Effect of Grazing Management and Land Cover Types on Mineral-Associated Organic Carbon and Particulate Organic Carbon in a Semi-arid Rangelands in Kenya

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Research

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Abstract

Background

Enhancing soil organic carbon storage in areas under extensive livestock grazing has become a challenge in most arid and semi-arid rangelands in Sub-Saharan Africa. In Kenya for instance, continuous unplanned grazing in community lands has led to overgrazing and degradation of the rangelands. For decades, livestock production has shaped the landscape through various management practices. Grazing can be used to increase soil organic carbon (SOC) content but intensive use of land can lead to its depletion. This study was set out to elucidate the effect of two types of grazing management under varying land cover types on mineral-associated organic carbon (MAOC) and particulate organic carbon (POC) in the soil. The study was carried out in two ranches, Mpala Research Centre (controlled grazing) and Ilmotiok Community Group Ranch (continuous grazing). The experimental design was a completely randomized block design in split-plot arrangement with three replicates. The main plots were the grazing practices; (controlled grazing and continuous grazing); and sub-plots were the land cover types: (bare ground, patches of grasses, and mosaics of trees). These treatments were randomly selected and replicated three times. Three topographical positions (mid-slope, foot slope and bottom land) were used as a blocking factor.

Results

The interaction had no significant effect on MAOC fraction in any soil depth interval. Controlled grazed zones significantly recorded higher organic carbon content (POC= 0.887% CC SD=0.49) compared to zones under continuous grazing (POC = 0.718% CC SD=0.3). Mosaic of trees (POC =1.15% CC, SD = 0.22) recorded the highest concentration of carbon followed by patches of grass (POC = 0.87% CC, SD= 0.37) and bare ground (POC = 0.38% CC SD = 0.12) had the least.

Conclusion

This study shows that grazing practices as well as land cover types have a significant effect on POC but not on MAOC. Mosaic of trees under controlled grazing has higher POC whereas bareground under continuous grazing had the least POC. Destocking should be done under continuous grazed zones to reduce further loss of POC and MAOC and allow vegetation recovery.

1. Introduction

Semi-arid rangelands in Sub-Saharan Africa have been managed for the past centuries by grazing leading to an increase in tree density (1). The types of grazing practiced in semi-arid rangelands include open land grazing, bunched grazing, enclosed grazing, holistic grazing, and rotational grazing (2–5). The two distinct grazing management practices in the semi-arid rangelands of Kenyan are continuous and controlled grazing practices. Continuous grazing is characterised as grazing throughout the year with no rest period for vegetation to recover. Whereas Controlled grazing is practised in private ranches where there is land allocation for forage, prioritization is given to both livestock and wildlife with taking into account drought scenarios with a rest period (1). The grazing intensity in both practices is heavy grazing intensity for the former and light to moderate grazing intensity in the latter.

Grazing intensity has a significant effect on soil carbon fractions on the surface which is correlated to species composition and functioning (6, 7). Soil labile and stable carbon fractions forms part of the SOC reserve with the former being very sensitive to management and can act as a huge source of atmospheric carbon dioxide CO_2 if mismanaged through anthropogenic activities like overgrazing (8, 9). The active labile carbon pool is indirectly influenced by grazing through the species richness and functioning (6, 7, 10). Studies on Continuous grazing, for instance in Ethiopia, showed that it has a negative effect on soil properties like total nitrogen, phosphorous and CEC unlike in controlled though it is unclear for the carbon pool as depth increases in semi-arid rangeland where there is co-existence of both grass and trees (11, 12). As it has been suggested as a good soil indicator of the effect of grazing management practices, it is essential to understand the sources and components of labile carbon fraction. Sources of labile carbon include vegetation and animal droppings. Urine and faecal matter from herbivorous animals have a high content of labile carbon and highly decomposable which act as hot spots and hot moments of sources of greenhouse gases (13–15).

