EFFECTS OF *EPIGEAL TERMITARIA* PHYSIOGRAPHY, ALTITUDE AND LOCATION ON VEGETATION LIFEFORMS ABUNDANCE IN KATOLO SUB-LOCATION, KISUMU COUNTY, KENYA

BY

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DECLARATION

Declaration by the Student

I hereby declare that this thesis is my original work and that it has never been presented for award of any degree in any other University.

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DEDICATION

To my loving mother Mrs. Caren Oluoch and my brother Harrison Oluoch whom have accorded me boundless care, moral support and spiritual sustenance. My loving son Kelly and wife Christine, this is a special dedication to you. Mr. Joshua B. Adede (the late), my primary school teacher and source of academic realignment, this is for you.

ABSTRACT

Termite mounds differ in their physiography (basal radii and heights) as well as altitudinal locations and host more vegetation assemblages ascribed partly to their conducive physiography and possibly elevated nutrients levels. Large termitaria have been documented to support better fruiting of acacia trees and growth of mopane trees while hindering grass growth. However, physiographic description and modeling of how varying physiography of *epigeal termitaria* and altitude influence abundance of vegetation lifeforms (trees, shrubs, lianas and grass) has not been studied to support their conservation efforts within Katolo Sub-Location. The purpose of this study is to demonstrate variability in vegetation lifeforms abundance with epigeal termitaria physiography in order to support local conservation needs. The general objective is to find out how epigeal termitaria affect vegetation lifeforms. The specific objectives of this study were to: determine the influence of termite mounds physiography and altitude on vegetation lifeforms abundance; find out the influence of on-mound and off-mound locations on vegetation lifeforms abundance; and develop model for prediction of on-mound vegetation lifeforms abundance based on physiography and altitude. Study population was unknown. Cross sectional descriptive research design was used. Saturated sampling was used and where 60 termite mounds were studied. Basal radii of the mounds were measured using 50m tape measure and classed into three categories while mound heights were determined using 50m tape measure and/or hand-held inclinometer and classed. Altitude data were captured by hand-held GPS and categorized as lower, middle and upper. Trees, shrubs and lianas were identified visually and counted while grass was estimated using 0.3m by 0.3m quadrat. One way ANOVA was employed to determine significant differences in means of vegetation lifeforms abundance based on classes of termite mound physiography and location on and off-mound. Simple linear regression was used to determine magnitude of variation in vegetation lifeforms that could be explained by mound physiography differences. Multiple linear regressions were used to model vegetation lifeforms abundance based on termite mound basal radius, height and altitude. The results showed that radius was the best predictor of all vegetation lifeforms abundance except grass; ($F_{(1, 59)} = 185.77$, p=0.000) with $R^2_{adj.} = 0.76$, ($F_{(1, 59)} = 46.31$, p=0.000) with $R^2_{adj.} = 0.43$, ($F_{(1, 59)} = 164.39$, p=0.000) with $R^2_{adj.} = 0.73$ and ($F_{(1, 59)} = 1.41$, p=0.241) with $R^2_{adj.} = 0.01$ for trees, shrubs, lianas and grass respectively. ANOVA revealed that location significantly ($p \leq 0.05$) influenced all vegetation lifeforms with all except grass being more abundant on termite mounds than off-mound. A multiple regression model significantly ($p \leq 0.05$) predicted vegetation lifeforms abundance; trees $R^2_{adj.} = 0.83$, shrubs $R^2_{adj.} = 0.42$ and lianas $R^2_{adj.} = 0.74$ using termite mound basal radius, height and altitude. Weak R^2_{adj} for shrubs could probably be attributed to competition from trees or preference by short grazers though not tested in current study. This study concluded that termite mound physiography (basal radius, height) and altitude influence abundance of vegetation lifeforms (trees, shrubs and lianas) but not grass. The study recommends investigations into predominant plant and termite species within the study area to anchor the need for their conservation.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
dbh	Diameter at breast height
DPOP	Dilution Position of Precision
GPS	Global Positioning System
ha	Hectares
HIV	Human Immunodeficiency Virus
JICA	Japan International Cooperation Agency
KSS	Kenya Soil Survey
M	Mean
MLR	Multiple Linear Regression
SD	Standard Deviation
SLR	Simple Linear Regression

WORKING DEFINITION OF TERMS

Epigeal termitaria	Mounds built by termites and visible above the ground level within the study area
Physiography	Measured dimensions of the termite mound as basal radius and height
Vegetation lifeforms abundance	Number of individual vegetation lifeforms (trees, shrubs and lianas) as well as estimate of population of grass both on-mound and off-mound.
Trees	Perennial woody vegetation lifeforms with diameter at the base (10 cm above the ground or mound) greater than 6 cm as determined by sliding Vernier caliper and have heights above 3 m (determined by inclinometer)
Shrubs	Woody vegetation lifeforms with diameter at the base (10 cm above the ground or mound) less than 6 cm as determined by sliding Vernier caliper and have heights below 3 m (determined by inclinometer)
Lianas	Twining or climbing plants with relatively long stems which can be woody or herbaceous
Grass	Plants of Gramineae family which are mostly herbaceous.
On-mound	Visible raised ground serving as termite nest within the study area
Off-mound	Visible location within the study area which is between 20 and 80 m away from observable termite nest and on random direction between 1° and 360°

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CHAPTER ONE

INTRODUCTION

1.1.Background to the Study

Termite mound physiography and altitudinal locations have been observed to pose influence on vegetation cover with distinct abundance of individual plant species on-mounds compared to off-mound plots in old literature from Thailand (Pendleton, 1942) as well as in Australia and East of Amazonia (Salick, Herrera & Jordan, 1983; Coventry, Holt & Sinclair, 1988). The findings were later ascribed to their apt physiography (Holt & Lepage, 2000; Wolters, 2000; Batalha, Silva Filho & Martius, 1995). General substantiation of distinct preference of mound to off-mound plots by plants has been demonstrated. However, there is need to quantitatively upscale such findings to reveal overall vegetation lifeforms (trees, shrubs, lianas and grass) abundance across physiographic attributes of the mounds (basal radii and height) and locations both on-mound and off-mound savannah sites against altitudinal variations. This will provide scientifically informed conservation efforts with respect to their physiography.

Review of later contradicting findings in 2007 divulged reduced root biomass of plants at 0.05m depth on termite mounds compared to root biomass of off-mound plants; ascribed to moisture deficit of 5mm and mechanical impedance for root penetration (Ackerman, Wenceslau, Susan, Johannes & Erick, 2007). Recently, however, stem density of tree seedling species was unearthed to be higher within on-mound (389 seedlings) than off-mound plots (32 seedlings) in Malaysia (Beaudrot, Du, Rahman, Rajmanek & Harrison, 2011; Lamoureaux & O'Kane, 2012). They further reported that mean density of all trees was higher on-mound (0.794 stems m^{-2}) compared to off-mound plots (0.367 stems m^{-2}). These global studies have demonstrated existence of relationship between termites and their mounds with vegetation root biomass and woody plants stem density. However, there is need to explore how various physiographic attributes of termite mounds (basal radii and height) and altitude impel abundance of vegetation lifeforms (trees, shrubs, lianas and grass) in archetypal savannah biome. Termite mounds in Africa, as elsewhere across the globe, have been shown to have more woody species of vegetation lifeforms in comparison to open savannah as early as 1972 (Josens, 1972). That was later indorsed to abundance of nutrients such as N, P, K, Ca, Mg and Fe and better water holding capacity on termite mounds (Abbadie, Lepage & Le Raux, 1992). Suitability of termite mounds for plants' survival has also been ascribed to their building materials comprising top and sub soil, harvested organic matter, mucus and fecal matter from termites (Uys, 2002). Even mounds with steep physiography, on which plants may not establish successfully, are customarily scoured by wind and water and stanchion lush vegetation in their periphery (Grohmann, 2010). Rich building materials which can be eroded support plant life not only on the mounds but also in their edges following translocation of mound soils by erosional agents. It is however not clearly provided in previous studies how individual vegetation lifeforms on termite mounds would respond to mound physiographic changes such as tall mounds and mounds of large basal radii.

Soil chemical probes were later commissioned in order to determine how much nutrients (nitrogen) is found in mound soil compared to fixation by *Acacia drepanolobium* (Fox-Dobbs, Doak, Brody & Palmer, 2010; Seymour *et al.*, 2013). That study reported enhanced content of nitrogen in termite mounds compared to fixation by acacia trees. That finding accounted for the enhanced *A. drepanolobium* fruiting success near termite mounds compared to off-mound plots (Brody, Palmer, Fox-Dobbs & Doak, 2010). *Epigeal termitaria,* therefore, portray microhabitats of elevated biodiversity in tropical savannah ecosystems as shown in Benin state of West Africa (Kirchmair, Schmidt, Zizka, Erpenbach & Hahn, 2012). The studies (Kirchmair *et al.,* 2012) have majored on soil nitrogen investigations to explain single woody plant species establishment in a savannah ecosystem. Thus, there is dearth of quantitative information to account for individual vegetation lifeforms abundance with respect to termite mounds physiography. It was also necessary to develop a model for predicting vegetation lifeforms abundance based on termite mound physiography of which case one of the best ways is to use more than one independent variable in a multiple regression model (Basu & Lokesh, 2014; Koklu, Sengorur & Topal, 2010). Multiple linear regressions are statistical tools for understanding relationship between a dependent variable and one or more independent variables (Pathak, 2012; Pathak, 2013; Mustapha & Abdu, 2012; Mustapha & Aris, 2012). Regression models have been used in ecological and biogeographical studies of termite mounds including elucidation on termite mounds occurrence with respect to canopy cover, distance from forest edge and logging and stump removal as multiple explanatory variables in Nepal (Axelsson & Andersson, 2010). Earlier, it was demonstrated that species richness and relative abundance of termites in a lowland Sumatran ecosystem depended significantly on canopy, plant basal area, ratio of plant species richness to plant functional types and plant species richness (Gillison, Jones, Susilo & Bignell, 2003).

The models have well supported explanation of occurrence of termite mounds using several independent variables other than physiography and altitude of the mounds even when such are pertinent in vegetation lifeforms abundance on mounds. Thus, there is need to develop a model that would support prompt assessment of vegetation lifeforms abundance on termite mounds using physiography (basal radii and heights) and altitudinal location of the mounds since the properties are easy to determine.

Some of successful applications of multiple regression models in termite studies include determination of mortality rates of termites as a function of time and dose rates of fungal isolates that was conducted in Ethiopia (Abebe, 2002). In West Africa, a multiple regression model was later developed to predict yield of sorghum with respect to density of termite mounds, labor and acreage of sorghum fields as predictor variables (Ogoudedji, Nuppenau &

Korb, 2010). Simple linear regression models have also been used to determine the number of termite taxa as a function of latitude, altitude, mean annual precipitation and Simpson index of vascular plants (Grohmann, 2010). The studies displayed possibility of assessing termite mounds using regression models. Nonetheless, in the area under study, there has been no studies to create a model using physiography of termite mounds and altitude to predict vegetation lifeforms abundance in savannah ecosystem.

