Original Research Article

Effects of Agricultural Land Use Practices on Soil Organic Carbon Stocks, Total Nitrogen and Available Phosphorous in Smallholder Farms in Embu County, Kenya

ABSTRACT

A study was conducted to determine soil organic carbon stocks (SOCs), total nitrogen (TN) and available phosphorous (AP) changes in agricultural land use practices with a focus on maize and coffee based agricultural systems along Kapingazi river catchment in Embu County. Demarcation was done into four agro-ecological zones (AEZ) following the river downstream; Lower Highland Zone 1 LH1; Upper Midland Zone 1, UM1; Upper Midland Zone 2, UM2; Upper Midland Zone 3, UM3. Soil samples were obtained from two depths of 0-25 cm and 25-50 cm across slope positions. The soil organic carbon stocks were high in LH1 at 58.38 kg/m^2 whereas UM3 had least amount at 29.48 kg/m^2. The total nitrogen was higher in LH1 at 0.27% while least at UM3 with 0.07%. The LH1 had higher mean amount of available phosphorous at 19.44 ppm and least at UM3. The coffee agricultural system had more available phosphorous in LH1 at 23.75 ppm whereas maize had more in UM1, UM2 and UM3. The soil organic carbon stocks, available phosphorous and total nitrogen decreased across the AEZ. The Farm Foot Slope sampling point had high soil organic carbon stocks with the lowest amounts in the Farm Summit sampling point at both depths. The concentration of total nitrogen in coffee was high in all slope positions, whereas, available phosphorous was higher in maize. Therefore, it is concluded that topography and agriculture land use and management practices influence soil nutrient status.

Keywords: Agricultural Land Use Practices, Agro-Ecological Zones, Soil Organic Carbon Stocks, Soil Nutrients, Smallholder Farmers.

INTRODUCTION

In view of land degradation, climate change and biodiversity loss, soils have become one of the most vulnerable resources in the world [1]. Agricultural land use changes have become an increasing focus of research because of its significance in affecting soil fertility and related properties, such as soil bulk density, soil organic carbon (SOC), total nitrogen (TN), available phosphorus (P), and ultimately the value of ecosystem services [2]. For example, deforestation for agricultural development or extension is a common land-use problem that may cause a series of changes in the ecological environment and soil carbon stock in planting systems [3]. Agricultural land use has been reported to show a greater reduction in total organic carbon and total nitrogen stocks [4] and the SOC is a common indicator of soil fertility [5]. Natural vegetation soil exhibited the highest SOC and N storage, and grasslands had the highest SOC sequestration rate and N sequestration potential [6]. A decline in soil organic carbon stocks, total nitrogen and available phosphorous creates an array of negative effects on land productivity such as loss of soil quality, decline in crop productivity and sustainability of the agricultural systems in river catchments. The type of land use system is an important factor that controls soil organic matter levels since it affects the amount and quality of litter input, the litter decomposition rates and the processes of organic matter stabilization in soils [7]. The continent of Africa is one of the current hotspots of land use and land cover changes and degradation affecting soil organic carbon stocks, available phosphorous and total nitrogen dynamics including changes along the vertical soil profile [8].

Smallholder farmers represent 80% of all farms in the Africa continent [9]. Productivity of crops per unit of land is low in Africa. Over the last several decades, crop harvest and erosion has led to depleted nitrogen in the soils and declining grain yields [10]. Inappropriate agricultural land use practices alters soil-plant nitrogen and phosphorous uptake resulting in erosion of nitrogen and phosphorous based compounds to waterways causing eutrophication [11]. A marginal reduction in soil organic carbon content in the order of one per cent can have a significant negative impact on soil natural capital and ecosystems services [12]. Agriculture is the mainstay of the Kenyan economy directly contributing 23.9% of the country's Gross Domestic Product (GDP) growth in 2012 [13] and another 25% indirectly. The sector accounts for 65% of