Most studies, on soil organic carbon in semi-arid rangelands of Kenya, report on soil organic carbon for the top 0.3m depth (5, 16, 17). There is insufficient information on various forms of carbon fractions and its trend down the soil profile. Depth tells us the trend of carbon and how much has been stored with time (18). It also reflects on the history of how various aspects like weather, land management and environmental factors influence SOC over time (19). Several studies show that SOC reduces as depth increases and it is more stable in the sub-soil compared to the topsoil. It is essential to study MAOC and POC with depth since it is a source of ecosystem services which is dependent on its availability and the nature it exists in the soil. There is insufficient information on carbon fractions to contribute to policy formulation on grazing management. Simple google search on studies focusing on grazing and its effect on carbon fraction in semi-arid rangelands of Kenya results is less than 50 studies. Against this backdrop, the current study was carried out to elucidate the quantity and trend of TOC, MAOC and POC fraction concentration up to 120cm in different topographic positions and land cover changes associated with grazing practices. This will help to demystify how different grazing management practices and land cover types influence soil carbon with depth in Laikipia County. This will contribute to coming up with better grazing management practices which will cub further loss of soil organic carbon.

2. Materials And Methods

2.1 Site description

Laikipia County lies between latitudes 0° 25’ 47.1” N and 0° 17’ 53.7” and longitudes 36° 57’ 32.9” E and 36° 47’ 39.9” E. It has been classified as semi-arid and arid rangelands. It is found in agro ecological zone V and experiences two rainy seasons and transition periods from the wet season to the dry season (20).

The short rains begin in October and end in November and the main rainy season occurs in the month of April to May which is erratic. Laikipia County experiences an average rainfall of 600±50 mm per annum and a high-temperature range between 25-30°C and low from 12-17°C (2). The elevation of Laikipia County varies between 1,500 m above sea level at Ewaso Nyiro basin in the North to a maximum of 2,611 m above sea level. The dominant soil type is Vertisols followed by Oxisols (3). A summary of the soil characteristics is presented in table 1.

The soils are characterized by imperfectly drained grey to black clay – vertisols and planosols, expanding into the lowland that comprises of metamorphic rocks of gneisses and migmatites with well drained soils; mostly dark reddish brown consisting of ferric and chromic luvisols (Ngigi 2006). The dominant soil type is vertisols followed by red sandy soils (3). Other soil properties of the study area have been summarized in table 1.

Table 1: Soil properties and grazing characteristics in Ilmotiok and Mpala Ranch

Grazing management	Ilmotiok	Mpala
Land Ownership	Community	Private
Total Livestock biomass (TLU)	897	2074
Total livestock and wildlife (TLU)	1334.4	4572.7
Land area (Ha)	3651	19000
Stocking density (TLU/Km^2)	37	24
Stocking intensity	Heavy	Light to moderate

Soil property		
pH (H_2O 1:2)	7.06	6.63
EC (dS/m)	0.13	0.07
Sand %	62.25	55.49
Silt %	26.99	32.25
Clay %	10.76	12.33
Texture class	Sandy clay loam	Sandy loam
Bulk density (g/cm3)	1.48	1.51
Total N (g/kg)	1.11	1.51
CN ratio	5.19	5.05
Total OC (%)	0.85	1.01

Source: Kibet *et al.,* (2016)

The main economic activities in Laikipia County includes but not limited to, livestock production, tourism, private and public conservancies, ranching, small- and large-scale farming, horticultural farming, sand harvesting and quarrying. This has made the entire region to be dependent on pastoralism and charcoal production. Two adjacent ranches Mpala Research Centre and Ilmotiok Community group ranch in Laikipia County, Kenya were selected for the study in 2016. Controlled grazing is practised in Mpala ranch and has been characterized to practice low to moderate grazing intensity is with a stocking density of wildlife and cattle with the exclusion of elephants to be 24TLU/Km^2. Illmotiok community group ranch has been classified to have a stocking density of 37TLU/Km^2 (Table 1) and categorized as heavy grazing intensity (1).

2.3 Experimental design and treatment

The experimental design was a completely randomized block design with a split plot arrangement. The main treatments were the grazing management practices, and land cover types were the sub-plots. Topographical positions were used as a blocking factor. Land cover types were selected randomly based on the most dominant cover that is bare ground, patches of grass and mosaic of trees. The topographical positions were classified into mid-slope, foot slope and bottom land (Figure 2) as described by (21).