Elsewhere, clay content of mound soils was determined using regression model with Aluminium, Natrium, Kalium, Magnesium, Phosphorus, Titanium, Iron and Manganese as the independent variables (Grohmann, 2010). He exhibited that up to 78% of overall variation in the clay content was significantly explained by Al, Mg, Ti, Fe and Mn. Following the study which showed elevated moisture content in termite mound soils (Abbadie *et al.,* 1992) a regression model was recently developed to explain decline in moisture content with respect to distance from termite mounds (Sileshi, Arshad, Konate & Nkunika, 2010). In those studies, however, there was no attempt to demonstrate how vegetation lifeforms abundance varies with respect to physiography and altitude of the mounds. Development of a model to predict abundance of vegetation lifeforms using physiography of termite mounds would thus be necessary.

Termite mound studies in Kenya commenced by investigation of grass density around termite mounds where highest density of grass biomass was found within 5m buffer around the mounds (Arshad, 1982). Termite mound shapes in Kenya are primarily of two types; the ‘Bissel type’ and ‘Marigat type’ (Darlington, 1984). The ‘Bissel type’ are low and hemispherical in shape and penetrated with numerous vent holes while the ‘Marigat type’ mound is topped by a very tall chimney (Darlington, 1984). It was later shown that termites play a key role in generating patches of nutrient rich habitat important to the reproductive success of *A. drepanolobium* in

Laikipia plateau savannas (Brody *et al*., 2010). Recently, rates of tissue bait consumption by termites were assessed in Kakamega forest of Western Kenya and termites' abundance showed decreasing trend from primary forests to farmlands (Kagezi *et al.,* 2011). The studies have been varied from shapes description to *A. drepanolobium* studies and termites abundance assessments. Being ecosystem engineers, it is necessary to investigate how their nests influence vegetation lifeforms abundance at a local scale.

A comprehensive review of diversity, properties and ecological significance of fungus cultivated by termites across Kenya and Africa as a whole has been demonstrated (Kuja, Boga, Matiru & Makonde, 2014). To find out how chemical nutrients vary in termites, soil and mounds, analysis was done on guts, soils and mounds in Kenya for carbon and nitrogen elements (Muwawa, Makonde, Budambula, Osiemo & Boga, 2014). They realized higher concentration of nitrogen in the hind guts of termites and hence explaining nutrient richness on-mounds due to fecal matter secretion and use during mound constructions. Activities of termite mounds in Kenyan soils are indicating boost in the soils suitability for vegetation establishment. Therefore, there is need to investigate how varying physiographic characteristics of termite mounds would influence abundance of individual vegetation lifeforms in a typical savannah ecosystem.

1.2 Statement of the Problem

Termite mound surfaces and location influence numerous individual plant species within tropical and sub-tro1pical regions of the world. Physiography of termite mounds which has been shown to influence erosion from the termite mounds and disturb vegetation growth needs statistical investigation across vegetation lifeforms (trees, shrubs, lianas and grass). This study will therefore address the problem and compare both on-mound and off-mound locations on vegetation lifeforms abundance. Assessing vegetation lifeforms abundance is tedious both at species and ecosystem scales which has made most studies to look at individual species performance on-mound. This study therefore develops models for easier assessment of vegetation lifeforms which will enable better plant functional types' abundance assessment on termite mounds. The purpose of this study was therefore to find out the effect of *epigeal termitaria* physiography and altitude on vegetation lifeforms abundance within Katolo Sub-Location of Kisumu County which is a typical tropical savannah biome rich in vegetated termite mounds worth investigation.

1.3 Objective of the Study

To find out the influence of termite mounds on vegetation lifeforms in Katolo Sub-Location of Kisumu County.

1.3.1 Specific Objectives

1. To determine the influence of termite mound physiography (basal radius and height) and altitude on vegetation lifeforms (trees, shrub, lianas and grass) abundance
2. To find out the effect of locations on-mound and off-mound on vegetation lifeforms (trees, shrub, lianas and grass) abundance
3. To develop regression model using termite mound physiography (basal radius and height) and altitude in predicting vegetation lifeforms (trees, shrubs, lianas and grass) abundance

1.4 Research Hypotheses

Following the specific objectives above, the following three null hypotheses were proposed for statistical tests:

Ho_1: There is no significant influence of termite mound physiography (basal radius and height) and altitude on vegetation lifeforms (trees, shrubs, lianas and grass) abundance

Ho_2: There is no significant influence of on-mound and off-mound locations on vegetation lifeforms (trees, shrub, lianas and grass) abundance

Ho_3: Vegetation lifeforms (trees, shrubs, lianas and grass) abundance cannot be predicted from termite mound physiography and altitude.

1.5 Justification of the Study

In the overall food chain in savannah ecosystem rangelands, termites are categorized among the decomposers as they perform the duty of converting back dead flora and fauna into humus rich in nutrients for living vegetation (Okwakol, 1992). Even though physiography of termite mounds (basal radii and heights) as well as altitudinal location varies from one termite mound to the other, minimal comprehensive studies have explored how such variation would influence vegetation lifeforms abundance. Assessment of how different vegetation lifeforms abundance varies with different termite mound physiography would help both local community and scientific community to rapidly assess vegetation abundance in termite mound rich ecological regions.

According to Oindo, Skidmore & De Salvo, (2001), a central task in community ecology is to determine biophysical controls of species richness patterns. Physiography and vegetation composition of termite mounds are biophysical aspects of termite mounds that when meticulously assessed shall aid in the conservation of termites, their nests and understanding of vegetation lifeforms abundance abound. The study also anchors on the realization that up to 30 illnesses in West Africa could be cured by plant materials obtained from termite mounds. Termite mound soils also enhanced fertility of maize farms leading to increase in maize yields by over 33% in Zambia. Katolo Sub-Location of Kisumu County was selected for the study since it is a savannah ecosystem rich in termite mounds which appear to support better vegetation lifeforms abundance though no scientific research investigations have been done on them. Understanding how vegetation lifeforms vary across termite mounds would thus inform their conservation measures on scientific investigations ground. The model developed in this study will support rapid vegetation lifeforms assessment hence reducing on time and cost of conducting vegetation lifeforms abundance assessments and possibly be modified to suit assessment in other academic fields. Accomplishment of the study also forms crucial part of the requirements of degree of Master of Arts in Geography of Maseno University, Kenya.

1.6 Scope and Limitations of the Study

The study performed quantitative description of the effect of physiography of termite mounds on vegetation lifeforms abundance in Katolo Sub-Location of Kisumu County Kenya. It assessed physiography of termite mounds in terms of basal radii, heights and altitude while vegetation lifeforms were operationalized as trees, shrubs, lianas and grass. Termite mound moisture content, chemistry, humidity, temperature, porosity, hydraulic conductivity and organic matter content which could influence vegetation growth and development were regarded uniform across all studied termite mounds and not investigated in this study. All termite mounds studied assumed hemi-spherical shape. It was not logistically possible to establish the total number of termite mounds in the study area since such data has never been gathered. Hence, all the accessible termite mounds were sampled using saturated sampling. Findings of the study shall be applicable to savannah ecosystem biome of the study area and should be applied elsewhere with caution as a result of possible differences in species of termites, soil types of the area and time factor.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter gives details on termite mound physiography and vegetation lifeforms abundance, location on and off-mound and vegetation lifeforms abundance and regression modelling of termite mound physiography to explain vegetation lifeforms abundance.

2.2 Influence of Termite Mound Physiography (Basal Radius and Height) and altitude on Vegetation Lifeforms (Trees, Shrubs, Lianas and Grass) Abundance

Physiography of termite mounds has been shown globally to contemporaneously increase with the size of colony beneath the mounds necessitating widening of the nest hence accumulation of more soil particles on external architecture of the mounds (Lee & Wood, 1971). With respect to height, Lee and Wood, (1971) found out that some mounds could rise beyond 8m in Australia thus becoming unfavorable to support vegetation directly but through eroded materials. Conical shaped mounds in Argentina were later used to relate heights with altitudinal location and were approximately 0.68m in height and 0.65m in radius and were covered with rich vegetation (Laffont, Torales, Coronel, Arbino & Godoy, 2004).

Heterogeneity in floristic composition has been related to the influence of mounds on the distribution of woody species (Jouquet, Traoré, Choosai, Hartmann & Bignell, 2011; Moe, Mobæk & Narmo, 2009; Traoré *et al.*, 2008). Those studies have allotted use of physiography (height and radii) of termite mounds in assessing vegetation. However, quantitative investigation of effects of the physiography (basal radius and height) and altitude on abundance of vegetation lifeforms (trees, shrubs, lianas and grass) abundance has not been done within the current study area.

Regional studies across Africa have shown that living termite mounds in African savanna with large basal radii and heights have been reported to slash the extent of land available for grazing by reducing grass population (Okwakol, 1992). The physiography of these mounds are varied with some mounds being regarded as conical-shaped in Ghana and Zimbabwe (Dowuona *et al.*, 2012; Joseph, Seymour, G. Cumming, S. Cumming & Mahlangu, 2012), others cathedral in Nigeria (Abe & Wakatsuki, 2010) and some dome-shaped or hemispherical (Abe & Wakatsuki, 2010) similarly in Nigeria. There is elaborate description of the physiography of termite mounds from these studies. It, however, remains unclear how varying physiography of termite mounds would influence abundance of vegetation lifeforms.

Residents of Benin exploited mound heights to isolate *epigeal termitaria*; those below 1.2m pigeonholed as small mounds while those above 1.2m were cataloged as large mounds (Dossou-Yovo, Vodouhe & Sinsin, 2010). Efforts to relate termite mound heights with land use types such as farmlands and forest lands in Nigeria had been shown by Ekundayo and Orhue, (2011) revealing decline in height of termite mounds with intensity of land use types. Observation made by Gosling *et al*., (2012) in South Africa revealed that tall mounds, with small diameters and thus steep slopes were eroded more easily hence witnessed much disturbance on the existing vegetation thus supporting the earlier findings of Grohmann, (2010) in Namibia. Physiography of termite mounds has been noted elsewhere to be varied displaying different sizes, shapes and architectural complexities (Ali *et al.*, 2013). Studies of termite mound heights have shown decline in heights with intensity of land use and elevated fertility of mound peripheral soils following erosion of mound soils. Limited efforts have, however, been put to investigate abundance of vegetation lifeforms in totality across height, radii and altitude of the mounds which shall be the output of this study.

