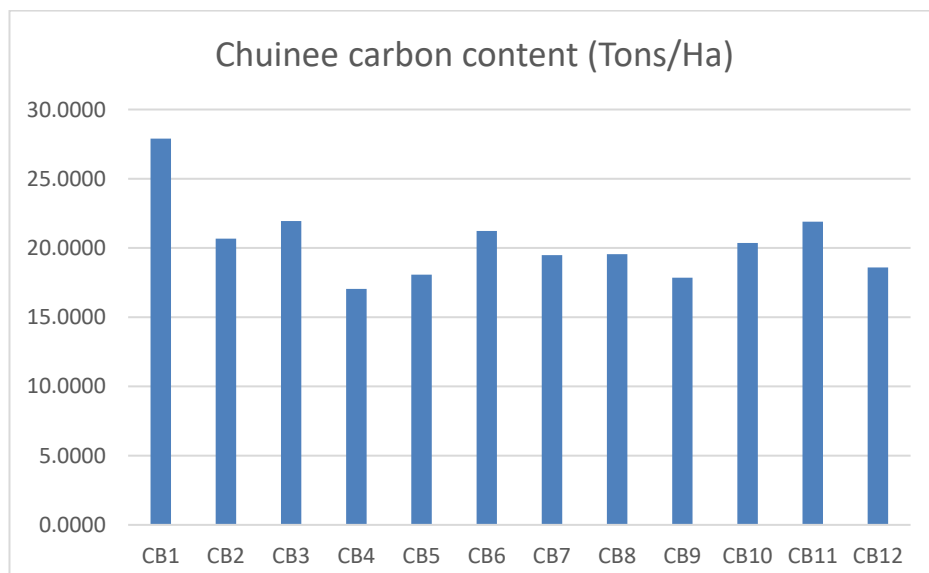


Figure 11: Chuinee carbon content

The Nasinya samples contained a noticeably high quantity of carbon, which spanned between 28.41 and 73.16 T/Ha and an average of 51.65 T/Ha. These figures corroborate with those above ground, which supports the findings that Nasinya has significant potential to store carbon. NB1 exhibited the highest carbon content of 73.16 T/Ha among all samples, and NB3 contained the lowest carbon amount of 28.41 T/Ha. However, the substantial sample variation indicated by the 14.33 standard deviation shows that localized patterns exist between soil characteristics, moisture availability, and biomass density. Nasinya demonstrates strong potential for below-ground carbon sequestration based on the median carbon content of 49.72 T/Ha, which indicates that most sample sites contained substantial levels of carbon.

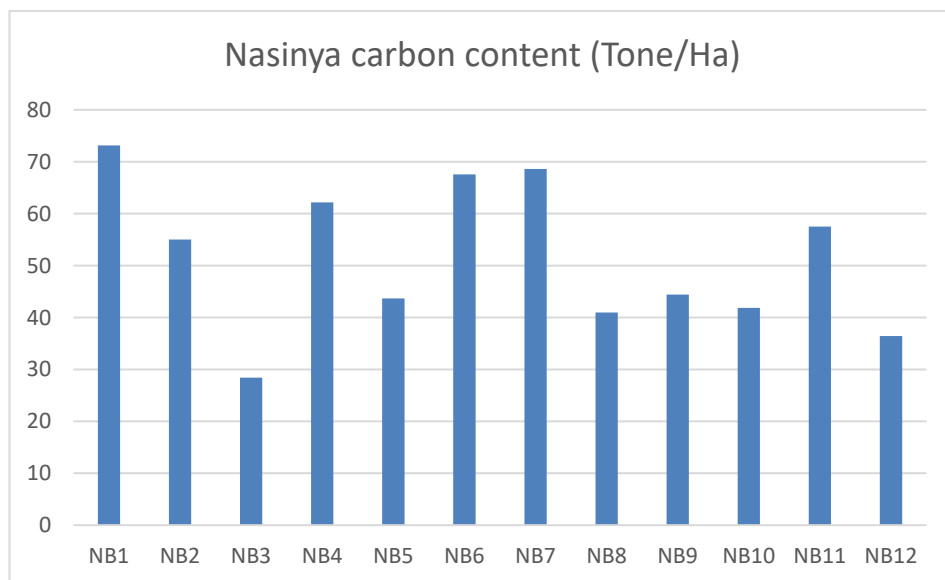


Figure 12: Nasinya carbon content

The BGB carbon content measurements in Kiborgochh ranged between 17.87 and 32.30 T/Ha, with an average of 25.69 T/Ha as shown in Figure 12. The maximum BGB carbon content measurement is 32.30 T/Ha in KB6, and the minimum is 17.87 T/Ha. A standard deviation of 4.24 indicates lower variations than Nasinya's biomass carbon content measurement, implying a uniform carbon distribution. The results showed a consistent level of carbon sequestration potential. Soil pH, organic matter differences, and site-specific root biomass growth restrictions may explain why the samples exhibited varied carbon content levels.

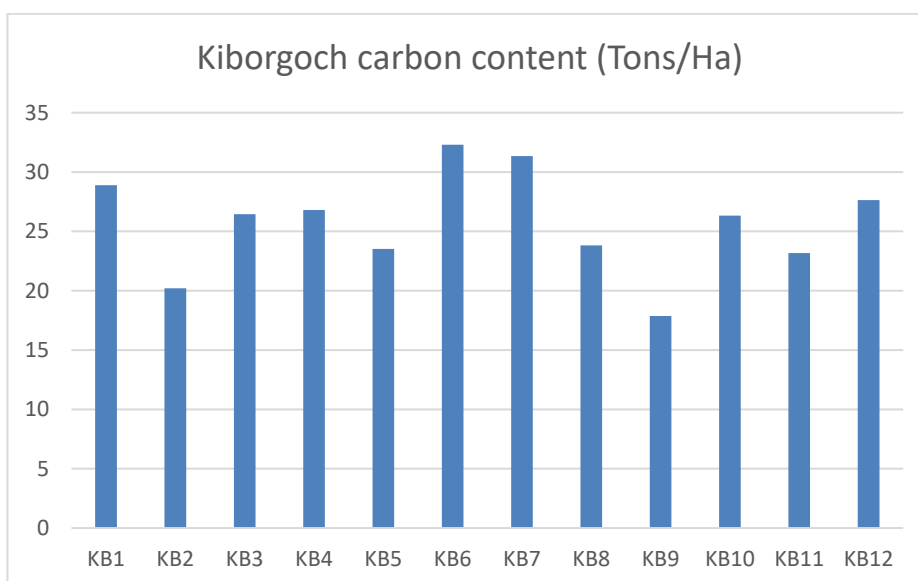


Figure 13: Kiborgoch carbon content

4.6 Soil Organic Carbon (SOC)

Table 6 below shows the summary results for the SOC for the three study sites. The study sites demonstrated substantially different SOC densities, as Kiborgoch recorded minimum values at 0.5048 tons/ha. In comparison, Nasinya registered 0.9413 tons/ha as the minimum, and Chuinee achieved the highest value of 1.1887 tons/ha. The study site Kiborgoch displayed the most extensive SOC range of 0.6770 tons/ha, demonstrating substantial differences in soil carbon content. Nasinya demonstrated the smallest SOC range at 0.2130 tons/ha, indicating uniform distribution of SOC in the entire landscape. Among the three sites, Nasinya possessed the highest average SOC values at 1.0620 tons/ha, followed by Chuinee at 0.9115 tons/ha, then Kiborgoch at 0.7533 tons/ha. These figures indicate that Nasinya offers beneficial conditions for carbon sequestration through its conducive soil characteristics and land management systems, contributing to higher SOC levels. Also, the variation in SOC values and their Standard Deviations reveals the varied stability levels of carbon in the different sites' soil samples. The Kiborgoch site showed the most extensive variability in SOC content, with a variance of 0.0256. At the same time, its standard deviation reached 0.1600, indicating significant changes in soil carbon levels possibly influenced by different Buffel grass, constant surface runoff, and soil composition and organic matter content. The Nasinya site demonstrated the least variation (0.0052) and standard deviation (0.0721) among the sites, indicating that SOC found uniform distribution throughout its area.