Topographical positions classification

Topographical positions were first classified as described by (21). A permanent point of reference was defined within the gradient point (A-F) and the coordinates and altitude of this point were recorded using a GPS gadget. Topographical positions within the study area were point sampled as shown in Figure 2.

Topographical positions within each grazing management practices were point sampled using a clinometer and two rods marked at equal height. At the starting point (A), reference point, the first rod was held vertically and the second rod was held parallel 30 m from the first rod as shown in figure 1. Variation in topographical points was determined using Equation 1 below.

Δ Topographical point = distance between sampling point x clinometer reading (Equation 1)

A cloth tape was used to demarcate the length of each transect line. 10 of the points were marked either as bottom-land, mid-slope, or foot slope if 33 percent of the length of transect (200 m) was considered to be bottom-land, mid-slope, or foot slope. The ratios of each topo-class within each transect and the total lengths of all contour lines were calculated out of these values. At each topographical location, depending on the elevation of neighbouring topographical positions, it was graded as mid-slope (A-B), foot slope (B-C), or bottomland (C-D). In each topographic positions, land cover types, bare ground, patches of grasses and mosaics of trees were randomly selected and used to plot, a 200m transect and replicated 3 times. In each land cover type, soil samples were collected up to 30cm soil depth at intervals of 10cm. The soils were later tested for MAOC and POC.

2.4 Soil Sampling and analysis

Soil samples were collected from a flat surface which had been cleared of roots and grass using a calibrated soil auger at depth intervals of 10cm from the surface (0cm) up to 30cm soil depth. A total of 162 (1kg) soil samples were collected i.e

2 grazing management practices * 3 topographical positions * 3 land cover types * 3 soil depths * 3 replicates = 162 soil samples

The samples were tested for POC, and MAOC classified into various C fractions (22). 50g of fresh soil was weighed and dispersed with 10% calgon solution for 6 hours. Sieves with a mesh size of 2mm, 250 μm and 50 μm were arranged in that order and the dispersed soil sample was placed on the 2mm sieve and the process of wet sieving was carried out. After 20 minutes had elapsed, the fractions that were in each sieve were collected and oven dried at 65ºC for 24 hours. The weight of the dried samples was recorded and used to determine the percentage of carbon fractions in terms of 2mm - 250 μm POC, and >53-38 μm MAOC carbon. C concentration in each fraction i.e. POC and MAOC was further classified using the Walkley-Black method described by (23). C content was isolated in each sieve i.e. 2mm, 250 μm and 50 μm was further analysed for C concentration using the Walkley-Black method described by (23). Carbon content percentage was calculated using equation 2.

$$\%C = \left\{\frac{\text{M.e dichromate—m.e FeSO4}}{\text{Weight of soil in grams}}\right\} * \mathbf{0.3} \qquad \text{(Equation 2)}$$

2.4.5 Statistical analysis

R software version 3.5.3 (24) was used to carry out a multiple ANOVA tests for POC, and MAOC data. Agricolae package was used to do post hoc analysis with Tukey HSD test for POC, and MAOC to separate the means at 5% significance level.

3. Results

The POC fraction had a significant ($p<0.001$) response to grazing practices, topographical positions and across different land cover types at a soil depth of 0-10cm and 11-20cm but was insignificant between 21-30cm (Table 2).