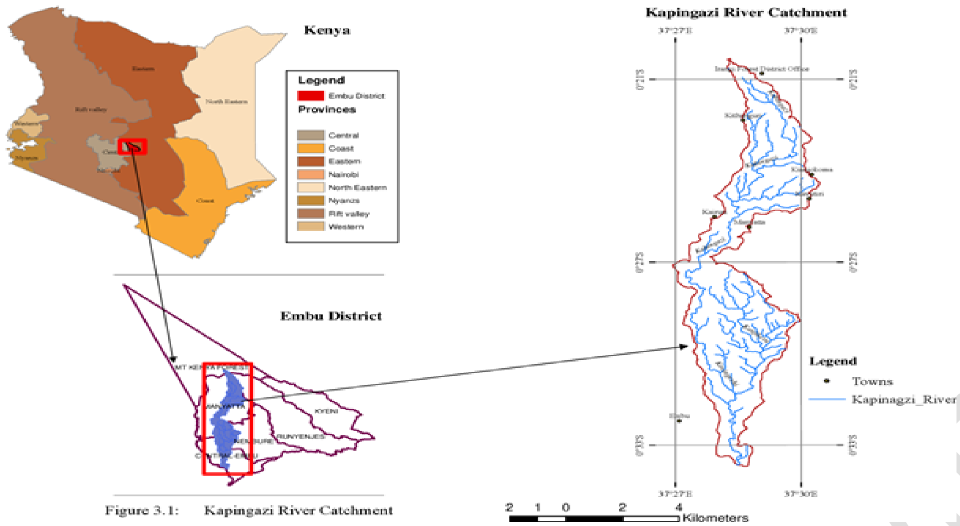
Kenya's total exports and provides more than 70% of informal employment in the rural areas [13]. In addition, the sector provides food security and livelihood to over 80% of the Kenyan population. Therefore, the agricultural sector is not only the driver of Kenya's economy but also the means of livelihood for the majority of population [13]. Over the years, population pressure and lack of growth in other economic sectors in Kenya has increased pressure on land resources, resulting in declining soil fertility, productivity and general environmental degradation [11].

Population pressure in the Eastern highlands of Kenya has increased demand on food production forcing smallholder farmers to practice poor methods of farming such as limited crop rotation [14]. The different agricultural land uses in Embu County include cultivation of upper zones with tea. At the lower altitude gradient coffee is grown as a cash crop. This zone is immediately followed by an area where maize, beans, horticultural crops are grown. In all the zones the crops receive different types and quantities of agricultural inputs like fertilizers and manure at different times [15]. Studies have been done on how soil organic carbon, total nitrogen and available phosphorous are affected by land use change in Africa and Kenya [16] but the effects of agricultural land use and spatial variation in soil organic carbon stocks, total nitrogen and available phosphorous in smallholder farms in localised Counties in Kenya has not been well documented. Change in land-use management practices such as cultivation of steep slopes, overgrazing, and no or limited fallow periods, and slope position affects the quality of soils [17]. Developing land management scenarios that potentially sequester carbon and reduce greenhouse gasses emission on a sustainable basis necessitates quantifying the current carbon stock under different land uses [18]. This study examined the effects of agricultural land use and spatial variation on soil organic carbon, total nitrogen and available phosphorous in smallholder farms in Embu County of Kenya. The focus was on coffee and maize based agricultural systems located along different agro ecological zones in the Kapingazi river catchment of the Embu County.

MATERIALS AND METHODS

Study Site

The study was conducted in the Kapingazi River Catchment which has an area of 61.23 square kilometre and is part of the larger Upper Tana River catchment. It drains into river Rupingazi at the lower parts of Embu town. It is located in Embu County, Kenya in the Central Highlands on Latitude 3^0 30' S and Longitude 37^0 30' E. The catchment illustrates a typical agro-ecological profile of the County. The catchment is 27 km long and is situated at altitudes of between 1230 m to 2100 m above sea level [19]. The smallholder farmers in the study area used fertilizer in both cropping systems of maize and coffee. The use of fertilizer in the maize crop was undertaken twice in the duration of the maize crop in the farms, which is ring the planting season and after weeding. There was increased use of Diammoinum Phosphate (DAP) fertilizer in the maize crop whereas in coffee there was high usage of a mixture of Nitrogen, Phosphorus and Potassium (NPK) and Calcium Ammonium Nitrate (CAN) fertilizers. The use of fertilizer in the coffee crop was three times a year by most of the smallholder farmers. The study established that most coffee crops in the farms were of more than ten years whereas maize was of approximately seven weeks. Soil was sampled after use of DAP fertilizer in maize and NPK was in coffee agricultural based systems



igure 1: Map showing the location of Kapingazi River Catchment [20]

Soil sample collection

A total of seventy-two (72) soil samples were collected for each of the two agricultural based systems making a grand total of one hundred and forty-four (144) soil samples. Three soil samples were collected across the landscape position in the two depths of 0-25 cm and 25-50 cm.