Adequate sample size of mounds to be used in investigating vegetation on them has been varied with Korb and Linsenmair, (1999) in their study on ventilation of termite mounds in Canberra Australia used a range of sample sizes; 72, 68, 60 and 54 based on the variables of interest for their study. Ackerman *et al.,* (2007) used only 21 termite mounds and matrix plots to investigate physico-chemical properties of termite mound soils. On the other hand, Dossou-Yovo *et al.,* (2010) relied on 60 termite mounds to study medicinal uses of plant species found on *epigeal termitaria* in the Pendjari biosphere reserve. There is evident variation in sample size of termite mounds appropriate in vegetation investigations and physico-chemical studies being more than 50 and about 20 respectively. This study, therefore, shall therefore capture as many termite mounds as possible within the study area by saturated sampling approach to investigate lifeforms (trees, shrubs, lianas and grass) abundance on them.

Grohmann, (2010) relied on 26 mounds to investigate habitat heterogeneity by termite mounds in Namibia. Fageria and Baligar, (2011) used 20 termite mounds to sample soils for determining response of rice and beans on their fertilization with mound soils as sources of NPK fertilizers. In their analysis of the phytodiversity on termite mounds in Northern Benin, Kirchmair *et al.,* (2012) used 57 termite mounds. Joseph *et al.,* (2012) used 98 termite mounds and 43 matrix plots to assess woody plants assemblages on them. From those studies, it is deduced that for chemical investigations or nutrient studies, the number of termite mounds was about 20 while for floristic studies it was over 50. In this study, therefore, a total of 60 termite mounds were studied to assess effects of *epigeal termitaria* physiography and altitude on vegetation lifeforms abundance in Katolo Sub-Location.

Termite mound shapes in Kenya were described by Darlington, (1984) to be of primarily two types; (the ‘Bissel type’ mound) being low and hemispherical in shape and penetrated with numerous vent holes, and (the ‘Marigat type’ mound) being topped by a very tall chimney.

Recent studies (Fox-Dobbs *et al*., 2010; Brody *et al*., 2010) within Kenya have primarily studied fruiting success of *A. drepanolobium* based on proximity to termite mounds (Brody *et al.,* 2010). Abundance of termites based on their consumption rates of tissue baits in Kakamega forest of Western Kenya has also recently been done (Kagezi *et al.*, 2011). Investigation of nitrogen and carbon content on-mound, savanna soils and guts of termites was recently achieved in Kenya (Muwawa *et al.*, 2014). The studies described shape of mounds, their suitability to *A. drepanolobium* establishment and abundance of termites neglecting vegetation abundance on mounds. Thus, there is need to find out relationship between termite mounds physiography and vegetation lifeforms abundance.

Katolo Sub-location is a typical savannah biome with numerous termite mound patches of varying physiography across the landscape with no prior documentation on how their physiography would influence vegetation lifeforms abundance (W. A. Oluoch, personal communication, October 10th, 2016). It is thus important to investigate whether there is any relationship between abundance of vegetation lifeforms and physiography of termite mounds in the area.

2.3 Effects of Location on and Off-mound on Vegetation Lifeforms (Trees, Shrubs, Lianas) and Grass Abundance

On-mound locations have been documented globally to be preferentially colonized by trees over the surrounding soils in Brazil (Ponce & Cunha, 1993). It is therefore possible that the enriched nutrient levels of the mounds positively affect the establishment of young trees on these mounds through soil disturbance (McComie & Dhanrajan, 1993). Studies by McComie and Dhanrajan, (1993) reported enriched nutrient levels in the internal chambers of *Macroterms carbonarius* mounds in comparison with adjacent open savanna soils. Later studies have revealed the positive impact of termite mounds on their surroundings, for example, Loveridge and Moe, (2004) and Ragnhild, Anne and Moe, (2005). However, the number of seedlings growing on termite mounds soils in an experimental study revealed that fewer seedlings grew on the mounds soils than on the surrounding savannah soils (Ackerman *et al*., 2007). These studies have given some evidence of richness of termite mounds for woody plants establishment. However, it remains unclear how individual vegetation lifeforms such as trees, shrubs, lianas and grass would vary in abundance across different physiographic characteristics of the mounds. A better understanding of how individual vegetation lifeforms would vary with respect to location (on-mound or off-mound) would thus be indispensable.

The preference to mound soils has been attributed to the proposition that termites contribute to the micro-topographical and nutrient heterogeneity of tropical milieu as portrayed by Beaudrot *et al*., (2011) in Malaysia. The study by Brody et al., (2011) revealed that overall tree stem density was higher on the termite mounds than on the nearby surrounding plots. Moreover, it was found that location on and off-mounds significantly influenced community composition when species were quantified by basal area (Ackerman *et al.,* 2007; Beaudrot *et al*., 2011; Gillison *et al.,* 2003) hence informing the need to investigate such physiographic attributes in relation to vegetation lifeforms (trees, shrubs, lianas and grass) abundance. These studies across the globe have demonstrated abundance of woody plants on termite mounds being more than off-mound plots. However, to better understand how location on-mound and off-mounds influence vegetation lifeforms abundance, it would be appropriate to look into the lifeforms as trees, shrubs, lianas and grass abundances and compare on-mound with off-mound sites.

Within regional scale of Africa, better soil physicochemical composition on-mound as compared to off-mound sites have been demonstrated without assessing abundance of vegetation lifeforms on them (Abe, Yamamoto & Wakatsuki, 2009; Deweer, 2014; Ekundayo & Orhue, 2011). For example, in the humid savannahs of West Africa, the density of woody species was found to be two to three times higher on *Macrotermes* mounds than in inter-mound areas (Abbadie *et al*., 1992). Early study in West Africa showed that plants from termite mounds play a great role among all environmental and social uses and almost 70% to 80% of the world populations use those plants for their primary healthcare (Cunningham, 1993; Hamilton, 2004; Grace, Nigro & Makunga, 2004) with over 30 illnesses being curable in Benin by termite mound extracted herbs (Dossou-Yovo *et al.,* 2010). Termite mounds are thus shown not only to be suitable sites for plants establishment but also as sites for rich medicinal vegetation. There is, however, need to show the influence of locations on and off-mounds on vegetation lifeforms (trees, shrubs, lianas and grass) abundance.

Specific soil conditions and the modification of the habitat by termites lead to a vegetation cover on the mounds that differ in density, composition and structure from the adjacent savanna (Smith & Yeaton, 1998). Termite mounds offer a better reservoir of soil water available for plants, especially in deeper soil horizons (Konaté, Le Roux, Tessier & Lepage, 1999). Mound soils have been used as fertilizers in some places such as Zambia due to their nutrient richness and physicochemical properties where they are applied once every 3 years and corresponding maize yield rise to the tune of 33% has been reported (Siame, 2005). On a savanna site in northern Burkina Faso, the density of trees and shrubs was five times higher (2859 ha^{-1}) on *Macrotermes* mounds compared with the inter-mound area (527 ha^{-1}) (Eldridge, Lepage, Bryannah & Ouedraogo, 2001). Lepage, Bryannah and Ouedraogo, (2001) realized that although the termite mounds covered only 2.7% of their study area, they supported 8.2% of the trees vegetation lifeforms on that site. This is probably because of the positive effect of mounds on woody plant establishment and recruitment through supply of more nutrients. Thus more needs to be done in order to fully understand individual vegetation cover both on-mound and off-mound in order to quantify any existing variation.

Contradicting studies have however shown that termite mounds of *Macrotermes* spp. contain only small amounts of nitrogen and phosphorus because they use materials from deep underground, hence, the termite mounds built by this genus are not suitable for vegetation lifeforms survival (Contour-Ansel, Garnier-Sillam & Lachaux-Ansel, 2000; Danilo, Michel, Jean & Michel, 2005; Duponnois, Paugy, Thioulouse, Masse & Lepage, 2005). On the other hand, *epigeal termitaria* are recognized as habitats for many plant species (Loveridge & Moe, 2004; Traoré *et al*., 2008). Savannah termite mounds in Africa have been documented to host specialist plant species (Sileshi *et al.*, 2010). Differing vegetation cover on termite mounds might have been attributed to differing species of termites as well as soil types and climatic factors. There is therefore need to find out the influence of on-mound vegetation lifeforms abundance with off-mound in order to clearly quantify the difference.

Termite mound soils are very important in myriad of uses such as in construction of houses (Yamashina, 2010; Deweer, 2014). Mound soils are also consumed by some expectant women during lactation to prevent health issues (Erens, 2010) and are well aerated due to termite galleries and tunnels underground hence supporting better plant survival during drought (Yamashina, 2010). Piglets with iron deficiency have also been noted to gain help when fed with red termite mound soils in Congo DRC as reported by Deweer, (2014). The studies are therefore showing great evidence of relevance of termite mounds for plants growth and development. However, how vegetation lifeforms (trees, shrubs, lianas and grass) abundance is affected by location on mound and off-mound has not been studied in the current study area.

Coupled with mineral nutrient richness (Joseph *et al.*, 2012), termite mounds would thus give denser vegetation lifeforms in the region under study. Significantly higher plant biomass on-mound than off-mound control savannah plots has also been shown by Grohmann (2010), Loveridge and Moe, (2004). Under semi-arid conditions, Yamashina, (2010) and Scott, (2000) found out that termites often construct their mounds under trees in order to shield their nests from heat and aridity in tropical regions. Soils sampled from termite mounds supported better vegetation life forms according to study by Gosling *et al.*,(2012).Plants that do not send their roots beyond 0.6 m into the soil have been reported to significantly respond to termitaria moisture availability in savanna ecosystem (Konate *et al.*, 1999). Nitrogen, phosphorus and organic matter have been shown to be higher on-mound than off-mound locations (Brody *et al.*, 2010, Kaschuk, Cesar, Almeida, Sinhorati & Berton-Junior, 2006) that could be ensuring better performance by trees on the *epigeal termitaria*.

By constructing passages through the mounds, termites improve aeration and drainage (Lal, 1987c). Better aerated and well drained soils are decisive factors for tree and shrubs vegetation, and the termites themselves benefit from the resultant constant moderate moisture conditions. Moe, (2009) also realized stability of forbs on the mounds as compared to the adjacent savanna. This resulted after fencing off the influence of herbivores; more forbs species were noted on the termite mounds while off the mound, up to 48% forbs species disappeared. Mounds therefore are better habitats for shrubs than off-mound savannah plots.

Earlier studies on on-mound and inter-mound sites in Kenya showed significant increase of vegetation on-mound as compared to inter-mound sites (Cox & Gakahu, 1985). A single notable study in Laikipia Kenya concluded that proximity to termite mounds, independent of herbivores and protection from ants, is the strongest predictor of fruiting success for *A. drepanolobium* (Brody *et al.*, 2010). Study by Brody *et al.*, (2010) also showed spatial heterogeneity that could be attributed to termite mounds. Even though the studies investigated mounds and *A. drepanolobium* success, there is no fully empirical investigation done on how location on and off-mound would influence vegetation lifeforms (trees, shrubs, lianas and grass) abundance. Therefore, there is a potential need for investigation of location on-mound and off-mound as a possible reason to micro-topographic heterogeneity in abundance of vegetation lifeforms (trees, shrubs, lianas and grass) within savannah ecosystems.