Table 2: Means of carbon content (CC) % under different grazing practices at different topographical positions and various land cover types at 0_30cm soil depth

Soil depth	Grazing practice	Topographical positions	Land cover types POC		
			Bare ground	**Patches of grass**	**Mosaic of trees**
0_10cm	Continuous grazing	Bottom land	0.41^{i}	0.98^{de}	1.05^{d}
		Foot slope	0.41^{i}	0.84^{f}	0.9^{ef}
		Mid-slope	0.18^{k}	**0.74^{g}**	0.94^{ef}
	Controlled grazing	Bottom land	**0.55^{h}**	1.39^{b}	1.49^{b}
		Foot slope	0.44^{i}	1.07^{d}	1.35^{b}
		Mid-slope	0.31^{j}	0.2^{k}	**1.18^{c}**
11_20cm	Continuous grazing	Bottom land	0.33^{j}	0.76^{ef}	$0.81d^{e}$
		Foot slope	0.31^{jk}	0.67^{g}	$0.69f^{g}$
		Mid-slope	0.16^{l}	**0.57^{h}**	$0.74f^{g}$
	Controlled grazing	Bottom land	**0.45^{i}**	1.09^{b}	**1.24^{a}**
		Foot slope	0.36^{j}	0.83^{cd}	1.05^{b}
		Mid-slope	0.24^{k}	0.17^{l}	0.9^{c}
21_30cm	Continuous grazing	Bottom land	0.19^{hi}	$0.52d^{e}$	0.55^{cde}
		Foot slope	0.18^{hi}	0.44^{ef}	0.46^{ef}
		Mid-slope	0.1^{i}	0.36^{fg}	0.5^{def}
	Controlled grazing	Bottom land	0.28^{gh}	0.67^{abc}	0.8^{a}
		Foot slope	0.21^{hi}	0.57^{cde}	0.75^{ab}
		Mid-slope	0.12^{i}	0.12^{i}	0.63^{bcd}

Means with similar letters are insignificant

Agricolae HSD test specifically under continuous grazing, POC content at mid-slope (POC =0.74% CC, SD=0.017) in patches of grass indicated significant difference. Under controlled grazed zones, the post hoc test showed POC means at bottom land in bare ground (POC =0.55% CC, SD=0.041) and mosaic of trees in mid-slope (POC =1.18% CC, SD=0.061) had a significant difference. Grazing practices and land cover types, in different topographical positions and respective soil depth, had a significant ($p<0.001$)

effect on MAOC fraction. However, the HSD test indicated there was no significant difference between the MAOC means (Table 3).

Table 3: Means of Mineral Associated Organic Carbon (MAOC) Content under different grazing practices at different topographical positions and various land cover types at 0_30cm soil depth

Soil depth	Grazing practice	Topographical positions	Land cover types MAOC		
			Bare ground	Patches of grass	Mosaic of trees
0_10cm	Continuous grazing	Bottom land	0.50^{ab}	0.29^{efg}	0.32^{def}
		Foot slope	0.45^{abc}	0.23^{gh}	0.34^{def}
		Mid-slope	0.51^{ab}	0.27^{efgh}	0.2^{h}
	Controlled grazing	Bottom land	0.4^{cd}	0.3^{efg}	0.24^{gh}
		Foot slope	0.44^{bc}	0.325^{fgh}	$0.24f^{gh}$
		Mid-slope	0.52^{a}	0.45^{abc}	0.28^{efg}
11_20cm	Continuous grazing	Bottom land	0.5^{ab}	0.29^{efg}	0.32^{def}
		Foot slope	0.45^{abc}	0.23^{gh}	0.34^{de}
		Mid-slope	0.51^{ab}	0.27^{efgh}	0.2^{h}
	Controlled grazing	Bottom land	0.4^{cd}	0.3^{efg}	0.24^{gh}
		Foot slope	0.44^{bc}	0.25^{fgh}	0.24^{fgh}
		Mid-slope	0.52^{a}	0.45^{abc}	0.28^{efg}
21_30cm	Continuous grazing	Bottom land	0.37^{ab}	0.36^{abc}	0.39^{a}
		Foot slope	0.3^{abc}	0.28^{bc}	0.38^{ab}
		Mid-slope	0.35^{abc}	0.29^{abc}	0.27^{c}
	Controlled grazing	Bottom land	0.32^{abc}	0.36^{abc}	0.36^{abc}
		Foot slope	0.33^{abc}	0.33^{abc}	0.37^{ab}
		Mid-slope	0.37^{ab}	0.3^{abc}	0.37^{abc}

Means with similar letters are insignificant.