Table 1: A Representation of the Agro-Ecological Zones, Farms and Soil Depths and Sampling Procedure

		Farm 1		**Farm 2**		**Farm 3**		**Total**	
	Soil depth (cm)	0-25	25-50	0-25	25-50	0-25	25-50	0-25	25-50
AEZ (Maize based system)	LH1	SSP1	SSP1	SSP1	SSP1	SSP1	SSP1	9	9
		SSP2	SSP2	SSP2	SSP2	SSP2	SSP2		
		TSSP	TSSP	TSSP	TSSP	TSSP	TSSP		
	UM1	SSP1	SSP1	SSP1	SSP1	SSP1	SSP1	9	9
		SSP2	SSP2	SSP2	SSP2	SSP2	SSP2		
		TSSP	TSSP	TSSP	TSSP	TSSP	TSSP		
	UM2	SSP1	SSP1	SSP1	SSP1	SSP1	SSP1	9	9
		SSP2	SSP2	SSP2	SSP2	SSP2	SSP2		
		TSSP	TSSP	TSSP	TSSP	TSSP	TSSP		
	UM3	SSP1	SSP1	SSP1	SSP1	SSP1	SSP1	9	9
		SSP2	SSP2	SSP2	SSP2	SSP2	SSP2		
	Total samples/Depth	TSSP	TSSP	TSSP	TSSP	TSSP	TSSP	36	36
AEZ (Coffee based system)	LH1	SSP1	SSP1	SSP1	SSP1	SSP1	SSP1	9	9
		SSP2	SSP2	SSP2	SSP2	SSP2	SSP2		
		TSSP	TSSP	TSSP	TSSP	TSSP	TSSP		

UM1	SSP1 SSP2 TSSP	SSP1 SSP2 TSSP	SSP1 SSP2 TSSP	SSP1 SSP2 TSSP	SSP1 SSP2 TSSP	SSP1 SSP2 TSSP	9	9
UM2	SSP1 SSP2 TSSP	SSP1 SSP2 TSSP	SSP1 SSP2 TSSP	SSP1 SSP2 TSSP	SSP1 SSP2 TSSP	SSP1 SSP2 TSSP	9	9
UM3	SSP1 SSP2 TSSP	SSP1 SSP2 TSSP	SSP1 SSP2 TSSP	SSP1 SSP2 TSSP	SSP1 SSP2 TSSP	SSP1 SSP2 TSSP	9	9
Total samples/Depth							36	36
Grand Soil samples								144

Key: SSP1-Summit- Sampling point; SSP2-Shoulder- Sampling point; TSSP -Toe slope- Sampling point; UM1-Upper Midland Zone; UM2- Upper Midland Zone 2; UM3- Upper Midland Zone 3; LH1- Lower Highland Zone 1

The landscape positions identified were the Farm Summit - Sampling point (SSP1), Shoulder - Sampling point (SSP2) and the Farm Foot Slope- Sampling point (TSSP) [Figure 2]. The soil samples were appropriately labelled, placed in *khaki* carrier bags and transported to the Kenya Agricultural and Livestock Research Organization (KALRO) laboratory in Embu for analysis.