Selection of comparative corresponding off-mound plots have been achieved differently by different scholars, for example, Scott and Soar, (2008) decided on a distance of at least 15 m away from neighboring mound to compare temperature difference on-mound and off-mound. Termite mounds remained relatively cooler than off-mound sites indicating minimal influence of the studied mounds beyond 15m away. Moe *et al.,* (2009), on the other hand, used random distance of between 20 m and 80 m away from the studied termite mound to reduce influence of mound soils in Uganda and realized four times more woody plant species on-mound than off-mound sites investigated.

Abe *et al*., (2009) in Nigeria sampled sites greater than 2 m away from the mounds and realized that soil morphological alterations by termites were not visible at such a distance. Grohmann, (2010) in Namibia picked sites ranging between 10 m and 50 m away from nearest termite mound and found that even though there were significant difference between mound nutrients and off mound nutrients, there was no significant difference off-mounds at distances 1, 5 and 25m from the mound. Ekundayo and Orhue, (2011) chose corresponding off-mound sites to be areas greater than 3 m away from studied mound in Nigeria and observed enhanced bulk density and clay content on-mounds compared to off-mound sites.

Dowuona *et al.,* (2012) in Ghana opted for sites between 5 m and 35 m away from mounds to assay a range of termite mound soil physical and chemical properties and noted significant difference in hydraulic conductivity. Recently, Gosling *et al.,* (2012) in South Africa used sites greater than 20 m away noting that presence of termite mounds influences grassland mosaics. Joseph *et al.,* (2012) studied termite mounds in Zimbabwe and relied on sites above 10 m away where it was found that through termite activities in concentrating nutrient and clay, termitaria provide habitat for species usually excluded from matrix plots. The latest study by Mbah *et al.*, (2014) opted for 50 m away from studied mounds to be adequate for corresponding off-mound plots selection in Nigeria where it was shown that termite mounds improved soil physico-chemical properties and heavy metal content. In this study, therefore, a random number generator, RANDBETWEEN function, was invoked in Microsoft Office Excel 2010 to identify random distance between 20 m and 50 m away from the nearest termite mound. In case the distance fell in an inaccessible site, another randomization was done. Inaccessible sites included fenced compounds with no access permission granted.

2.4 Regression modelling of termite mound physiography and altitude to explain vegetation abundance

Multiple linear regressions is a statistical tool for understanding relationship between a dependent variable and one or more independent variables (Basu & Lokesh, 2014; Koklu *et al.*, 2010; Mustapha & Abdu, 2012; Mustapha & Aris, 2012; Pathak, 2012; Pathak, 2013). Normally, regression model is given in the form: $Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_m X_m + \varepsilon$ where Y represent the dependent variable; $X_1, ..., Xm$ represent the several independent variables; $\beta_0, ..., \beta_m$ represent the regression coefficients and; ε represent the random error (residuals). The regression formula is therefore suitable for assessing vegetation lifeforms abundance since it can combine variables of different measurement units. Therefore, termite mound physiography and altitude can be modeled in the equation to explain abundance of vegetation lifeforms on termite mounds.

Regression model has been used in studies of termite mounds including explanation of termite mounds occurrence with canopy cover, distance from forest edge and logging and stump removal as multiple explanatory variables in Nepal (Axelsson & Andersson, 2010). In West Africa, a model was developed to predict yield of sorghum with respect to density of termite mounds, labor and acreage of sorghum fields as predictor variables (Ogoudedji *et al.*, 2010). Earlier, in another study, Cox regression models were used to determine mortality rates of termites as a function of time and dose rates of fungal isolates (Abebe, 2002). Regression models were run elsewhere to determine the number of termite taxa as a function of latitude, altitude, mean annual precipitation and Simpson index of vascular plants (Grohmann, 2010). Even though environmental parameters such as canopy cover and altitude have been used in developing regression models in termite mound studies, limited models have used physiographic attributes of termite mounds (basal radii and heights) and altitude to predict vegetation lifeforms (trees, shrubs, lianas and grass) abundance. There is thus need to fill the gap by developing a model using physiography of termite mounds to explain vegetation lifeforms abundance.

Clay content of mound soils was determined using regression model with Aluminium, Natrium, Kalium, Magnesium, Phosphorus, Titanium, Iron and Manganese as the independent variables (Grohmann, 2010). Results showed up to 78% of overall variation in the clay content being explained by Al, Mg, Ti, Fe and Mn in the equation: % Clay = -7.0 + 6.4Al – 0.8Mg – 11.0Ti + 1.3Fe – 3.9Mn. In order to explain the moisture retention of soils with distance from termite mound, Sileshi *et al.,* (2010) developed a regression model which showed declining moisture retention ability of soil with distance from the base of termite mound; $Y = 21.219x^{-0.206}$, R^2=0.871. The studies are showing possibility of using both soil physical and chemical properties to carry out investigations on termite mounds. Accordingly, there have been limited attempts in literature to model vegetation lifeforms (trees, shrubs, lianas and grass) abundance on termite mounds using various physiographic characteristics of the mounds as predictor variables. This study therefore shall develop a model using termite mounds basal radii and heights and altitude to predict vegetation lifeforms (trees, shrubs, lianas and grass) abundance on termite mound.

2.5 Conceptual framework

The study used a conceptual framework which presents the variables into measurable units hence facilitated collection of data. Independent variables were physiography of the termite mounds (basal radius and height) and altitude and location (on- and off-mound). Vegetation lifeforms (trees, shrubs, lianas and grass) abundance was the dependent variables (Figure 2.1).

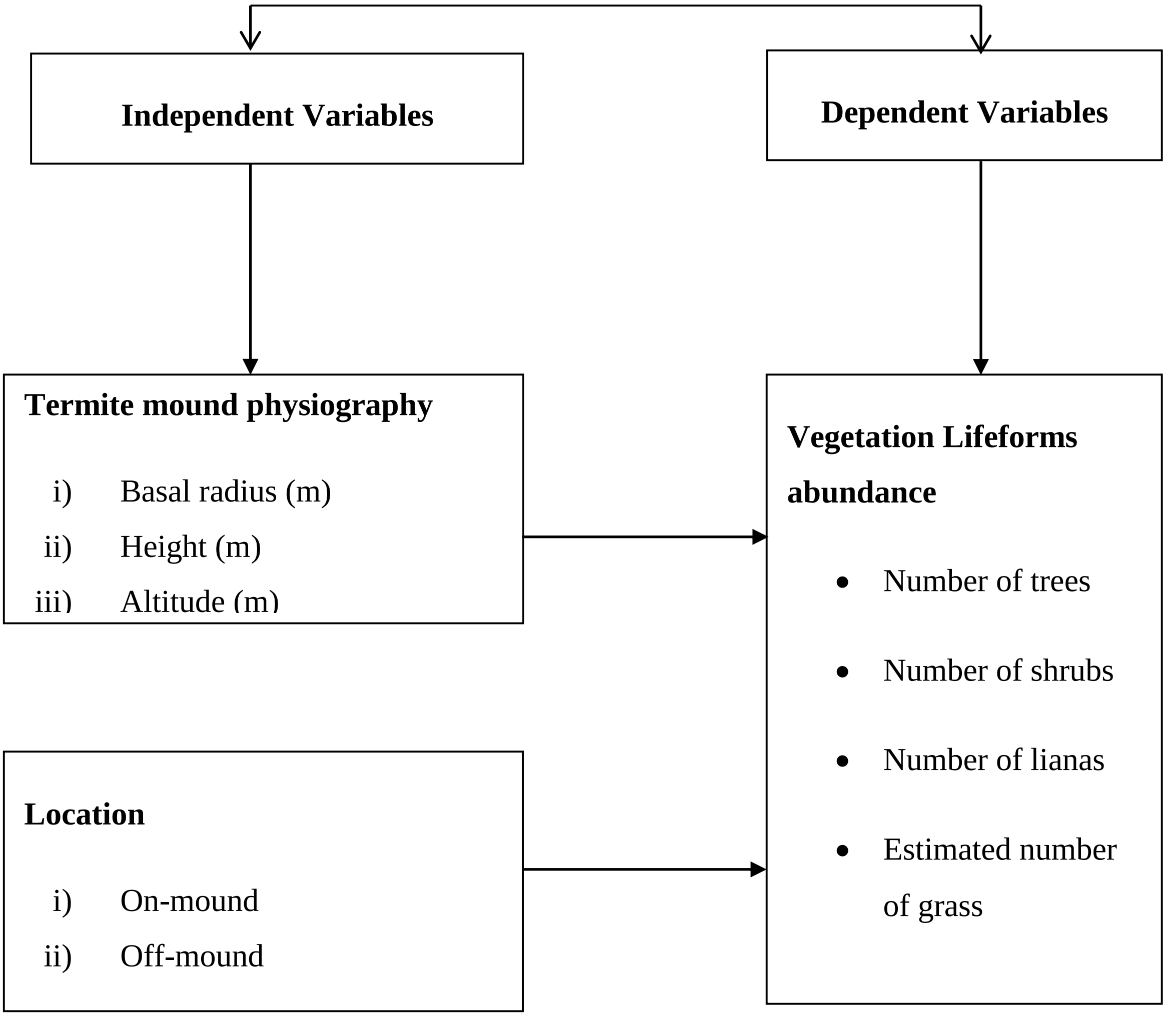

Figure 2.1: Effects of Epigeal termitaria physiography (basal radius and height) and altitude on vegetation lifeforms (trees, shrubs, lianas and grass) abundance

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter presents information on the research methodology that was employed in data collection, analysis and presentation. This chapter looked at the study area, research design used, primary methods of collecting data and the data analysis tools.

3.2 Study Area

Katolo Sub-Location is located within Kano Plains centered at latitude 0^0 14′ S and longitude 35^0 00′ E with altitude ranging from 1150 m on the lowest Western end to 1240 m to the Eastern end bordering Kapsarok Sub-Location of Rift Valley Province (Figure 3.1). Katolo Sub-Location is a savanna grassland area that lies in the Eastern part of large lowland surrounding the Nyanza Gulf, much of it being in Kano Plains (Kenya Soil Survey, 1990).

Even though the topography is generally flat, there are several scattered termite mounds that appear as "topographic accidents". Being a plain, many studies in this area have focused on rainfall run-off modeling (Rwigi, Opere & Mutua, 2010), gully erosion along the river banks (Kenya Soil Survey, 1990) and education standards (Okuom *et al*., 2012). However, *epigeal termitaria* appear to display richer assemblages of flora that look patchy from one *termitarium* to the other in the study area; usually more visible during the dry season where they stand out as greener patches than their savannah surroundings (O. Wyclife, personal communication, March 4, 2016); yet lack in documentation so far. Limited studies have been done on the effects of *termitaria* physiography (basal radii and heights) and altitude on vegetation lifeforms (trees, shrubs, lianas and grass) abundance in the area, yet.