4. Discussions

4.1 Particulate Organic Carbon

Grazing practices had a significant effect on POC. This is attributable to the varying stocking density in the two grazing management practices. Under continuous grazing practice, the stock density varied and has been classified to have a high grazing intensity (1). High grazing intensity has been associated to decrease POC in the active soil depth layer. According to Stavi (25) and Pringle (26) grazing practices had no significant effect on POC. In other studies, grazing has been associated to decrease POC through trampling which loosens the soil and also reduces the plant cover which is a major source of POC in form of litter (27). The POC content was observed to be 38% which is within the range observed in other studies in semi-arid rangelands such as Chan (28), Gill (29), Kaye (30), and Oduor (4). According to Cao (18), Riggs (31) and Eze (32) POC was detectable because it is sensitive to human-induced practices with grazing management being one of them. On the other hand, a study carried out in Switzerland was able to detect less than 20% of POC content and the rest of the CC was linked to MAOC (33). This was due to the nature of the grassland which consisted of clay loamy soil.

The high CC under mosaics of tree cover was attributable to variation of tree species which have different amounts of carbon input in form of leaf litter, shoots and twigs which are rich in cutin, suberin and lignin. Land cover types had a significant effect because of the variation in species composition. Mosaic of trees recorded the highest followed by patches of grass. Bare ground recorded the least CC. Patches of grass and mosaics of trees are the main source of POC through the leaf litter. According to Kurgat (16) variation in vegetation covers types in semi-arid areas protects the soil surface from direct sunlight. Canopies of trees, such as Acacia species which is common in semi-arid rangelands, have been linked to having high soil moisture (16). This, in turn, enhances soil decomposition in the root zone.

Moreover, vegetation species have different C content especially trees like Boscia spp and Balanities spp have high quality and quantity of leaf litter lignin with high mineralization and the C: N ratio input unlike Acacia species (34-35). Rabbi (36) had similar findings and explained besides patches of land cover being sources of nutrients; they have a microclimate which slows down the decomposition of SOC in the soil thus influencing the physiochemical nature of carbon in the soil. On the contrary, Gili (37) associated high POC under tree canopies to the existence of herbaceous cover which was characterized to be unpalatable and hard. Also, under mosaics of trees and patches of grass, they have been characterized to have saturated hydraulic conductivity which enhances SOC content (34). According to Hibbard (38) and Zhou (39) they associated high clay content to accrue POC under herbaceous and woody cover.

Besides, the drastic loss of POC as the depth increased was due to the high sand percentage at 0_10 soil depth which was observed to range between 65-70%. The sand was higher at 0_10cm compared to 21_30cm soil depth in the bare ground land cover type. Sandy soils have been associated to have weak van der Waal forces which enable microbes to easily access POC (40). Also, sandy soils make POC prone to wind and water erosion.

4.2 Mineral-associated organic carbon

Grazing system, topographical position and land cover type do not influence soil MAOC. This is attributed to the similarity in clay content across all the grazing systems and topographical positions. According to Berryman (41), controlled environments such as lab experiments will detect significant effects. Since this was a field experiment with ongoing natural perturbations, both unknown and known, observing/obtaining significant difference between the interactions of grazing management, land cover types as well as topographical positions on MAOC is a challenge. MAOC is strongly associated with fine silt and clay particles (42-43). In this study, the silt and clay particles are uniformly distributed across all land cover types suggesting that the grazing systems and topographical positions had similar capacities to accumulate MAOC. These results corroborate with studies conducted in the drylands of South-west Kenya and Northern China (44,27). Furthermore, MAOC was unaffected with depth and similar observations were made by Ward (45) under grassland cover type.

Continuous grazing recorded higher MAOC compared to controlled grazing. This is because continuous grazing had higher bare ground cover which is as a result of intensive grazing and high stocking density of livestock. Intensive grazing leads to less vegetation cover. This in turn leads to oxidation of leaf litter to POC and MAOC. Due to high temperatures and soil texture, POC is lost through decomposition or erosion. This explains why under bare ground MAOC was higher compared to patches of grass and mosaic of trees at the bottomland under continuous grazed zones. A study in Ethiopia had dissimilar observations whereby uncontrolled grazing record low SOC in micro aggregates (43).