Table 6: Summary results for the SOC for the three study sites

Study Site	Min(tons /ha)	Max(tons/ha)	Range (tons/ha)	Average (tons/ha)	Variance	SD
Chuinee	0.7450	1.1887	0.4437	0.9115	0.019230	0.1130
Nasinya	0.9413	1.1543	0.2130	1.0620	0.0052	0.0721
Kiborgoch	0.5048	1.1818	0.6770	0.7533	0.0256	0.1600

Observations of soil organic carbon demonstrate that site elements, including vegetation-type soil moisture levels and land-use practices, directly affect carbon sequestration processes. The higher SOC in Nasinya results from enhanced soil conservation methods and additional organic matter additions. The wide variability of SOC content at Kiborgoch points to possible degradation of the soils as well as inconsistent land-use practices. The analysis confirms that sustainable land management practices that combine biochar application with soil restoration strategies need inclusion across diverse landscapes to boost SOC sequestration. The combination of Buffel grass with biochar and half-moon interventions presents excellent potential for maximizing carbon sequestration success in areas that exhibit significant diversity in SOC levels. The relationship between SOC and OM in the three sites is shown in the charts below. Soil Organic Carbon (SOC) is a critical component of soil health and directly correlates with Soil Organic Matter (OM). Organic matter serves as a reservoir for carbon, nutrients, and microbial activity, playing a fundamental role in soil fertility and carbon sequestration. The conversion between SOC and OM follows the well-established relationship:

$$OM = SOC \times 1.724$$

1.724 is the Van Bemmelen factor, which assumes that organic matter contains approximately 58% carbon. This relationship allows us to estimate total organic matter from measured SOC values, providing insights into soil quality and productivity across different study sites.

4.7 Total Carbon Stocks

Table 7 shows the total carbon stocks from AGB, BGB, and SOC pools for the Chuinee, Nasinya, and Kiborgoch study sites. The pooled total carbon stock amounts include measurements from all three carbon pools. The Nasinya site recorded the highest overall carbon stock among the three sites at 53.25 tons/ha, higher than the carbon stocks measured in Chuinee (21.98 tons/ha) and Kiborgoch (27.16 tons/ha). The total carbon stock of Kiborgoch exceeded Chuinee as Kiborgoch demonstrated higher carbon sequestration capabilities. The carbon pools measuring AGB, BGB, and SOC display similar patterns at all sites. Total carbon stock peaked in Nasinya because the site held above- and below-ground biomass levels at their highest points. The results

suggest that site-specific factors, including vegetation type, soil quality, and land management practices, play a crucial role in determining the carbon sequestration potential of grasslands.

Table 7: Total carbon stocks

Study Site	Average Carbon in AGB	Average Carbon in BGB	Average Carbon in SOC	Total Carbon
Chuinee	0.9115	20.3830	0.6846	21.8344
Nasinya	1.0620	51.6466	0.5398	53.3931
Kiborgoch	0.7533	25.6937	0.7148	27.16167

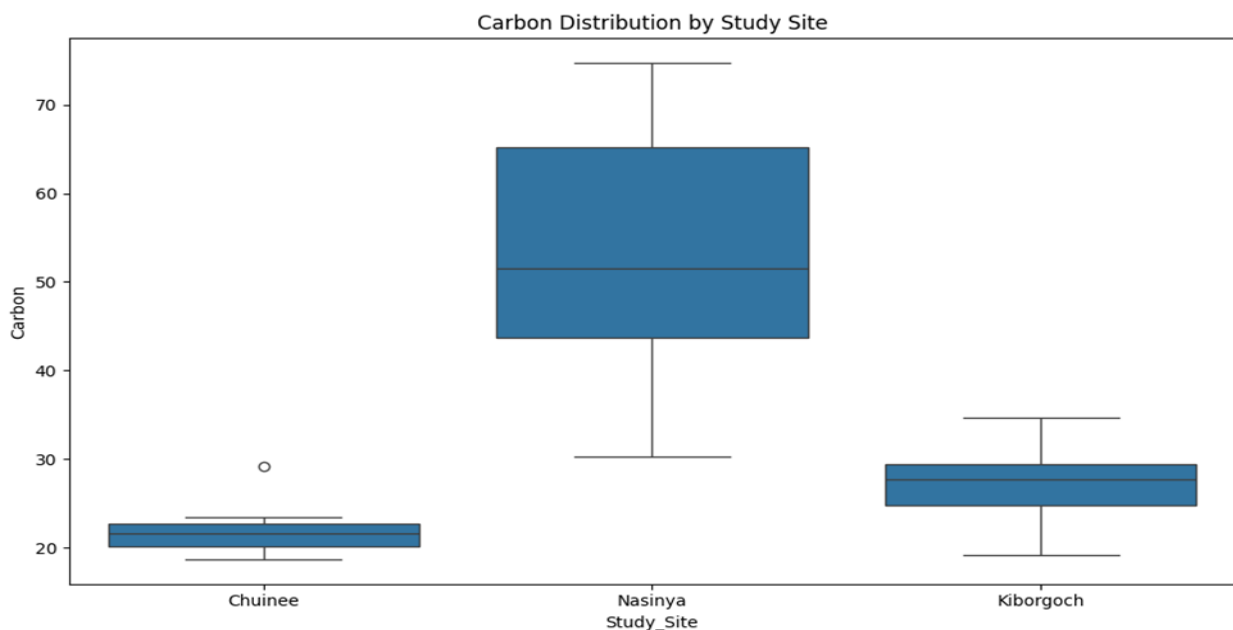


Figure 14: Carbo Distribution by Study Site

4.8 Exploratory Data Analysis (EDA)

The exploratory data analysis (EDA) revealed varying distributions across the key variables. The pH and soil organic carbon (SOC) distributions appeared approximately normal, with their means and medians closely aligned. The Shapiro-Wilk test results confirmed no significant deviation from normality for these variables ($p > 0.05$). In contrast, aboveground biomass (AGB) exhibited slight right-skewness, with a mean slightly lower than the median, though its normality test result suggested no strong departure from normality. Belowground biomass (BGB) and total carbon displayed strong right-skewness, as indicated by their means being significantly higher than their medians. The Shapiro-Wilk test results for these variables confirmed significant non-normality. Log transformations were applied to BGB and carbon to address this skewness, resulting in improved normality, as evidenced by closer mean and median values and higher Shapiro-Wilk test p-values. These findings suggest that log-transformed versions of BGB and carbon may be more appropriate for statistical analysis requiring normality

assumptions.