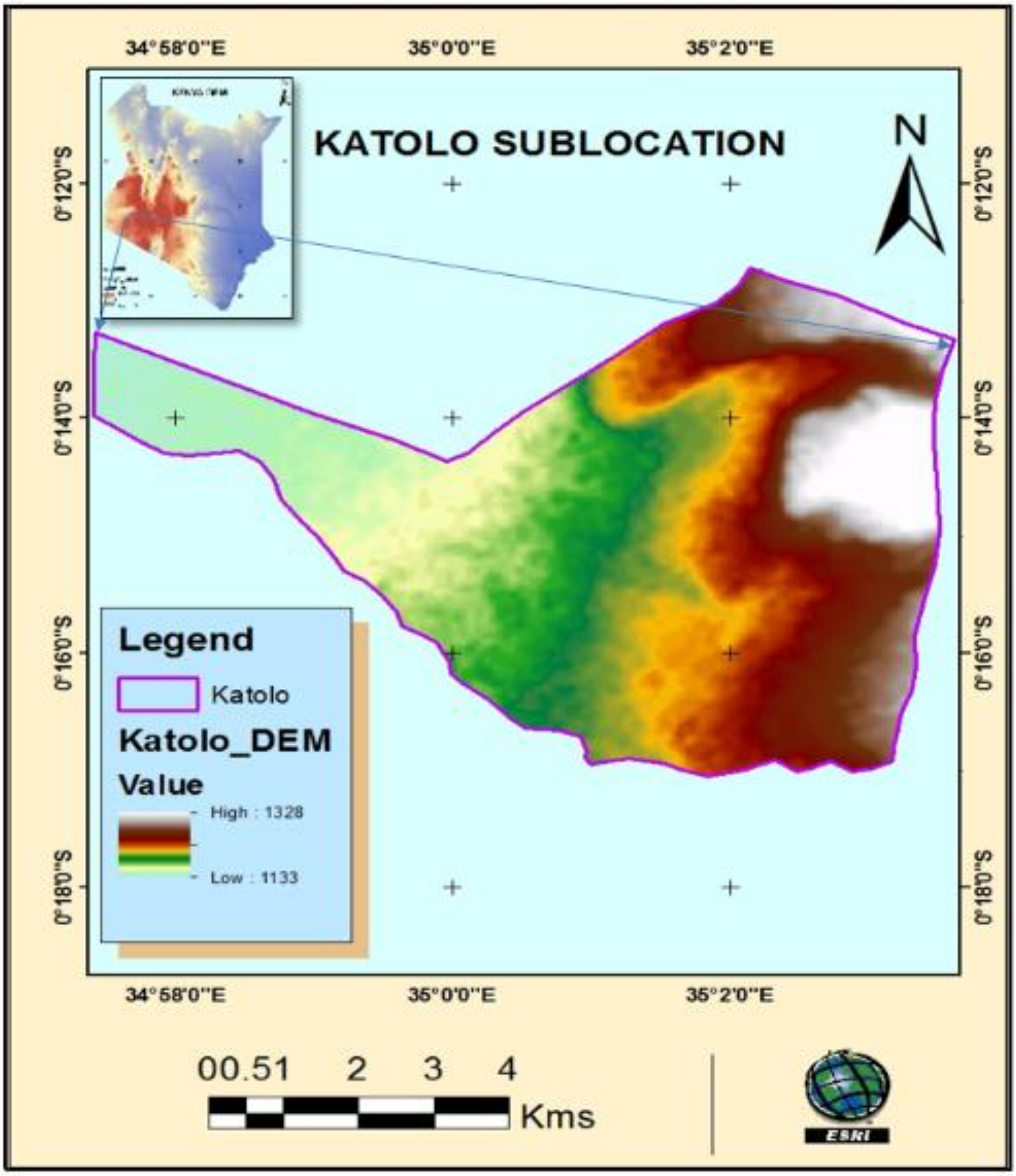

Figure 3.1: Study Area with inset map of Kenya. (*Source*: Developed in Esri's ArcGIS 10.1, using SRTM digital elevation model)

3.2.1 Climate, Soil, Topography, Drainage and Vegetation of the Study Area

The area receives long rains in the month of May and short rains normally come in September (Okuom, Simatwa, Olel & Wichenje, 2012). Mean annual rainfall in the area is 1200mm (Yamane, Asanuma & Umenaura, 2015) with mean annual temperature being 31°C (Nyasimi *et al.,* 2007). These enhanced visisbility of mounds during drought to aid sampling. The area comprises of black cotton soils with moderate fertility and poor drainage ("Food Security District Profile", 2004) classified as vertisols and crack during drought and flood in rainy seasons (Nyasimi *et al.*, 2007). The topography of the study area is predominantly plain to the West and altitude increases towards the East bordering Kericho County.

The drainage of the area is poor due to the predominant black cotton soils with water logging characteristics (Nyasimi *et al.,* 2007). There are few seasonal streams including Awach bordering Southern end of the study site. The termite mounds could therefore be enhancing the infiltration of water into the soils hence boosting drainage of the study area.

The major vegetation in the area include *Acacia drepanolobium*, *Acacia tortilis*, *Cholla cactus,* Sycamore fig, *Candelubrum spurge*, *Cynodon dactylon* grass. These characterized a typical savannah biome on which termite mounds predominate hence informed the execution of the study within the area.

3.2.2 Population and Livelihood of the Study Area N

The area has large rural population, 75%, and the stage of economic growth is undermined by high absolute poverty, poor infrastructure and the HIV pandemic (Swallow, Onyango & Meinzen-Dick, 2005; JICA, 2007). Livestock rearing (cattle, sheep and goats) and crop farming (maize, sorghum, beans and assorted local vegetables) dominate the area (Nyasimi *et al.*, 2007). Vegetation growing on termite mounds are regarded as good for browsing by the livestock and hut construction within the area (Village Elder, Personal Communication, October 10th, 2016).

3.3 Research Design

A cross-sectional descriptive research design was used in this study. The design was employed because it allowed for studying of the termite mounds in their current situation at the time of study. The design allowed for future detailed investigation on key variables studied (trees, shrubs, lianas and grass as well as basal radii, heights and altitude of the termite mounds) and gave opportunity to gather in-depth information about the variables. This was an appropriate method for this study since the units of analysis; termite mounds, vegetation lifeforms and off-mound sites were already in the study area and could be studied within a short span of time.

3.4 Study Population and Sampling

Study population of termite mounds was unknown. Saturated sampling was used to sample humanly accessible termite mounds and equal number of corresponding off-mound plots. Inaccessible termite mounds included those inhabited by bees and those located in homesteads or private lands with no permission granted by the owners during this study. The number of studied mounds was regarded adequate following the studies of Korb and Linsenmair, (1999) who relied on 68 termite mounds, Dossou-Yovo *et al.,* (2010) who used 56 mounds and Kirchmair *et al.,*(2012) who used 57 termite mounds all of whom were assessing vegetation diversity on termite mounds.

In this study, termite mounds were selected randomly provided they fell within the study area of Katolo Sub-location. Starting termite mound for sampling was chosen randomly based on the convenience to the researcher and its location within the area of study following the work of Beaudrot *et al.*, (2011). Captured Global Positioning System (GPS) (Global Mapper, Japan) coordinates helped in avoiding repetitive sampling of the already studied termite mounds.

3.5 Data Collection Methods

Data used in this study were obtained between December, 2016 and March, 2017. Primary data collection methods adopted were observation, measurement, counting and recording. These methods were appropriate for the data collection because the data to be collected could be obtained by measurement (height, radius and altitude), counting (trees, shrubs and lianas), observation (termite mounds and off-mound sites) and quadrat (estimate of grass population).

3.5.1 Determination of Termite Mound Radius

A 50 m tape measure was wound round the base of every sampled termite mound to find out the circular distance round it (basal circumference, c_b). The circumference was then subjected to the following formula to get the basal radius, r_b, of the termite mound: $r_b = c_b / 2\pi$. The formula was applied as adopted from Scott, (2000).

3.5.2 Determination of Termite Mound Height

A 50 m tape measure was used to quantify termite mound height (m) by holding it vertically adjacent to the termite mound walls and vertical rise observed by the researcher. In case where the termite mound was taller than the researcher, inclinometer was used alongside simple trigonometric ratios to determine exact mound heights: $H = h + d \tan\theta$, where H is the termite mound height (m), h is the height of the observer (m), d is the distance from the centre of the termite mound to observer (m) and θ is the angle of elevation (in degrees) of the top of the mound from the horizontal line of sight of the researcher.

3.5.3 Determination of Termite Mound Altitude

Altitude of the termite mounds was determined using hand-held Global Positioning System (GPS) and given in metres only when Dilution Distance of Precision (DPOP) was less than 1m to boost precision.

3.5.4 Determination of Off-mound Plots Location

RANDBETWEEN function was invoked in Microsoft Office Excel 2010 to generate random bearing (1°-360°) and distance (20m – 50m) from centre of termite mounds to control off-mound plots. Whenever the corresponding off-mound plot landed in an inaccessible area, repeated randomization was done until an accessible site was found. RANDBETWEEN function eliminated subjective selection of off-mound plots. A distance of between 20 and 50 m lowered the chances of effect of termite mound on the selected off-mound site. The procedure had previously been used (Moe *et al.,* 2009; Joseph *et al.,* 2012; Mbah *et al.,* 2014).

3.5.5 Determination of Corresponding Off-mound Plot Radius

Using the radius of the termite mound, a hemispherical surface area of the mound was determined. The area was equivalent to the area of corresponding off-mound circular plot hence used to obtain the radius of the off-mound plot. The number of off-mound plots were equal to the number of termite mounds studied.

3.5.6 Determination of Trees, Shrubs, Lianas and Grass Abundance on and Off-mound

Trees were counted by two observers and actual population obtained by averaging the results of the two observers. Counting of shrubs and lianas was done as in the case of trees. Due to labor intensity of counting individual grass throughout the mound or off-mound plots, a 0.3m by 0.3m quadrat was used to estimate the population of grass on every termite mound and corresponding off-mound plots. The quadrat was thrown onto every termite mound randomly and grass within the quadrat was/were counted. That was done thrice on every termite mound to obtain average number of grass per termite mound after multiplying the average quadrat value by the area of the whole mound and dividing by the quadrat area. Adoption of quadrat method followed the works of Kaspari *et al.,* (2014) and Beaudrot *et al.,* (2011).