5. Conclusions And Recommendations

Controlled grazing had higher POC and MAOC content compared to continuous grazing. Carbon content of POC and MAOC was highest in mosaic of trees followed by patches of grasses. Bareground recorded the least POC and MAOC. Controlled grazing management should be adopted under continuous grazed areas to curb further loss of particulate organic carbon. Regardless of the grazing management practice and topographical position, mosaic of trees having recorded high particulate organic carbon content, more trees should be planted to increase soil organic carbon. This will help to reduce bare ground cover and restore soils deprived of soil organic carbon. Controlled grazing should be used to reduce overgrazing of vegetation which is the main source of particulate organic carbon in the form of litter. SOC should be studied for the first 0-20cm soil depth under various land cover types under different grazing management in each topographical position as shown this study despite IPCC recommendation of sampling more than 30cm soil for carbon studies.

Abbreviations

SOC: soil organic carbon; MAOC: mineral-associated organic carbon; POC: particulate organic carbon; CC carbon content; SD: standard deviation; TOC: total organic carbon; TLU: total livestock unit; ANOVA: analysis of variance; HSD: honestly significant difference

Declarations

Authors contributions

All authors contributed to the development of the concept and implementation of the study. AGN did the field data collection, lab and data analysis as well as drafted the manuscript. RNO, JSM, SMM, and JC made comments on the

manuscript. All authors read and approved the final manuscript.

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Competing interests

All the authors declare there have no competing interests

Availability of data and materials

We are unable to share the research data publicly. It can be made only available upon request.