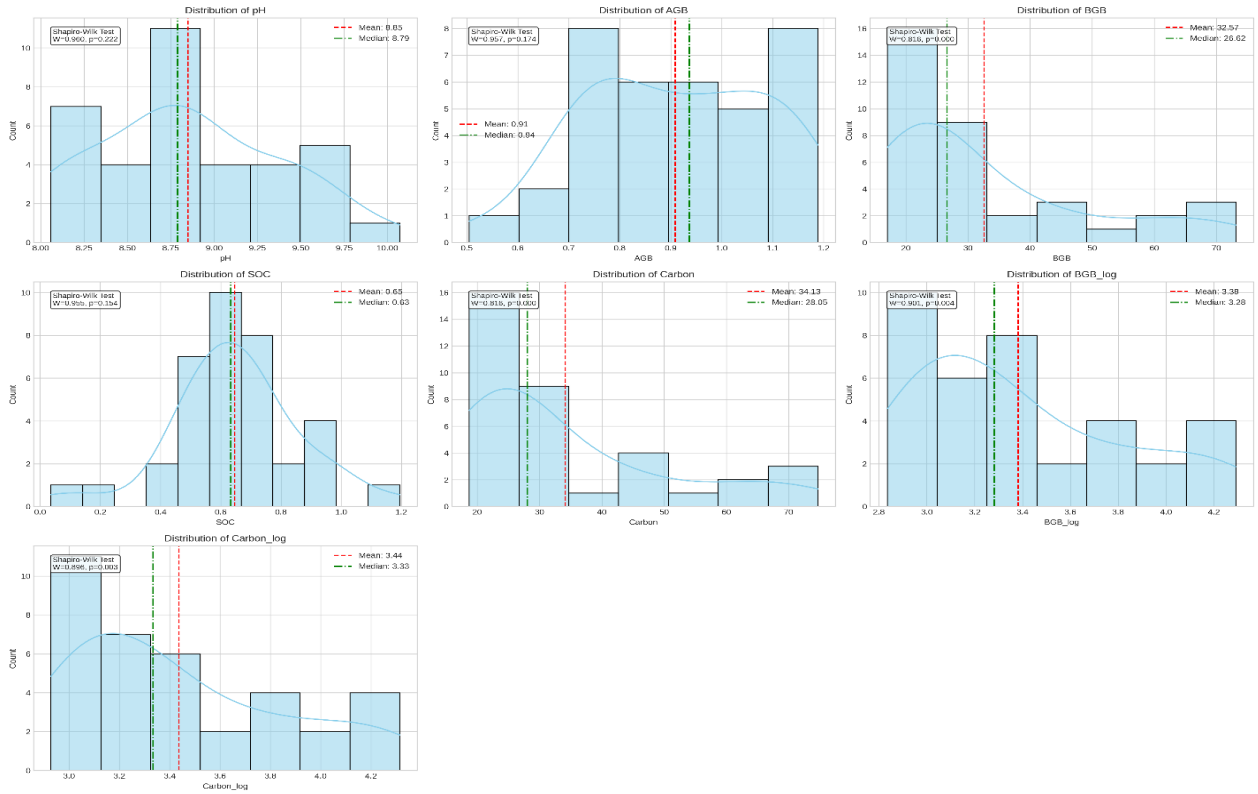


Figure 15: Distribution of key soil and biomass variables. Histograms display density curves, means (red dashed lines), medians (green dashed lines), and results of the Shapiro-Wilk normality test. Log transformations of BGB and carbon were applied to improve nor

The distribution of total carbon (tons/ha) varied across study sites and textural classes. As shown in Figure 14, Nasinya exhibited the highest variability in total carbon, with a wider interquartile range and several extreme values. In contrast, Chuinee and Kiborgoch had lower total carbon values with less variation. When analyzed by textural class, clay loamy and clay loam soils displayed the greatest variation in total carbon, while sandy clay and silty clay had relatively lower and more consistent carbon levels. These patterns suggest that both location and soil texture influence total carbon distribution.

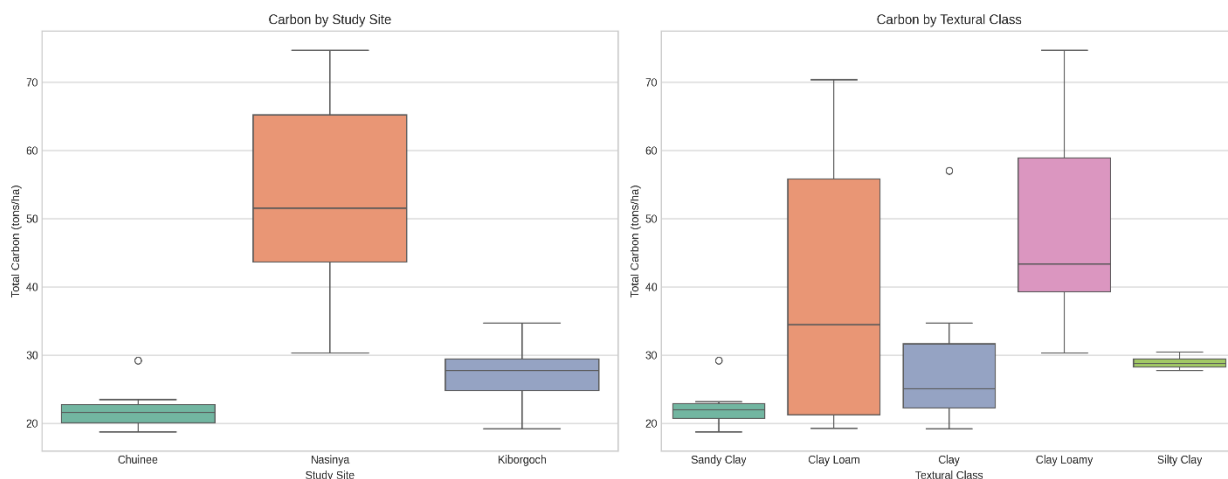


Figure 16: Boxplots of total carbon (tons/ha) across study sites (left) and textural classes (right), showing median values, interquartile ranges, and potential outliers.

4.9 Descriptive Statistics

Descriptive statistics were computed for the key biophysical variables influencing carbon sequestration in Buffel grass landscapes. The variables examined included soil pH, above-ground biomass (AGB), below-ground biomass (BGB), soil organic carbon (SOC), and total carbon sequestration. Additionally, log-transformed values of BGB (BGB_log) and Carbon (Carbon_log) were included to meet the normality assumption. The results indicate that the mean soil pH was 8.80 (SD = 0.50), with a minimum and maximum value of 8.06 and 9.72, respectively, suggesting that the study area predominantly exhibits alkaline soil conditions. The mean AGB was 0.90 Mg ha⁻¹ (SD = 0.18), while the mean BGB was 31.64 Mg ha⁻¹ (SD = 15.31), indicating a higher carbon storage potential below ground than above ground.

SOC had a mean value of 0.65% (SD = 0.17), with a range between 0.18% and 0.98%. The mean total carbon sequestration was 33.19 Mg ha⁻¹ (SD = 15.42), with a minimum of 18.71 Mg ha⁻¹ and a maximum of 70.36 Mg ha⁻¹. The log-transformed BGB and carbon values had mean values of 3.36 (SD = 0.43) and 3.41 (SD = 0.41), respectively, suggesting that log transformation effectively normalized these variables.

The summary statistics, including quartile distributions, are presented in Table 8.

Table 8: Descriptive Statistics for Key Variables (N = 33, upon removing outliers)

Statistic	pH	AGB (Mg ha ⁻¹)	BGB (Mg ha ⁻¹)	SOC (%)	Carbon (Mg ha ⁻¹)	BGB_log	Carbon log
M	8.8	0.9	31.64	0.65	33.19	3.36	3.41
SD	0.5	0.18	15.31	0.17	15.42	0.43	0.41
Min	8.06	0.5	17.04	0.18	18.71	2.84	2.93
25%	8.4	0.75	20.37	0.54	21.85	3.01	3.08
50%	8.79	0.93	26.44	0.65	27.7	3.28	3.32

75%	9.14	1.05	40.97	0.72	42.71	3.71	3.75
Max	9.72	1.19	68.61	0.98	70.36	4.23	4.25

Figure 17: Descriptive Statistics for Key Variables (N = 33, upon removing outliers)

Note: **M** = Mean; **SD** = Standard Deviation; **Min** = Minimum; **Max** = Maximum; **SOC** = Soil Organic Carbon; **AGB** = Above-Ground Biomass; **BGB** = Below-Ground Biomass.

4.10 Correlation Analysis of the Variables

A Pearson correlation analysis was conducted to examine the relationships between soil pH, above-ground biomass (AGB), below-ground biomass (BGB), soil organic carbon (SOC), and total carbon sequestration. The correlation matrix, presented in Table 4.2, provides insights into the strength and direction of associations among these variables. The results indicate that pH was negatively correlated with both AGB ($r = -0.61, p < 0.001$) and BGB ($r = -0.47, p = 0.003$), suggesting that higher soil alkalinity may be associated with reduced biomass accumulation. Similarly, pH showed a significant negative correlation with total carbon sequestration ($r = -0.48, p = 0.003$), implying that carbon storage potential may decline as soil pH increases.

AGB exhibited a strong positive correlation with BGB ($r = 0.47, p = 0.004$) and total carbon sequestration ($r = 0.48, p = 0.003$), indicating that higher above-ground biomass is associated with increased below-ground biomass and overall carbon sequestration. BGB had an extremely strong positive correlation with total carbon sequestration ($r = 0.999, p < 0.001$), reinforcing the critical role of root biomass in carbon storage. Interestingly, SOC did not exhibit significant correlations with most of the variables. Its correlation with BGB ($r = 0.11, p = 0.53$) and total carbon sequestration ($r = 0.12, p = 0.48$) was weak and statistically insignificant, suggesting that soil organic carbon levels might be influenced by additional site-specific factors not captured in this analysis.