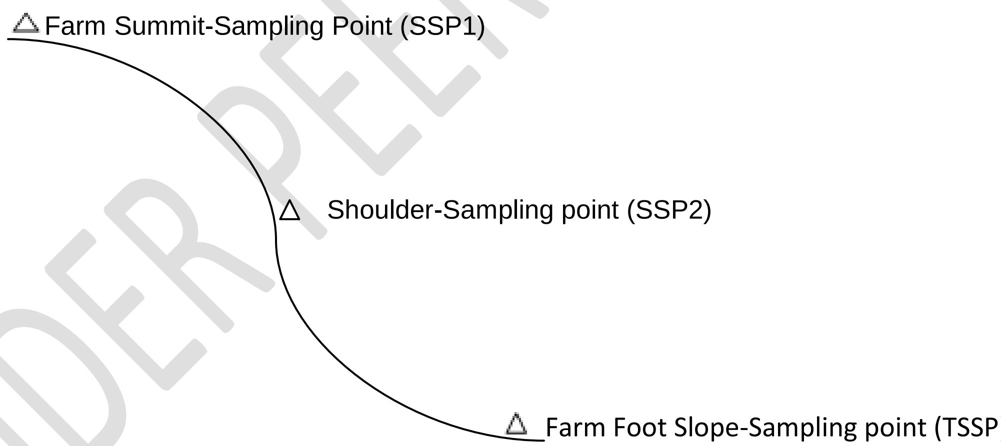


Figure 2: Landscape outline of soil sampling points in the slope positions

Soil analysis

Total nitrogen (TN) was analysed by the micro-Kjeldahl procedure [21], available phosphorous by the Olsen and Sommers method due to the acidic nature of soil in the study area. The Soil organic carbon (SOC) was analysed using the Walkey and Black method [26]. Computation of soil organic carbon was done through the following method.

*SOC = BD * d * %C …………………………………………………. Equation (1)*

Where, SOC = Soil Organic Carbon [kg/m^2]; BD = Bulk Density [$g\ cm^{-3}$]; d = Depth of the Soil Sample [cm]; % C = Carbon Concentration [%]

Statistical analysis

The nominal data obtained from the questionnaire were analysed using cross tabulation in Statistical Packages for Social Science (SPSS) where descriptive statistics (measure of location and dispersion) were obtained. An analysis of variance (ANOVA) was used to analyse data on SOCs, AP and TN obtained from coffee and maize based agricultural land use practices at the two depths. Analysis of variance (ANOVA) was further used to evaluate any significant differences in distribution of soil organic carbon across the coffee and maize based agricultural land use practices. The significantly different means were separated using the Tukey test at α=0.05.

RESULTS AND DISCUSSION

Quantification of the Spatial Distribution in SOC Stocks, TN and AP Contents in Coffee and Maize Based Agricultural Systems along the Kapingazi River Catchment

The findings of this study indicated that the coffee-based agricultural system had the highest concentration of soil organic carbon stocks as compared to the maize-based agricultural systems (Figure 3-a). The results show that soil organic carbon stocks were higher upstream at LH1 and decreased downstream towards UM3 in both agricultural based systems. The mean amount soil organic carbon stocks across the agroecological zones were 48.21 kg/m^2. From the result α=0.000 < 0.05, the null hypothesis is rejected and conclude that there was statistical significance between the soil organic carbon stocks and the agroecological zones. Similar studies have established that areas of high altitude have large quantities of soil organic carbon stocks [22].

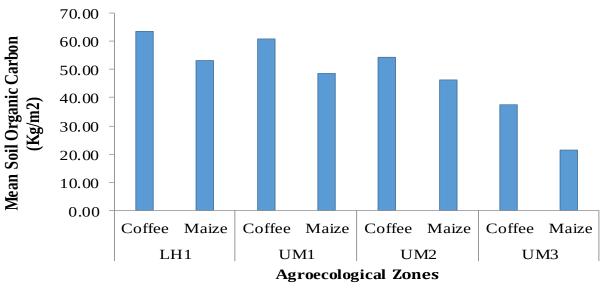


Figure 3-a: Comparison of the spatial distribution of soil organic carbon stocks in the agricultural systems

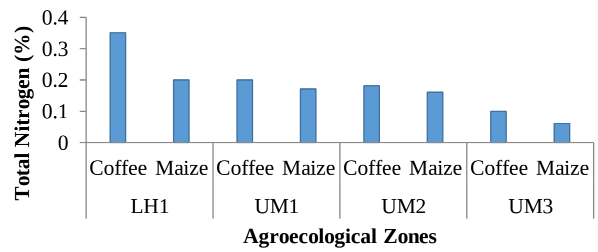


Figure 3-b: Comparison of the spatial distribution of total nitrogen in the agricultural systems

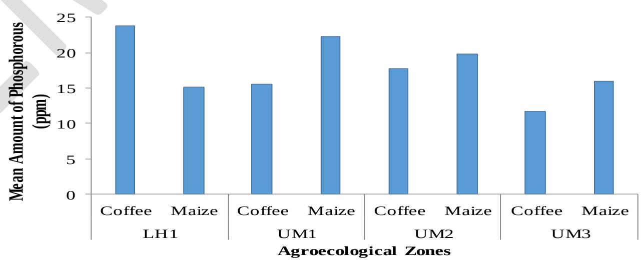


Figure 3-c: Comparison of the spatial distribution of available phosphorous in the agricultural systems

The results showed that coffee based agricultural system had a higher concentration of total nitrogen compared to the maize based system. Total nitrogen was highest in LH1 and reduced towards UM3 in both agricultural systems (Figure 3-b). The mean amount of total nitrogen across the agroecological zonation was 0.18%. The results of total nitrogen as per the zonation depicts that α=0.002 < 0.05. The results obtained in the study have been supported by early studies conducted by Biazin [22]. The results indicates that the null hypothesis is rejected and a conclusion that there was statistical significance between the total nitrogen and the agroecological zonation. The results indicate that as one moves down the agro ecological zonation the amount of total nitrogen decreases [23].