3.6 Data Analysis and Results Presentation

Radii of the termite mounds were classified into three classes according to values obtained as: small (< 1.6 m), inter-mediate (1.6 - 2.1 m) and large (> 2.1 m), following the procedure of Joseph *et al.,* (2012). Heights of the termite mounds were categorized into three classes based on the height values obtained (Short, < 0.68 m; Medium, 0.68 – 0.99 m; Tall, > 0.99 m) as adopted from Grohmann, (2010). Altitude was also categorized into three classes as Lower (< 1175 m), middle (1175 m –1205 m) and upper (> 1205 m) above sea level as captured by GPS.

Every class of mound physiography (basal radius, height and altitude) had 20 representative termite mounds selected for one way ANOVA of mean differences in corresponding vegetation lifeforms (trees, shrubs, lianas and grass) abundances in MSTAT-C (Version 2.10) statistical package. Duncan's Multiple Range test was used to separate means based on Least Significant Differences (LSD) values obtained.

Of the 60 termite mounds and 60 corresponding off-mound plots studied, 20 were categorized randomly in each group leading to three replicates thus constituting adequate set for ANOVA in MSTAT-C (Version 2.10) programme. All corresponding vegetation lifeforms (trees, shrubs, lianas and grass) abundances were subjected to analysis of variance and significant differences in group means were separated using Duncan's Multiple Range Test based on the Least Significant Differences (LSD) values obtained.

Four multiple linear regression models with vegetation lifeforms (trees, shrubs, lianas and grass) abundance as dependent variables and termite mounds physiography (basal radius, height and altitude) as independent variables were developed in Statistical Package for Social Sciences (SPSS, Version 16.0, Microsoft Inc.) programme. Models gave the best predictions that were tested for significance at $p \leq 0.05$.

3.7 Reliability and Validity

Lincoln (1930) and Petersen (1986) model (two samples) was used to improve reliability of the data. The model is suitable since it involves only two individuals to carry out the sampling of the vegetation lifeforms to arrive at individual count. It embraces test-retest method of ascertaining reliability as shown below:

$$\widehat{\mathrm{N}} = \frac{\mathrm{n}_1 * \mathrm{n}_2}{\mathrm{m}^2}$$

where n_1 is the number of individuals observed by sampler 1, n_2 is the number of individuals observed by sampler 2 and m^2 is the square of the number of individuals observed by both of the observers. $\widehat{N}$ cannot be less than 1 neither can it be negative. The closer it is to 1 the more reliable the data is; the upper limit is infinite.

On the other hand, validity of the data collection instruments and results were verified by the professionals in the department, primarily supervisors of the thesis.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents results of the analyzed data. It begins by giving effect of termite mound physiography (basal radius and height) and altitude on vegetation lifeforms (trees, shrubs, lianas and grass) abundance. That is then followed by results on effects of location on-mound and off-mound on vegetation lifeforms abundance and lastly a model to predict vegetation lifeforms abundance with respect to termite mound physiography (basal radius and height) and altitude.

4.2 Effects of Termite Mound Physiography (Basal Radius and Height) and Altitude on Vegetation Lifeforms (Trees, Shrubs, Lianas and Grass) Abundance

Variations in termite mound basal radii significantly ($p \leq 0.05$) influenced vegetation lifeforms (trees, shrubs, lianas and grass) abundance (Table 4.1). Small termite mounds (radii < 1.60 m) had significantly ($p=0.000$) lower mean number of trees, shrubs, lianas and grass abundance (Table 4.1). Large termite mounds (radii >2.1 m) had the largest abundance of vegetation lifeforms except grass which was most abundant among medium sized mounds (radii 1.60 m – 2.10 m) (Table 4.1).

Variation in termite mound heights showed no significant (p) effect on abundance of vegetation lifeforms (trees ($p=0.862$), shrubs ($p=0.661$), lianas ($p=0.459$) and grass ($p=0.581$)) investigated (Table 4.1). Among the studied vegetation lifeforms, only trees abundance responded significantly ($p=0.034$) to variations in altitude (Table 4.1). There was however no statistically significant ($p \leq 0.05$) difference among shrubs ($p=0.756$), lianas ($p=0.125$) and grass ($p=0.873$) abundance across various altitudinal classes studied (Table 4.1).

Table 4.1: Effects of termite mound physiography (basal radii, height) and altitude on vegetation lifeforms abundance (trees, shrubs, lianas and grass). NS stands for Not Significant, LSD stands for Least Significant Difference

Termite mound physiography	**Vegetation lifeforms abundance**					
	Class	**Number (*n*)**	**Trees**	**Shrubs**	**Lianas**	**Grass**
Basal radii (m)	**Small (<1.60)**	*20*	4.60 (±3.12)	10.40 (±4.96)	4.65 (±2.65)	811.40 (±250.88)
	Medium (1.60-2.10)	*20*	13.85 (±5.63)	15.15(±3.76)	10.55 (±4.25)	1497.70 (±815.05)
	Large (>2.1)	*20*	28.45 (±6.44)	27.45 (±6.38)	17.70 (±3.41)	939.65 (±605.91)
LSD$_{(P\leq0.05)}$			**2.71*****	**3.10*****	**1.91*****	**397.94****
Height (m)	**Short (<0.68)**	*20*	16.15 (±12.15)	18.95 (±9.77)	9.55 (±7.23)	1005.85 (±800.20)
	Moderate (0.68-0.99)	*20*	16.25 (±8.48)	17.70 (±8.22)	12.05 (±4.12)	1213.05 (±638.35)
	Tall (>0.99)	*20*	14.50 (±12.28)	16.35 (±8.24)	11.30 (±7.04)	1029.85 (±535.90)
LSD$_{(P\leq0.05)}$			**NS**	**NS**	**NS**	**NS**
Altitude (m)	**Lower (<1175)**	*20*	12.90 (±11.00)	16.50 (±9.81)	10.45 (±6.64)	1035.20 (±659.36)
	Middle (1175-1205)	*20*	13.10 (±10.84)	18.60 (±9.36)	9.20 (±6.43)	1067.65 (±484.04)
	Upper (>1205)	*20*	20.90 (±9.59)	17.90 (±6.93	13.25 (±5.30)	1145.90 (±827.75)
LSD$_{(P\leq0.05)}$			**6.94***	**NS**	**NS**	**NS**

Identified increase in trees, shrubs and lianas abundance with increase in termite mounds basal radii (Table 4.1) could be attributed to their widened surface area hence providing larger nutrient rich surface area to support better growth and development vegetation. All vegetation lifeforms (trees, shrubs, lianas and grass) showed reduced abundance on small radii mounds (Table 4.1) which could be attributed to limited surface area for their better establishment. It was also observed that most of the small radii termite mounds were still young and could then possibly have minimal influence on vegetation lifeforms abundance. Decrease in grass abundance on large radii mounds (Table 4.1) could be supported by the fact that such mounds had higher trees abundance which shaded the ground beneath due to shadowing effect hence minimal conducive conditions for establishment of grass.

Heights of termite mounds did not differ with wider margins as was the case with radii of the mounds (Table 4.1). Therefore, any significant differences in vegetation lifeforms abundance could not be discerned based on heights (Table 4.1) probably due to minimal height differences across the studied mounds. With respect to altitude of the termite mounds, only trees varied significantly (p=0.034) across the termite mound altitudinal locations (Table 4.1). Shrubs, lianas and grass showed no significant differences across altitudinal gradients with p-values of 0.756, 0.125 and 0.873 respectively. Upper altitude areas could probably be minimally affected by seasonal flooding in the area allowing for better trees establishment. The lower altitude areas on the other hand (Table 4.1) probably had least vegetation cover following seasonal flooding hence poor conditions for establishment of trees.

These findings were consistent with those of Josens, (1972) who identified large termite mounds as richer sites for plant colonization. It follows that larger radii termite mounds could be old enough to provide richer accumulation of nutrients to boost vegetation lifeforms and enhanced water holding capacity as was reported by Abbadie *et al.*, (1992). As was recently demonstrated, large radii mounds could be hosting richer plant-available nitrogen nutrient to enhance vegetation lifeforms establishment (Brody *et al*., 2010; Fox-Dobbs, *et al.,* 2010). These findings are, however, different from those of Maduakor, Okere and Onyeanuforo, (1995) who reported reduced vegetation cover on termite mounds. They, however, studied termite mounds in utisols of Nigeria hence variation in soils could inhibit vegetation cover.

Termite mound heights could not explain vegetation lifeforms abundance as was demonstrated elsewhere that it is only until tall mounds splinter and get eroded that they support lush vegetation in the surrounding soils (Grohmann, 2010). Splintering and erosion of tall mounds by various erosional agents such as wind and water to support vegetation establishment in the open savannah was also noted in South Africa (Gosling *et al*., 2012; Grant & Scholes, 2006). Preference of large termite mounds by vegetation had also earlier been reported by Konate, Le Roux, Tessier & Lepage, (1998). In this study, however, the heights of the termite mounds were quite uniform that no significant difference in vegetation lifeforms abundance could be obtained on them statistically.

Decline in trees abundance in low altitude could be explained by seasonal flooding allowing for better tree colonization of termite mounds in the high altitude areas as opposed to lowland areas as was found elsewhere by de Oliveira, (1992). It is, however, noted that different classes of altitude could significantly affect trees abundance. Similar findings were demonstrated by Grohmann, (2010) who demonstrated significant linear relationship between vegetation and altitude. Khan, W., Khan, S. & Ahmed (2015) realized similar findings when it was found that woody vegetation abundance varied significantly with altitude. A new realization in this study is that only trees could respond significantly (p=0.34) to altitudinal variations while others; shrubs (p=0.756), lianas (p=0.125) and grass (0.873) did not respond significantly to altitude.

4.2.1 Simple Linear Regression Summary of Relationship between Termite Mound Physiographic Characteristics and Vegetation Lifeforms Abundance

Overall termite mounds physiography (radii, heights) and altitude were subjected to simple linear regression analysis with vegetation lifeforms (trees, shrubs, lianas and grass) abundance on them. Results obtained were as follows:

There was a significant (p=0.000) linear positive relationship between termite mound radii and trees abundance ($F_{(1, 59)} = 185.77$, p = 0.000) with $R^2_{adj.} = 0.76$ (Table 4.2). This is indicating that up to 76% of variation in trees abundance on termite mounds could be explained by change in radii. The remaining 24% could probably be due to other variables influence vegetation growth such as soil nutrients, moisture availability and predation. There was also statistically significant ($p \leq 0.05$) positive linear relationship between termite mounds radii and shrubs abundance ($F_{(1, 59)} = 46.31$, p = 0.000) with $R^2_{adj.} = 0.43$ (Table 4.2). Herbivore and browsers preference of termite mound vegetation could probably account for the 53% variation in shrubs abundance on the termite mounds. Lianas abundance on termite mounds also showed significant ($p \leq 0.05$) positive linear response to termite mounds radii ($F_{(1, 59)} = 164.39$, p = 0.000) with $R^2_{adj.} = 0.73$ (Table 4.2). Up to 73% variation in lianas abundance could be explained by variation in termite mound radii in the study area. The remaining 23% could be influenced by other factors prevailing in the area such as environmental factors and human influence on the savannah vegetation. However, there was no significant ($p \leq 0.05$) linear relationship between termite mound radii and grass abundance in the study area ($F_{(1, 59)} = 1.41$, p = 0.241) with $R^2_{adj.} = 0.01$ (Table 4.2).