Table 9: Pearson Correlation Matrix for Key Variables

Variable	pH	AGB	BGB	SOC	Carbon
pH	1	-0.61** ($p < 0.001$)	-0.47** ($p = 0.003$)	-0.03 ($p = 0.864$)	-0.48** ($p = 0.003$)
AGB	-0.61** ($p < 0.001$)	1	0.47** ($p = 0.004$)	-0.03 ($p = 0.854$)	0.48** ($p = 0.003$)
BGB	-0.47** ($p = 0.003$)	0.47** ($p = 0.004$)	1	0.11 ($p = 0.528$)	0.999** ($p < 0.001$)

SOC	-0.03 ($p = 0.864$)	-0.03 ($p = 0.854$)	0.11 ($p = 0.528$)	1	0.12 ($p = 0.482$)
Carbon	-0.48** ($p = 0.003$)	0.48** ($p = 0.003$)	0.999** ($p < 0.001$)	0.12 ($p = 0.482$)	1

The correlation heatmap (Figures 17 and 18) visually supports the relationships presented in Table 9. It illustrates the strength and direction of associations between pH, AGB, BGB, SOC, and total carbon sequestration, with significant correlations appearing in darker shades.

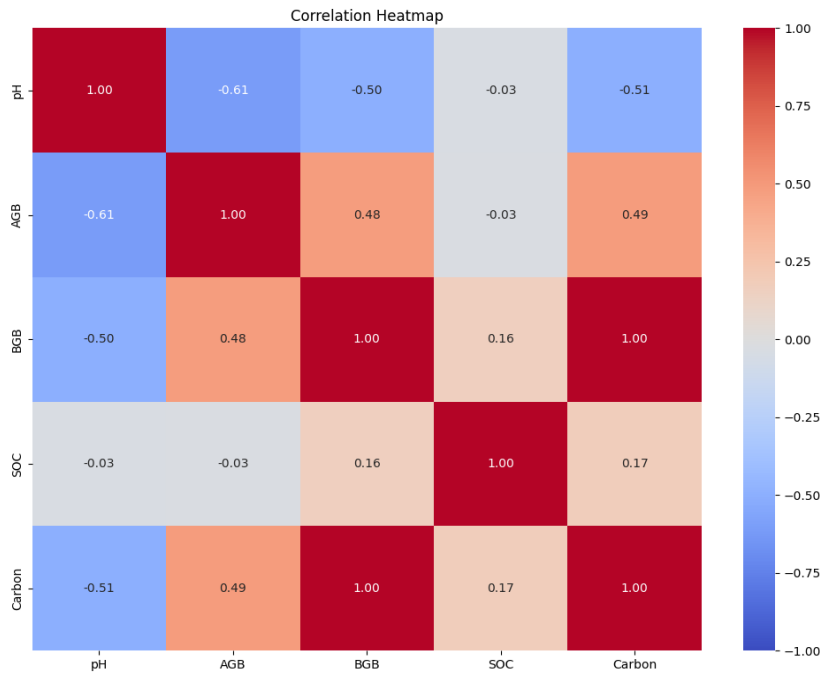


Figure 18: Correlation Heatmap of Soil Properties and Biomass variables

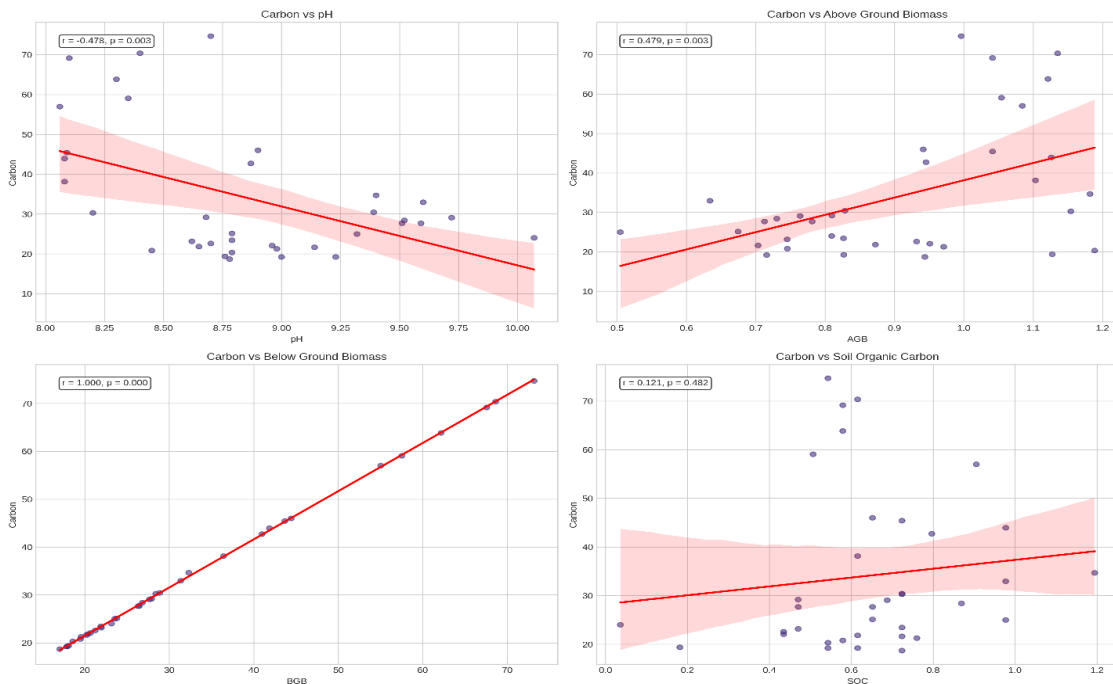


Figure 19: Carbon vs Predictors

4.11 Multiple Linear Regression Model for Carbon Sequestration

The multiple linear regression analysis examined the biophysical factors influencing carbon sequestration, with the log-transformed total carbon (tons/ha) as the dependent variable. As presented in Table 4.3, aboveground biomass carbon ($\beta = 0.035$, $p < .001$), belowground biomass carbon ($\beta = 0.954$, $p < .001$), and soil organic carbon ($\beta = 0.032$, $p < .001$) were significant predictors of total carbon. These results indicate that increases in biomass and soil organic carbon contribute positively to total carbon storage.

Conversely, soil pH and textural class did not significantly correlate with total carbon ($p > .05$), suggesting that soil texture variations and pH had minimal influence on carbon sequestration within the studied sites. The overall model fit was strong, with an R^2 of 1.000 and a highly significant F-statistic ($F(8, 27) = 42145.576$, $p < .001$), indicating that the predictors collectively explained nearly all the variation in total carbon.

In the case of textural class, none of the categories were significant predictors of total carbon sequestration. For instance, compared to Clay soil, Clay Loam had a coefficient of $\beta = 0.002$, $p = .397$, indicating that, holding all other factors constant, sites with Clay Loam soil were associated with an estimated 0.2% increase in total carbon sequestration. However, since this effect was not statistically significant ($p > .05$), it suggests that Clay Loam did not have a meaningful impact on total carbon storage relative to Clay soil. This finding implies that soil texture alone was not a strong predictor of carbon sequestration in this study.

The model coefficient for AGB carbon ($\beta = 0.035$) suggests that for every one-unit increase in AGB carbon, total carbon increases by approximately 3.5% when controlling for other variables. Similarly, SOC carbon ($\beta = 0.032$) indicates that a one-unit increase in SOC carbon corresponds to a 3.2% increase in total carbon. The strongest predictor was log-transformed BGB ($\beta = 0.954$), meaning that a one-unit increase in log (BGB) leads to a 95.4% increase in total carbon, holding all other factors constant.

The final estimated multiple linear regression model for predicting log-transformed total carbon (TC) is given as:

$$\text{Log (TC)} = 0.152 + 0.035 * (\text{AGB}) + 0.954 * (\text{Log BGB}) + 0.032 * (\text{SOC})$$

The overall model was highly significant ($F(8, 27) = 42145.576$, $p < .001$), with an R^2 of 1.000, indicating that the predictors collectively explained nearly all the variation in total carbon. Other variables, including soil pH and textural class, were insignificant, suggesting that these factors had minimal influence on carbon sequestration within the studied sites. According to the findings, above-ground biomass (AGB) and below-ground biomass (BGB) serve as essential factors for carbon sequestration. The results suggest that managers should implement vegetation management approaches such as soil amendments and water retention practices to boost terrestrial

ecosystem carbon storage potential. The model exhibited a perfect fit condition with an R^2 value of 1.000, which may indicate overfitting of the data, as shown in Figures 19 and 20 and supported by the data in Table 10. The model needs independent dataset validation with cross-validation verification for practical use to guarantee its robustness.