The available phosphorous in the soil indicated that the trend did not follow the spatial distribution trend of soil organic carbon stocks and total nitrogen. The agroecological zone LH1 showed the highest concentration of available phosphorous in coffee whereas in agroecological zone UM1 showed the higher concentration of available Phosphorous in maize (Figure 3-c). The mean amount of available Phosphorous across the agroecological zones was 0.79%. The results show that α=0.000 < 0.05, this indicates that the null hypothesis is rejected and conclude that there was statistical significance between the available phosphorus and the agroecological zonation

Contribution of smallholder farms landscape differences on soil organic carbon stocks, total nitrogen and available phosphorous in coffee and maize based agricultural systems

The results indicated that coffee based agricultural system had the highest concentration of soil organic carbon stocks in all slope positions as compared to the maize based agricultural system. This is probably due to the fact that coffee based systems exists as a natural vegetation compared to maize crop land which lasts for a short duration of time. Changes in land use from natural vegetation to cropland have been reported to cause significant reductions in SOC stocks in the long term [3]. The results showed that soil organic carbon stocks in TSSP was higher than that in SSP1 and SSP2 (Figure 4-a). It has been established that the soil organic carbon stocks of the Farm Foot Slope position were 2.5 times higher than other slope positions [24]. Similar studies by Reza [25] established that steep slopes have lower soil organic carbon stock content than flat land, as they are more vulnerable to erosion, especially when associated with inappropriate management and overuse. The landscape position SSP2 had the lowest mean concentration in both depths of soil organic carbon stocks (Figure 4-a). This could be attributed to erosion in this position. The higher concentration in TSSP could be due to deposition that occurs in this slope position. Similar studies by Nelson [26] revealed higher soil organic carbon stocks in bottom slope which is probably associated to the effect of cultivation and geomorphologic processes, that result in the transportation and deposition of soil materials. Studies by Hao [27] established lower concentration of soil organic carbon stocks in the middle slope due to soil erosion. There is more occurrence of soil erosion on the steeper middle slope than upslope hence the latter is likely to have more soil organic carbon amounts than the former.

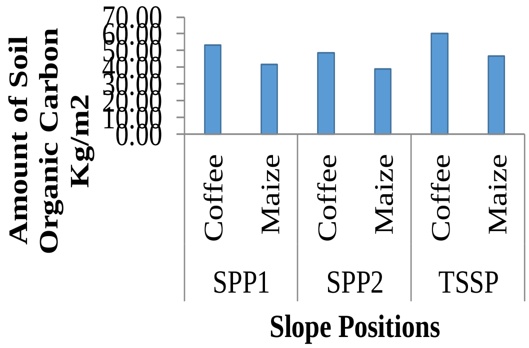


Figure 4-a: Comparison of soil organic carbon stocks in different slope positions of the agricultural based systems

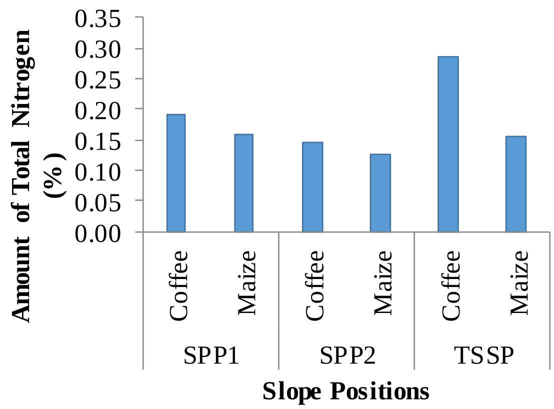


Figure 4-b: Comparison of total nitrogen in different slope positions of the agricultural based systems