Table 4.2: Simple linear regression results of termite mound physiography (radii and heights) and altitude on vegetation lifeforms (trees, shrubs, lianas and grass) abundance

Physiography	*Lifeforms*	*Adj. r^2*	*df*	*F*	*p-value*	*Intercept*	*Coefficient*
Radii	**Trees**	76%	F(1,59)	185.77	0.000	-5.49	10.54
	Shrubs	43%	F(1,59)	46.31	0.000	4.87	6.38
	Lianas	73%	F(1,59)	164.39	0.000	-0.95	5.94
	Grass	1%	F(1,59)	1.41	0.241	857.79	112.27
Heights	**Trees**	-1%	F(1,59)	0.26	0.609	17.28	-1.86
	Shrubs	2%	F(1,59)	1.98	0.165	21.19	-3.98
	Lianas	-1%	F(1,59)	0.28	0.598	9.99	1.10
	Grass	-2%	F(1,59)	0.00	0.963	1091.92	-10.18
Elevation	**Trees**	-2%	F(1,59)	0.06	0.804	205.46	0.74
	Shrubs	-1%	F(1,59)	0.44	0.509	-12.99	0.03
	Lianas	4%	F(1,59)	3.19	0.079	-47.18	0.05
	Grass	10%	F(1,59)	7.36	0.009	-133.51	0.13

Variation in termite mound radii significantly ($p \leq 0.05$) influenced the abundance of trees ($p=0.000$), shrubs ($p=0.000$) and lianas ($p=0.000$) but not grass ($p=0.241$).

As was the case with ANOVA on termite mound height classes (Table 4.1), linear regression analysis revealed no statistically significant ($p \leq 0.05$) relationship between termite mounds heights and all vegetation lifeforms abundance in the study area (Table 4.2). Non-statistically significant ($p \leq 0.05$) regression values obtained with respect to termite mound heights were ($F_{(1, 59)} = 0.26$, $p = 0.609$) with $R^2_{adj.}$ of -0.01, ($F_{(1, 59)} = 1.98$, $p = 0.165$) with $R^2_{adj.}$ of 0.02, ($F_{(1, 59)} = 0.28$, $p = 0.598$) with $R^2_{adj.} = -0.01$and ($F_{(1, 59)} = 0.00$, $p = 0.963$) and an $R^2_{adj.}$of -0.02 for trees, shrubs, lianas and grass abundance respectively (Table 4.2). This is implying that merely -2% of variability in grass abundance could be explained by termite mound heights.

Explanation of vegetation lifeforms (trees, shrubs, lianas and grass) abundance with altitude as predictor variables in linear regression models showed that there was a statistically significant ($p \leq 0.05$) positive linear relationship between grass abundance and altitude ($F_{(1, 59)} = 7.36$, $p = 0.009$) with $R^2_{adj.} = 10\%$ (Table 4.2). Trees, shrubs and lianas showed no statistically significant ($p \leq 0.05$) relationship with altitude, ($F_{(1, 59)} = 0.06$, $p = 0.804$) with $R^2_{adj.}$ of -2%, ($F_{(1, 59)} = 0.44$, $p = 0.509$) with r^2 of -1% and ($F_{(1, 59)} = 0.3.19$, $p = 0.079$) with $R^2_{adj.} = 4\%$ respectively.

Proposed null hypothesis is therefore rejected based on the findings indicating existence of significant influence epigeal *termitaria* physiography (basal radius and height) and altitude on vegetation lifeforms abundance (trees, shrubs, lianas and grass) abundance within Katolo Sub-Location. Third objective will develop the best fitting model for prediction of vegetation lifeforms abundance in the study area.

Termite mound physiography therefore significantly influenced vegetation lifeforms abundance as was found elsewhere (Ackerman *et al.*, 2007; Beaudrot *et al.,* 2011). Such findings showed that existence of termite mounds in ecosystem improved diversity of vegetation which was also reported by Lamoureux and O'Kane, (2012). Larger termite mounds were also reported in Benin to harbor richer assemblages of medicinal plants by Dossou-Yovo *et al.,* (2010). In this study, however, distinct boundary is derived on which individual vegetation lifeforms could be explained by varying physiography of termite mounds.

Density of termite mounds explained up to 89% variation in dense thicket in a study in Uganda (Moe *et al.,* 2009). The study also reported that vegetation which thrived on termite mounds survived better even during fire outbreaks in the open savannah supporting abundance of vegetation lifeforms in termite mounds of larger radii. Consistent with other studies, it was found that height of termite mounds did not significantly influence abundance of vegetation lifeforms studied. Tall termite mounds have been shown to get eroded by splintering of their peaks to support richer establishment of vegetation in their periphery (Ali *et al*., 2013).

Termite mounds have been shown to be more humid, hold richer nutrient levels and have well drained soils (Konate *et al.,* 1999; Mahaney *et al.,* 1999) which in turn supported better plants especially in mounds of larger radii. Konate *et al.,* (1999) had also demonstrated preference of large termite mounds by plants within savannah ecosystem. Succulent vegetation normally occupies taller termite mounds better since they get opportunity to escape forest fires in the savannah ecosystems (Kirchmair *et al.,* 2012; Perez-Garcia & Meave, 2006). However, in this study, height of termite mounds did not significantly affect lianas abundance. This could probably be explained by minimal incidences of forest fires in the study area since it is settled by people.

4.3 The Influence of Location On-mound and Off-mound on Vegetation Lifeforms (Trees, Shrubs, Lianas and Grass) Abundance

This section of the thesis is concerned with presentation of results from the analysis of vegetation life forms including trees abundance, shrubs abundance, lianas abundance and grass abundance with respect to locations on-mound and off-mound. Results of the findings have been presented in tables and narrations.

There was statistically significant ($p \leq 0.05$) difference in abundance of trees, shrubs and lianas on-mound compared to off-mound sites (Table 4.3). On-mound location displayed more trees, shrubs and lianas than off-mound plots (Appendix 13-14). Grass abundance was however significantly more off-mound compared to on-mound plots (Table 4.3).

Table 4.3: Effects of on-mound and off-mound locations on vegetation lifeforms abundance. LSD means Least Significant Difference

Location	Vegetation lifeforms abundance (Mean ±SD)			
	Trees	Shrubs	Lianas	Grass
On-mound	^{a}15.63 (±11.14)	^{a}17.67(±8.84)	^{a}10.97(±6.38)	^{a}1082.92(±673.48)
Off-mound	^{b}2.00 (±1.88)	^{b}8.67(±5.80)	^{b}0.67(±1.55)	^{b}7309.37(±7652.95)
LSD$_{(p\leq0.05)}$	**2.82*** **	**2.83*** **	**1.62*** **	**1943.16*** **

*Means with the same letter down the column are not significantly different at ($p\leq0.05$) according to Duncan's Multiple Range Test (DMRT). *** Significant at $p\leq0.001$. ±SD is positive or negative standard deviation value from mean.*

There is evidence that trees within the study area grow more on on-mound locations compared to off-mound locations. The finding agrees with that of Beaudrot *et al.,* (2011) who found that mounds had significantly higher tree stems (>1 cm dbh) than areas immediately surrounding mounds. Scott (2006) further asserted that trees associated with termite mounds showed greener appearance compared to those on off-mound savannah plots during dry seasons implying availability of moisture to sustain their establishment. Establishment of large trees with taller structure on mounds have been reported elsewhere (Fleming & Loveridge, 2003; Joseph *et al.,* 2011; Traoré *et al.,* 2008) since they create sub-canopy microclimate which enhance establishment of more woody species as was reported in preceding studies (Belsky & Canham, 1994; Dean, Milton & Jeltsch, 1999).

Brody *et al*, (2010) noted that *A. drepanolobium* growing adjacent to termite mounds were significantly more likely to produce fruits than those growing farther away from mound edges: About 30.7% of those trees growing adjacent to a mound produced fruits, while only 13.9% of those growing further away from a mound fruited. The presence of a termite mound therefore plays a key role in enhancing trees growth and development. Trees have been reported elsewhere to preferentially colonize termite mounds (Ponce and Cunha, 1993; Yamashina, 2010).

Increased abundance of shrubs on termite mounds mimic those by Pomeroy (1976) who realized that termite mounds covered with and often completely hidden under dense shrub and tree vegetation occur in both dry and seasonally flooded savannahs. In both savannah types, the physical and chemical properties of the soil of the termite mounds provide more favorable growing conditions to trees and shrubs compared to the surrounding grasslands with scattered trees and shrubs (Mbah *et al.,* 2014; Moe *et al.*, 2009).

There was over 16 times more lianas on-mound than off-mound study sites (Table 4.3). Implication of this was that lianas tended to colonize raised grounds to reach for light as well as obtained the nutrient richness in the *epigeal termitaria* which was shown by Brody *et al.,* (2010). The findings are in line with those of Kirchmair *et al.,* (2012) who reported that succulents, geophytes and lianas were more on termite mounds than off-mound sites. Open savannah plots are normally rich in grass which normally have weaker stems and may not adequately support successful support to weak stemmed lianas. The lianas therefore tended to grow more on raised termite mounds where there are richer trees populations to offer adequate support to them.

Grass tended to grow in the open flat grounds to on-mound locations (Table 4.3). Significantly ($p \leq 0.05$) higher individual grass count was recorded off-mound than on mound plots according to the findings of Grohmann, (2010) in Namibia. The noted higher abundance of grass off-mound compared to on-mound is in agreement with the several other works (Uys, 2002; Lobry de Bruyn & Conacher, 1990) who reported that termites forage on tall grass layers hence minimizing the population of grass on-mound in comparison to off-mound plots. Jouquet, Tavernier, Abbadie & Lepage (2005), Lavelle (1997), Holt and Coventry (1990) and Coventry *et al.,* (1988) reported nutrient contribution of eroded mound materials into the savannah to release nutrients as part of the termite mounds importance. Contradiction emanates from the works of Elkins (1986) who reported complete disappearance of predominant grass following removal of subterranean termites in Chihuahuan desert following a chain of changes in soil physical properties.

Location on-mound and off-mound significantly affected population of all the vegetation lifeforms (trees, shrubs, lianas and grass) studied as had earlier been shown (Dossou-Yovo *et al.,* 2010; Joseph *et al.,* 2012; Yamashina, 2010). Apart from grass, all other lifeforms (trees, shrubs and lianas) were significantly higher in abundance on-mound than off-mound control plots, mimicking the findings of Sileshi *et al.,* (2010). The implication is that mounds formed perfect niches for establishment of majority of the plant materials probably as a result of richness in highly needed nutrients.