Consent for publication

Not applicable

Ethics approval and consent to participate

Not applicable

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Figures

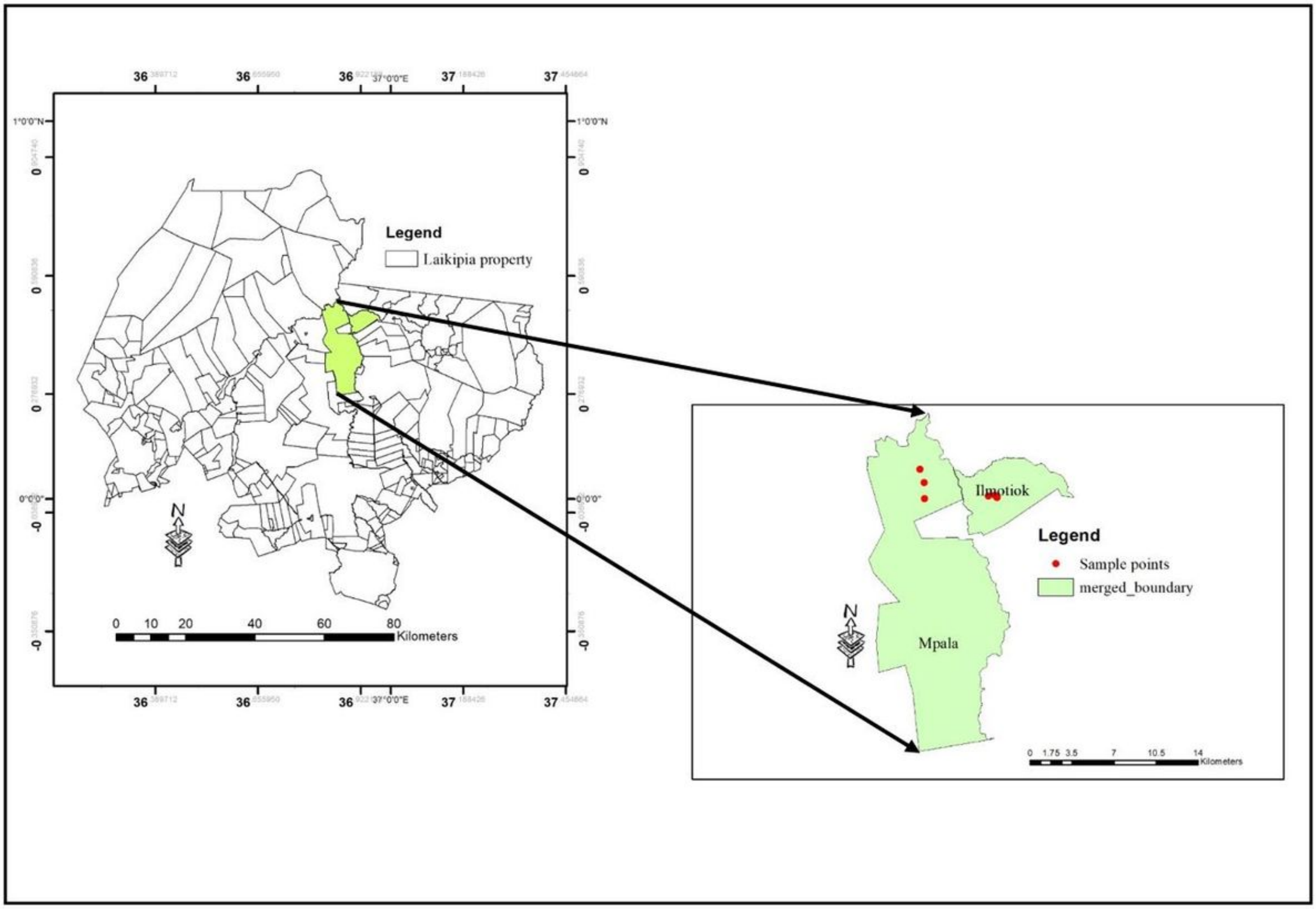

Figure 1

Map showing the study site in Mpala and Ilmotiok.

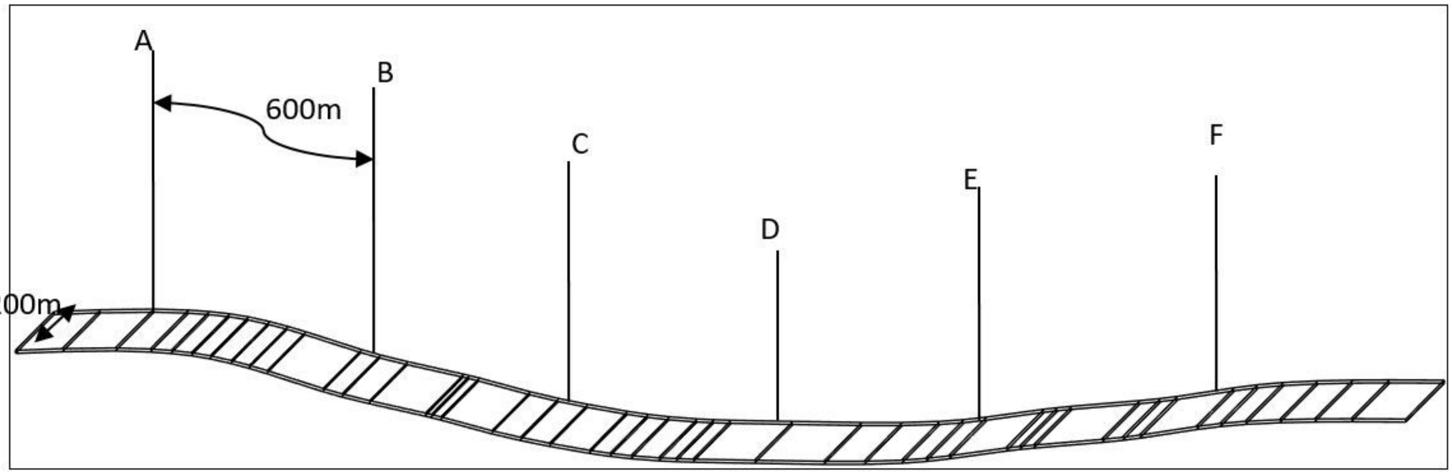

Figure 2

Topographical classification (Source: Eric et al., 2002)