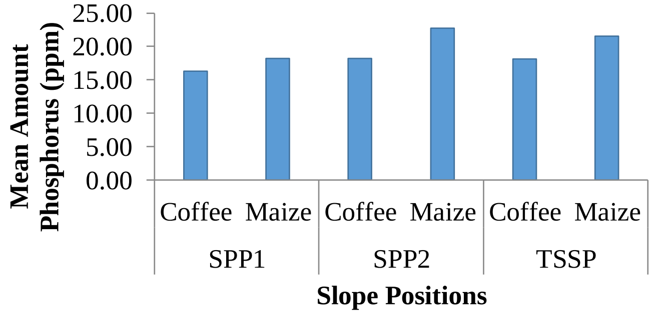


Figure 4-c: Comparison of available phosphorous in different slope positions of the agricultural based system

The results indicate that coffee based agricultural system had the highest concentration of total nitrogen in all slope positions as compared to the maize based system (Figure 4-b). Similar studies have established that cultivated soils have significantly lower total nitrogen at all depths when compared to grasslands and forestlands, indicating that continuous cultivation ultimately reduces the total nitrogen contents in the soil [28]. The results show that total nitrogen in TSSP was higher in coffee whereas in maize SSP1 showed higher concentration of total nitrogen. The landscape position SSP2 had the lowest mean concentration in both depths of total nitrogen (Figure 4-b). This could be attributed to accumulation of SOC at the farm foot slope due to soil erosion in this position which increased the organic matter which is a store of most nutrients. The higher concentration in TSSP could be contributed to deposition that occurs in this slope position. Similar studies have supported these findings that total nitrogen significantly differs with the slope positions [29]. The result depicts similar concentrations that were derived in soil organic carbon stocks. The enhanced levels of total nitrogen and soil organic carbon stocks in coffee based agricultural system could be attributed to management practices that minimised soil disturbances and erosion, these increased the soil organic matter which is a primary source of nitrogen in soils. Similar studies have indicated improved agricultural management plays a vital role in protecting soils from degradation in Eastern Africa and changing practices such as reducing tillage, fertilizer use or cover crops are expected to enhance soil organic carbon (SOC) storage, with climate change mitigation co-benefits, while increasing crop production [30].

The result indicates that maize based agricultural system had the highest concentration of available phosphorous in all slope positions as compared to the coffee based agricultural system (Figure 4-c). The presence of greater available phosphorous concentration in maize based agricultural system might be due to the differential uptake of phosphorus between coffee and maize. Similar results of Nelson [26] revealed that soil high in available phosphorous also have high organic matter contents. The results show that available phosphorous in SSP2 was higher in both coffee and maize based agricultural systems (Figure 4-c). In most agricultural land use systems farmers intensify the soil management practices on the shoulder region because of increased activities in this area. It has been reported that agricultural intensity positively correlates with phosphorous content [31], and the mean total phosphorus stocks was observed to increase with increasing management intensity [5]. Increase in agricultural land use may result to a soil that is well restored and that has less phosphorus fixation that may explain why there was higher levels of available phosphorus in the shoulder region.

Conclusion

The study established that soil organic carbon stocks, total nitrogen and available phosphorous significantly varied among agricultural practices, agroecological zones, soil depths and slope positions. In areas such as those on shoulder slopes as shown in this study, greater efforts to increase soil organic carbon stocks, total nitrogen and available phosphorous are required. However, further study of the area is recommended, especially agricultural practices in combination with other topographic features such as altitude and their effects on soil organic carbon stocks, total nitrogen and available phosphorous content.

Factors and agricultural practices that increase soil organic carbon stocks, total nitrogen and available phosphorous whilst at the same time enhancing other aspects of the environment such as improved soil fertility, enhanced carbon sequestration, decreased erosion and improved yield of agricultural production should be taken into consideration. There is need to enhance management practices that retain soil organic carbon, total nitrogen and available phosphorous. Such practices are widely advocated by international agreements and conventions, and hence, smallholder farmers can play a role in contributing towards this and benefit from funds associated with the role they play towards this.

Consent

As per international standard or university standard, respondents' written consent has been collected and preserved by the author(s).

Ethical Approval

Ethical issues were considered during the study. The researchers clarified research advantages to all participants and ensured privacy during data analysis and obtained approval letters for the study from Chuka University Ethical Review Committee and a letter of authority from National Commission for Science, Technology and Innovation which is responsible for research authorization in Kenya.

Competing Interests

Authors have declared that no competing interests exist.

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