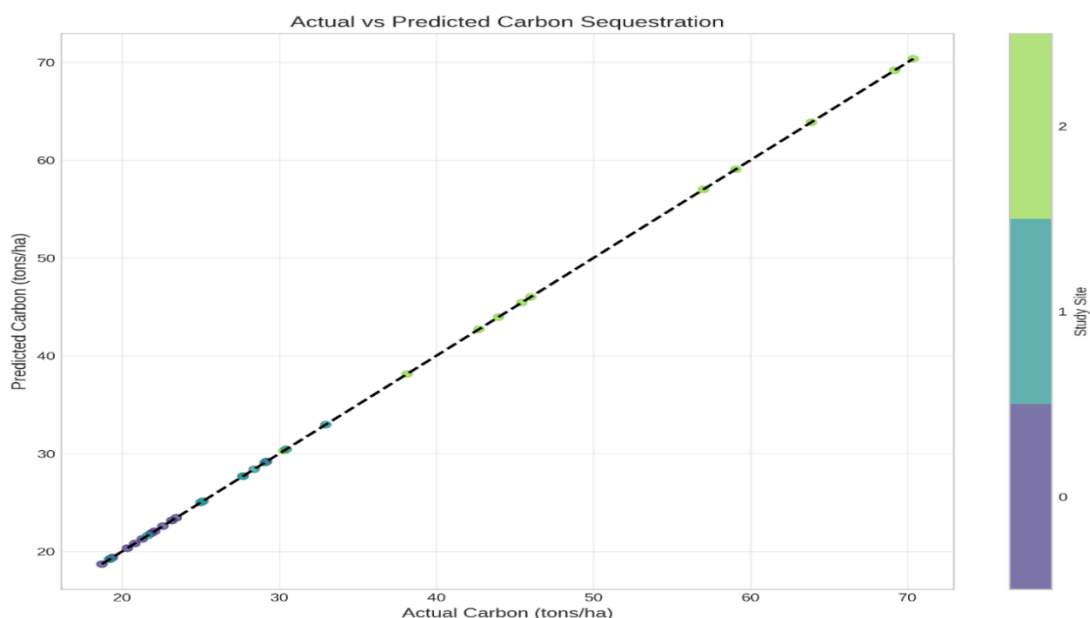


Figure 20: Actual VS. Predicted Sequestration

Table 10: Multiple Linear Regression Analysis for Carbon Sequestration:

Variable	β	SE	t	p	95% CI
Intercept	0.152	0.027	5.686	<.001	[0.097, 0.207]
C (Textual Class) [T. Clay Loam]	0.002	0.003	0.861	0.397	[-0.003, 0.008]
C (Textual Class) [T. Clay Loamy]	0	0.003	0.054	0.957	[-0.006, 0.006]
C (Textual Class) [T. Sandy Clay]	0.004	0.003	1.302	0.204	[-0.002, 0.009]
C (Textual Class) [T. Silty Clay]	-0.001	0.003	-0.399	0.693	[-0.007, 0.004]
pH	0	0.002	0.134	0.894	[-0.005, 0.005]
AGB Carbon	0.035	0.006	6.401	<.001	[0.024, 0.047]
log (BGB)	0.954	0.002	431.043	<.001	[0.950, 0.959]
SOC Carbon	0.032	0.004	8.127	<.001	[0.024, 0.040]

Model Summary: $R^2 = 1.000$, Adjusted $R^2 = 1.000$, $F(8, 27) = 42145.576$, $p < .001$

Note: Dependent variable is log-transformed Total Carbon (tons/ha).

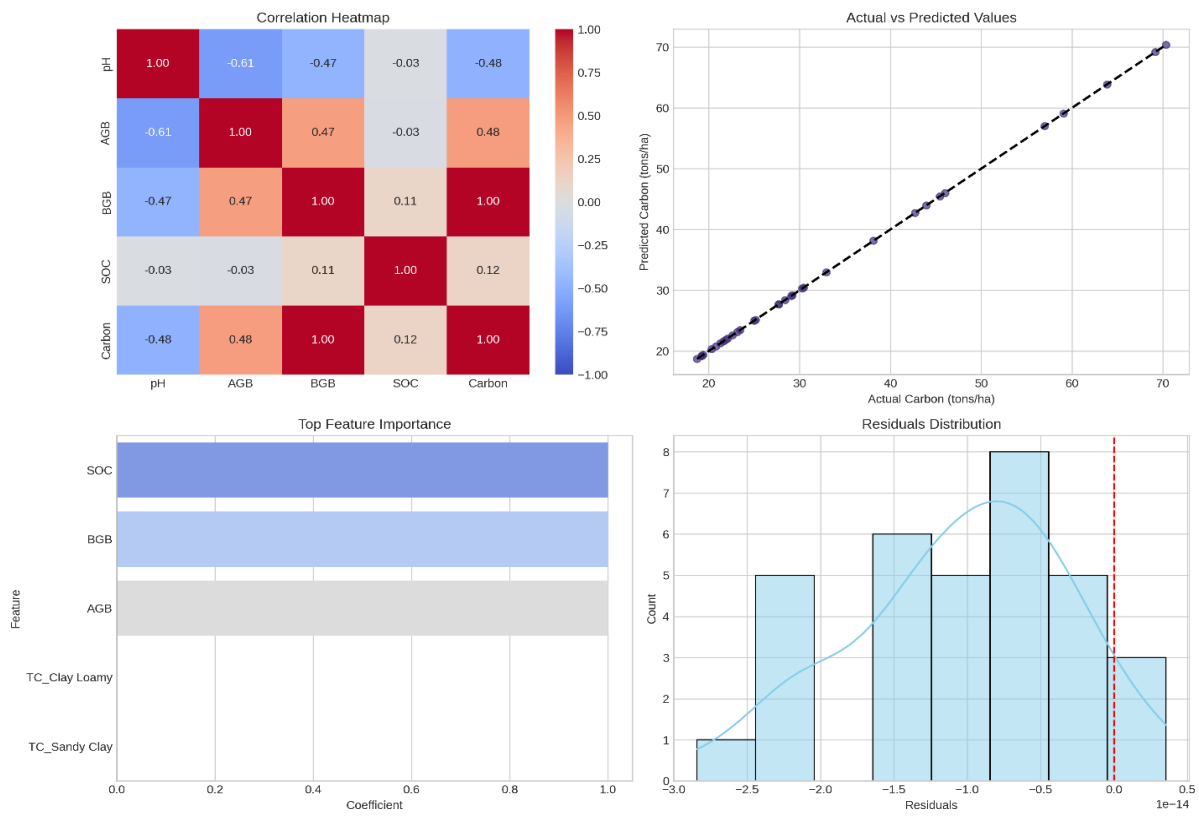


Figure 21: Model summary

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This research investigated the climate change mitigation abilities of Buffel grass (*Cenchrus ciliaris*) in South Baringo County by quantifying its capacity to store carbon in above-ground biomass (AGB), below-ground biomass (BGB), and soil organic carbon (SOC). Multi-linear regression models determined the correlation between environmental factors (soil pH, bulk density, texture, and carbon content) and carbon sequestration abilities. The model developed can be used to quantify carbon sequestered in a given Buffel grass landscape when the values of biophysical factors are known.

The research findings demonstrated that Buffelgrass accumulates carbon based on unique soil characteristics and climatic conditions, as the study hypothesized. Areas with beneficial soil conditions, such as clay loam textures, demonstrated the highest carbon sequestration because they maintain higher soil moisture retention and provide better nutrient availability. The study revealed that rainfall distribution and temperature shifts affected plant development significantly, reducing carbon sequestration levels during protracted dry spells, as seen in the dry fields. Dry conditions extending to droughts create severe limitations for carbon sequestration because they reduce plant productivity. Also, soil pH and bulk density proved essential elements for carbon storage since strong alkaline conditions are shown to restrict organic matter decomposition and microbial action, affecting carbon sequestration efficiency as observed in Kiborgoch Conservancy.

5.2 Recommendations

Developing future sustainability and climate resilience in the studied regions needs to capitalize on the research findings from this study. Buffel grass ecosystems have proven potential to fight climate change through carbon sequestration. Therefore, going forward, the research has recommended the following steps to optimize its potential for both environmental and socioeconomic good.

- I. **Scale-Up Restoration Efforts:** Because Buffel Grass delivers dual benefits of accelerating soil restoration and carbon storage, scaling-up restoration work across arid and semi-arid land zones becomes essential. To assess Buffel grass's performance across multiple environmental settings, a scale-up of restoration initiatives within South Baringo County and similar ecosystems should be implemented and monitored over a long period. The land restoration program helps recover damaged grasslands while boosting soil carbon quantity and developing more food resources and animal feed for local community members.
- II. **Generation of Carbon Credits/Offset Projects:** Generating carbon credits is one of the

encouraging results of Buffel grass restoration of degraded areas. By determining Buffel grass landscape carbon sequestration potential, these sites can be certified as carbon offset projects. Creating these restoration projects brings landowners and community members sustainable earnings and contributes to carbon reduction initiatives. To establish marketable credibility, the offset projects need credible certification from programs such as Verified Carbon Standard (VCS) and Gold Standard.

- III. **Continuous Monitoring and Data Collection:** Regular carbon sequestration tracking in restored areas will determine the complete contribution of Buffel grass implementation to grazing land soil quality, forage productivity, and entire ecosystem operations. Therefore, monitoring systems are recommended to aid in assessing restoration projects' effectiveness and modifying management approaches.
- IV. **Adaptation to Climate Change:** As the impacts of climate change continue to intensify and the ASAL regions face the consequences of prolonged droughts and intense rainfall events, adapting climate-smart practices in restoration projects is crucial to enhance vegetation success and carbon sequestration. Adapting to these shifts is also needed to boost ecosystem resilience to future climatic changes and offer community co-benefits. The study's findings underscore the importance of moisture retention in promoting carbon sequestration as a climate-smart practice. Therefore, integrating water conservation techniques, such as rainwater harvesting, mulching, and constructing half-moon structures, would be beneficial in improving soil moisture and reducing the negative impact of droughts on biomass production and carbon storage in Buffel grass landscapes.
- V. **Collaborative Efforts with Stakeholders:** Moving forward, the success of restoration and carbon sequestration initiatives requires an active partnership between local communities, government agencies, research institutions, NGOs, private institutions, and international financial institutions. These stakeholders can create sustainable solutions by sharing information, resources, and knowledge frameworks that leverage Indigenous and traditional practices and knowledge to enhance carbon uptake from the atmosphere and offer co-benefits to local and Indigenous populations.
- VI. **Policy Integration:** Going forward, it is essential for policymakers to incorporate carbon sequestration strategies into national and local policies. Findings from this research and other similar studies should be included in the policy frameworks, such as National Climate Action Plans (NAPs), to contribute to the country's broader climate mitigation goals and international goals such as the Paris Agreements.
- VII. **Expanding the Scope of Research:** While this research provided valuable insights on the

potential of Buffel grass to sequester carbon in South Baringo, expanding the study to regions with different edaphic and climatic conditions will enhance the replicability of restoration projects in many regions. Also, an experimental study design that monitors the contribution of Buffel grass over long periods under the effect of other interventions, such as soil amendments with biochar and the use of constructed half-moons on carbon sequestration in different ecological settings, is necessary.

Going forward, the future of carbon sequestration and ecosystem restoration will succeed through effective implementation and large-scale deployment of Buffel grass restoration projects. Through research advancement, multistakeholder collaboration, and adaptive management practices, meaningful climate change mitigation efforts will lead to strengthening vulnerable ecosystems and generating economic opportunities through carbon credit programs and enhanced livestock productivity.

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APPENDICES

Appendix 1: Data for Chuinee

Chuinee Sample	Textual Class	pH	Bulk Density (g/cm³)	Carbon content in AGB (tons/ha)	Carbon content in BGB (tons/ha)	Carbon content SOC (tons/ha)	Total Carbon
C1	Sandy Clay	8.68	1.5	0.8097	27.9033	0.4705	29.1835
C2	Sandy Clay	8.96	1.5	0.9509	20.6762	0.4343	22.0614
C3	Sandy Clay	8.62	1.5	0.745	21.9445	0.4705	23.16
C4	Sandy Clay	8.78	1.5	0.9436	17.0387	0.7238	18.7061
C5	Clay Loam	8.76	1.3	1.1272	18.0677	0.1809	19.3758
C6	Clay Loam	8.7	1.3	0.9317	21.2266	0.4343	22.5926
C7	Clay Loam	8.45	1.3	0.7454	19.4796	0.579	20.804
C8	Clay	8.98	1.2	0.9708	19.5514	0.76	21.2822
C9	Clay Loam	9	1.3	0.8266	17.8523	0.5429	19.2218
C10	Sandy Clay	8.65	1.5	0.8723	20.3651	0.6152	21.8526
C11	Clay Loam	8.79	1.3	0.8264	21.8966	0.7238	23.4468
C12	Sandy Clay	8.79	1.5	1.1887	18.5942	0.5428	20.3257
							21.8344

Appendix 2: Data for Nasinya

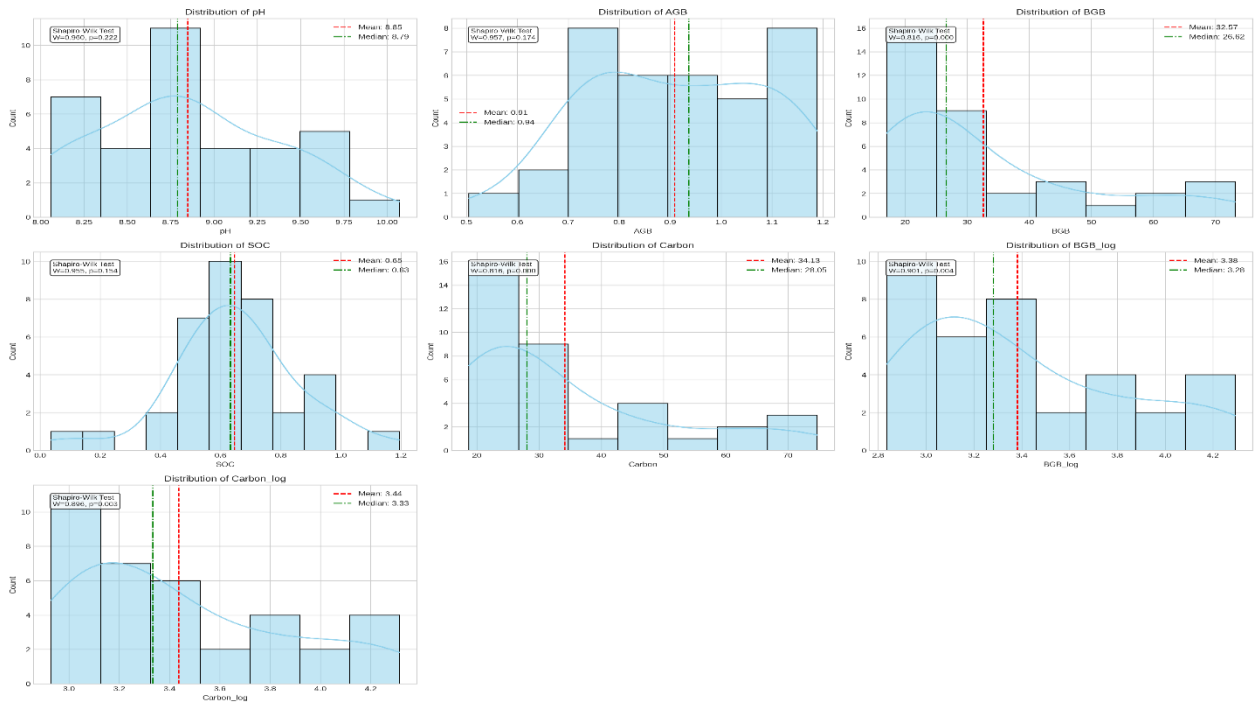
Nasinya Sample	Textual Class	pH	Bulk Density (g/cm³)	Carbon content in AGB (tons/ha)	Carbon content in BGB (tons/ha)	Carbon content SOC (tons/ha)	Total Carbon
N1	Clay Loamy	8.7	1.3	0.996	73.1563	0.5429	74.6952
N2	Clay	8.06	1.2	1.0842	55.0168	0.9048	57.0058
N3	Clay Loamy	8.2	1.3	1.1543	28.4058	0.7238	30.2839
N4	Clay Loamy	8.3	1.3	1.1212	62.1721	0.579	63.8723

N5	Clay Loam	8.09	1.3	1.0413	43.6736	0.7238	45.4387
N6	Clay Loam	8.1	1.3	1.0413	67.5565	0.579	69.1768
N7	Clay Loam	8.4	1.3	1.135	68.6095	0.6152	70.3597
N8	Clay Loamy	8.87	1.3	0.9453	40.9695	0.7962	42.711
N9	Clay Loam	8.9	1.3	0.9413	44.4155	0.6514	46.0082
N10	Clay Loamy	8.08	1.3	1.1261	41.8549	0.9771	43.9581
N11	Clay Loam	8.35	1.3	1.0543	57.5056	0.5067	59.0666
N12	Clay Loamy	8.08	1.3	1.1032	36.4226	0.6152	38.141
						Average	53.3931

Appendix 3: Data for Kiborgoch

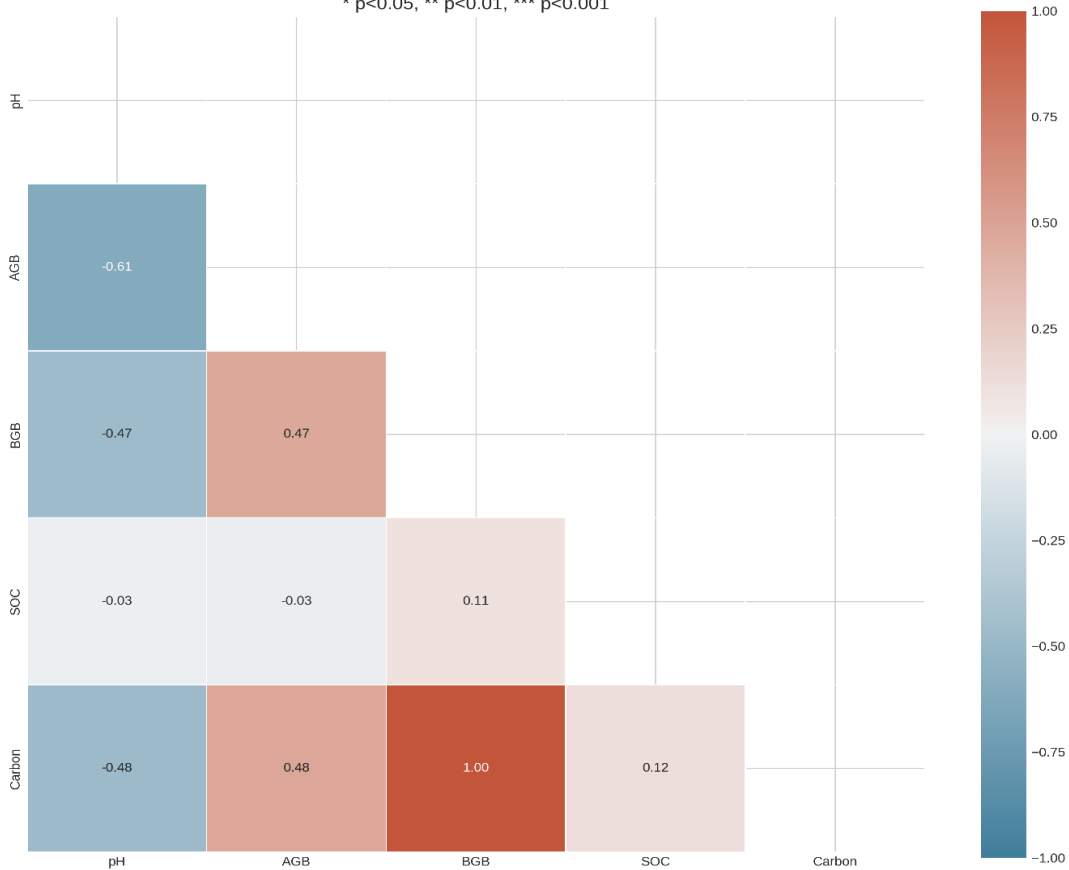
Kiborgoch Sample	Textual Class	pH	Bulk Density (g/cm³)	Carbon content in AGB (tons/ha)	Carbon content in BGB (tons/ha)	Carbon content SOC (tons/ha)	Total Carbon
K1	Silty Clay	9.39	1.2	0.8285	28.8844	0.7238	30.4367
K2	Clay	9.14	1.3	0.7033	20.1976	0.7238	21.6247
K3	Silty Clay	9.51	1.2	0.7811	26.4435	0.4705	27.6951
K4	Silty Clay	9.52	1.2	0.7302	26.8024	0.8686	28.4012
K5	Clay	9.32	1.3	0.5048	23.5239	0.9771	25.0058
K6	Clay	9.4	1.3	1.1818	32.3065	1.1943	34.6826
K7	Clay	9.6	1.3	0.6339	31.3493	0.9771	32.9603
K8	Clay	8.79	1.3	0.6744	23.8111	0.6514	25.1369
K9	Clay	9.23	1.3	0.7157	17.8763	0.6152	19.2072
K10	Clay	9.59	1.3	0.7125	26.3238	0.6514	27.6877
K11	Clay	10.07	1.3	0.8093	23.165	0.03619	24.01049
K12	Silty Clay	9.72	1.2	0.7638	27.64	0.6876	29.0914
						Average	27.16167

Appendix 4: Variable Distribution

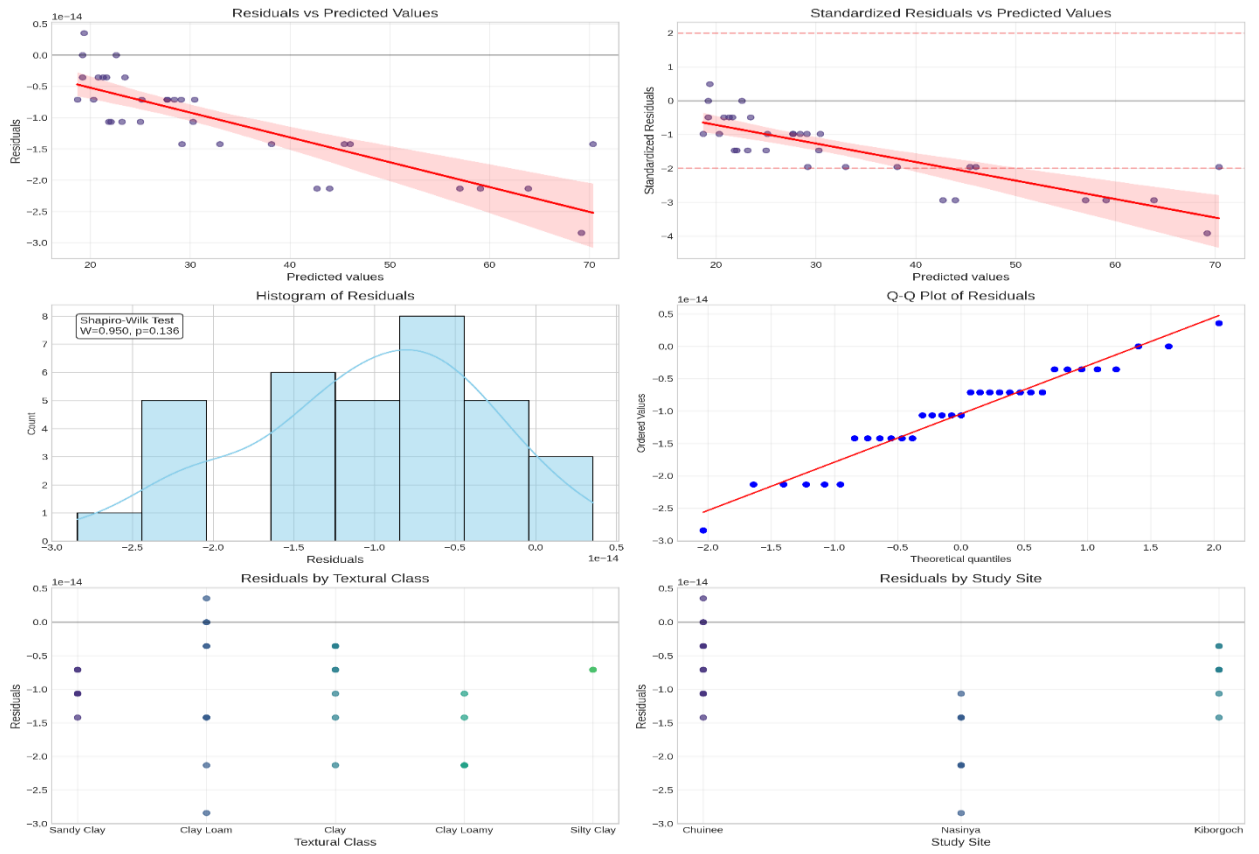


Appendix 5: Correlation Heatmap with significance levels

Correlation Heatmap with Significance Levels
 * p<0.05, ** p<0.01, *** p<0.001

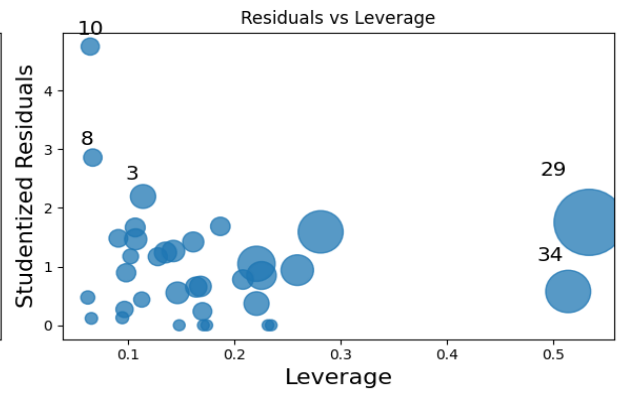
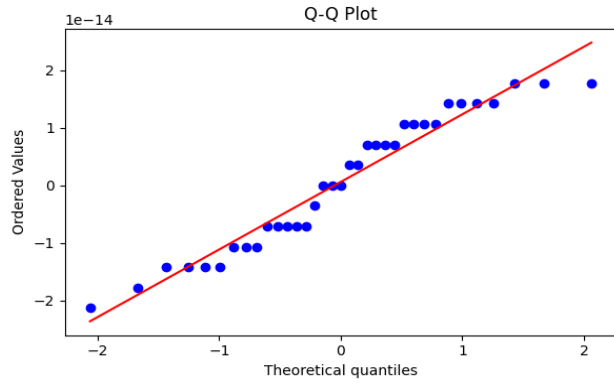
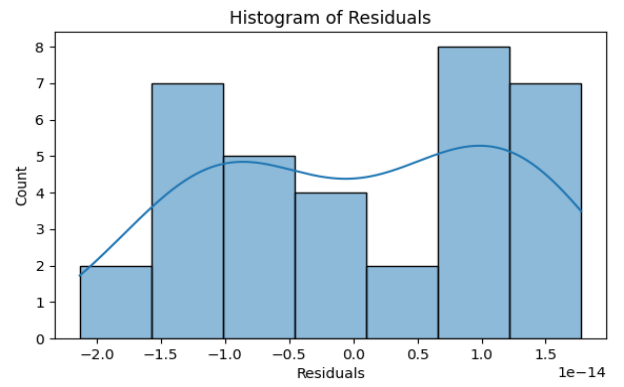
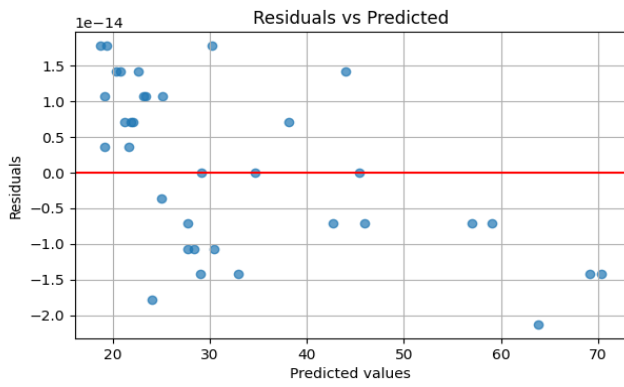


Appendix 6: Comprehensive Residual Analysis

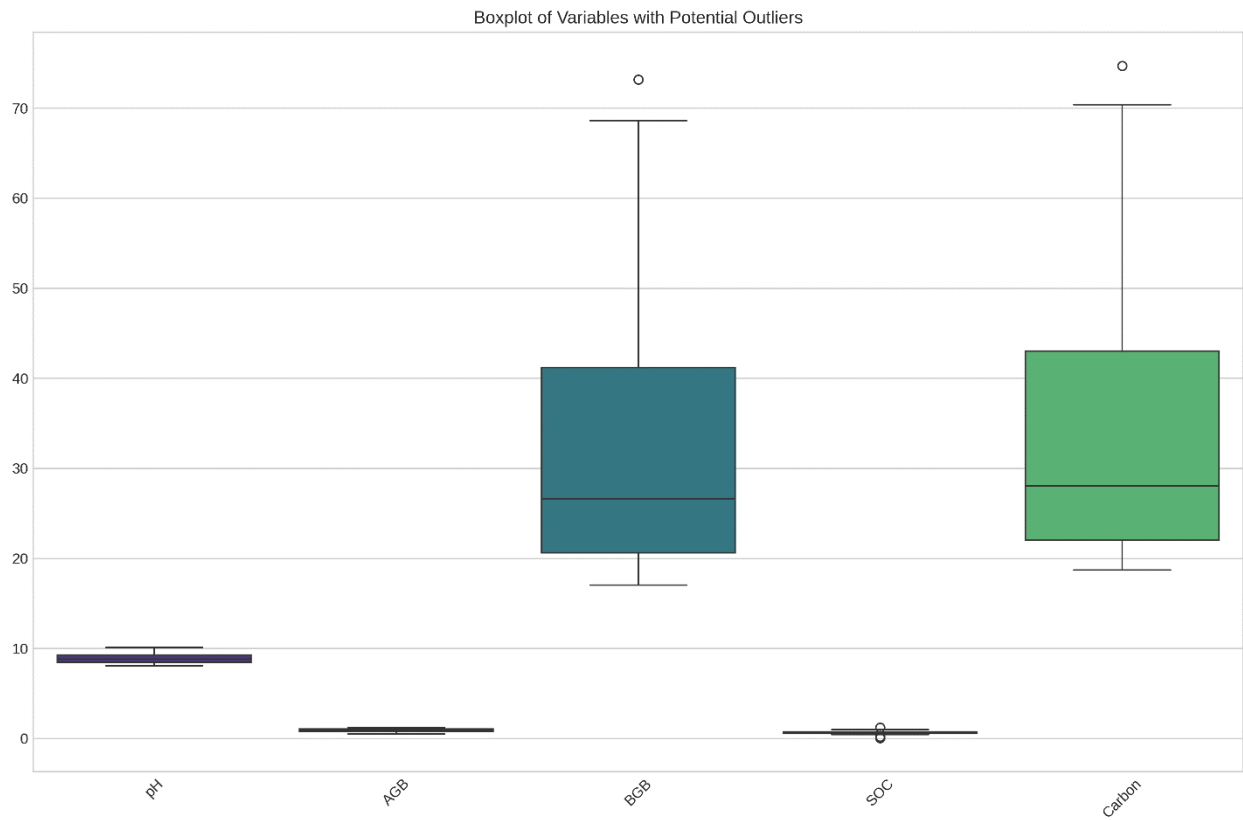


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Appendix 7: Residual diagnostics



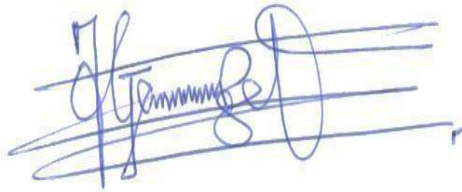
Appendix 8: Boxplot of variables with potential outliers



Appendix 9: Field Work Photos

Appendix 10: Lab Work Photos

Signatures



Supervisor

Student

Prof. George M. Ogendi

Okwach Francis O.