As to the null hypothesis that there is no statistically significant difference in vegetation lifeforms abundance on-mound and off-mound locations, there is enough evidence to reject the null hypothesis. Therefore, location on and off-mound significantly ($p \leq 0.05$) influenced abundance of vegetation lifeforms with trees, shrubs and lianas being more abundant on-mound than off-mound plots probably due to favorability of the mound physiography (radii, height) and altitudes and possibly nutrient contents.

4.4 Regression Model of Vegetation Lifeforms Abundance Using Termite Mound Physiography and Altitude as Predictor Variables

Three independent variables of termite mound physiography (basal radius, height) and altitudinal location were used to develop a predictive regression model. Prior to model development, a test for collinearity was done among the variables. The test for collinearity was meant to leave out independent variables that were significantly correlated. Test results showed that none of the variables were significantly ($p \leq 0.05$) correlated with each other (Table 4.4) hence all were used to develop a predictor model for the various vegetation lifeforms abundance.

Table 4.4: Spearman's test for collinearity results indicating non-significance among the independent variables

	Basal radii	**Heights**	**Altitude**
Basal radii	1.000	NS	NS
Heights	0.135	1.000	NS
Altitude	0.153	-0.023	1.000

Key: NS-Non Significant at p≤0.05

A multiple regression model to predict trees abundance on termite mounds was developed at 95% confidence level with $F_{(3, 57)} = 94.77$, $p = 0.000$) with adjusted r^2 of 0.83. The relationship gave the following regression equation:

Predicted trees abundance = -89.2587 + 10.46157 (radius (m)) – 4.96989 (height (m)) + 0.074074 (altitude (m)).

On the other hand, shrubs abundance on termite mounds could also be modeled with a statistically significant ($p \leq 0.05$) linear relationship with physiographic attributes of termite mounds and altitude in a multiple regression model ($F_{(3, 57)} = 20.21$, p = 0.000) with adjusted r^2 of 0.49. The relationship gave the following regression equation:

Predicted shrubs abundance = 19.26065 + 6.780626 (radius (m)) – 6.09157 (height (m)) – 0.00822 (altitude (m)).

Lianas abundance was also significantly ($p \leq 0.05$) explained by variation in termite mound physiographic attributes and altitude ($F_{(3, 56)} = 56.18$, p = 0.000) and adjusted $r^2 = 0.74$. The regression model equation which could help to estimate lianas abundance within the study area was found to be:

Predicted lianas abundance = -24.9345 + 5.881659 (radius (m)) – 0.68423 (height (m)) + 0.020729(altitude (m)).

The last vegetation lifeform investigated was grass abundance which did not show significant response to variation in termite mound physiographic attributes and altitude ($F_{(3, 56)} = 0.47$, p = 0.706) with an adjusted $r^2 = -0.03$. An equation to support prediction of abundance of grass on the termite mounds studied was:

Predicted grass abundance = 676.4303+ 114.0194 (radius (m)) – 45.1003 (height (m)) + 0.182634 (altitude (m)).

The significant ($p \leq 0.05$) association between various *epigeal termitaria* physiographic attributes and vegetation lifeforms abundances together with multiple regression equations obtained could help in predicting abundance of vegetation lifeforms in Katolo Sub-Location.

This application of multiple linear regression models to predict vegetation lifeforms abundance borrowed from the work by Axelsson and Andersson (2010) in Nepal who modeled termite mounds occurrence based on canopy cover, distance from forest edge, logging and stump removal. The concept equally followed the study by Oguededji *et al.*, (2010) who modeled sorghum yield based on termite mounds density, labor and acreage as predictor variables.

Mortality rates of termite mounds had also been presented elsewhere by Abebe, (2002) to depend on time and dose of fungal inoculation. Grohmann, (2010) gave a multiple regression model of predicting termite mound taxa based on altitude, latitude, precipitation and Simpson's index of vascular plants. There have also been great efforts to explain termite mounds based on latitudinal extents (Baxton, 1981; Zeidler, 1997). They have shown that altitude influence rainfall patterns hence indirectly regulating the abundance and diversity of termites especially in the southern Africa region.

Earlier studies which have relied on modelling of termite mounds gave significant relationship between the mounds with altitude as well as canopy cover of the forests (Axelsson & Andersson, 2010). The study did not however capture the important termite mounds physiographic aspects such as basal radius and height which are addressed in this study. The models developed could explain better the existence of trees, shrubs and lianas but not grass as had been shown elsewhere (Erpenbach, Bernhardt-Romermann, Wittig, Thiombiano & Hahn, 2013; Moe *et al.,* 2009; Traoré *et al.,* 2008). Loveridge and Moe, (2004) equally realized minimal grass existence on termite mounds hence supporting the weakness in using a regression model in prediction of abundance of such vegetation lifeforms. However, all other vegetation life forms could be explained by the model developed.

As was the study of Brody *et al.,* (2010), determinant of grass distribution or density on termite mounds remained unclear. Scarcity of grass vegetation lifeforms on termite mounds (Okwakol, 1992) could be some of the reasons for the difficulty of their prediction. Grohmann, (2010) pointed out erosion of the termite mounds to result in lush vegetation in the surrounding matrix savannah plots support pasture development which could explain grass distribution. This study has however gave a new model for explaining vegetation lifeforms abundance based on basal radius, heights and altitudinal location of termite mounds. These findings are therefore supporting rejection of the null hypothesis since there is a significant relationship between termite mound physiographic attributes and vegetation lifeforms abundance in Katolo Sub-Location.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter of the thesis presents summary of the findings of the study, gives conclusions, recommendations and suggests areas that need further research.

5.2 Summary of the Findings

Physiography of *epigeal termitaria* conceptualized as basal radius and height and altitude affected vegetation lifeforms (trees, shrubs, lianas and grass) abundance significantly ($p \leq 0.05$) in different ways. Basal radii of the termite mounds significantly influenced trees ($p=0.000$), shrubs (0.000), lianas (0.000) and grass (0.0032). Heights of the termite mounds did not significantly influence trees ($p=0.862$), shrubs (0.661), lianas (0.459) and grass (0.581). Altitude of the termite mound only affected abundance of trees significantly ($p=0.034$) but not shrubs ($p=0.756$), lianas ($p=125$) and grass (0.873). Termite mounds with large basal radii had the highest vegetation lifeforms abundance while termite mound heights could not be used to explain vegetation lifeforms abundance. Lower altitude areas had the least trees abundance; however, all other vegetation lifeforms were not affected by changes in altitude.

It was found out that on-mound location significantly ($p \leq 0.05$) displayed higher abundance of trees, shrubs and lianas than off-mound savannah plots in the study area. This implied that these vegetation life forms tended to occupy primarily termite mounds as opposed to off-mound savanna plots. Grass abundance, however, displayed a different scenario; higher grass abundance was found off-mound than on-mound locations. Grass preferentially established off-mound savannah plots than on the termite mounds.

Multiple linear regression models significantly predicted vegetation lifeforms abundance on termite mounds based on basal radius of the mounds, height and altitudinal locations as predictor variables. These models were able to predict vegetation lifeforms abundance (trees, shrubs and lianas) significantly but not grass.

5.3 Conclusions

The study concludes that variations in vegetation lifeforms (trees, shrubs, lianas and grass) in Katolo Sub-Location could be explained by termite mound basal radius. This is implying that termite mounds with larger basal radii in the study area had equally more abundant vegetation lifeforms. Height of termite mound in the study area cannot produce noticeable effect on vegetation lifeforms abundance hence cannot be used in estimating vegetation lifeforms (trees, shrubs, lianas and grass) in Katolo Sub-Location. Termite mounds in high altitude areas within the study area had more abundant trees but altitude per se could not be used to assess other vegetation lifeforms abundance.

On-mound sites were more suitable for three vegetation lifeforms abundance (trees, shrubs and lianas). Grass abundance was however noted to be more off-mound than on-mound. Termite mounds provide more suitable plant establishment sites in savannah than off-mound plots. However, for the purpose of grass establishment, off-mound plots would be preferable.

Multiple linear regression models predict vegetation lifeforms (trees, shrubs and lianas) abundance within Katolo Sub-Location. This could be a more rapid method to carry out assessment of vegetation lifeforms (trees, shrubs and lianas) abundance on termite mounds within the study area.

5.4 Recommendations

Within the study area, termite mound radii should be used to support assessment of vegetation lifeforms abundance within savannah ecosystems except grass.

The study recommends more elaborate conservation of termite mounds within the study area since they are richer in various vegetation lifeforms (trees, shrubs and lianas).

Finally, the study recommends the use of developed regression models using termite mounds basal radii, heights and altitude to predict vegetation lifeforms (trees, shrubs and lianas) abundance on termite mounds within the study area.

5.5 Suggestions for Further Studies

Further studies are recommended in the study area to investigate physico-chemical properties of the termite mounds soils. This will boost the appropriateness of developed regression models in explaining vegetation lifeforms abundance on-mound.

It would also be interesting to conduct a qualitative research on perceived societal relevance of the termite mounds. This will strengthen the need for their conservation as embraced by the residents of the study area.

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APPENDICES

APPENDIX 1

Observation and recording form

1. Termite mound serial number ……………………….

2. Latitude:…………………………Longitude…………………..Altitude……………m

3. Mound height:…………………………m

4. Mound basal circumference:…………………m

5. Approximate radius of the mound…………….........(m)

6. Estimate control plot radius………………………………………………………(m)

7. On-mound trees abundance:

   Enumerator 1 (T_1)…………………………………...Trees

   Enumerator 2 (T_2)…………………………………..Trees

   Average number of trees= $\frac{T_1+T_2}{2}$ …………………….....Trees

8. On-mound shrubs abundance

   Enumerator 1 (S_1)…………………………………...Shrubs

   Enumerator 2 (S_2)…………………………………..Shrubs

   Average number of shrubs= $\frac{S_1+S_2}{2}$ ……………………Shrubs

9. On-mound lianas abundance

   Enumerator 1 (L_1)…………………………………...Lianas

   Enumerator 2 (L_2)…………………………………..Lianas

   Average number of lianas= $\frac{L_1+L_2}{2}$ ……………………Lianas

10. On-mound grass abundance:

   Quadrat 1(Q_1) ………………………………….

   Quadrat 2(Q_2) ………………………………….

   Quadrat 3(Q_3) ………………………………….

Average = $\frac{Q_1+Q_2+Q_3}{3}$ ……………………………………

On-mound grass abundance= $\frac{Average \times SurfaceArea}{0.09}$ =…………………………..

11. Off-mound trees abundance

Enumerator 1 (T_1)…………………………………...Trees

Enumerator 2 (T_2)…………………………….……Trees

Average number of trees= $\frac{T_1+T_2}{2}$ ……………………....Trees

12. Off-mound shrubs abundance

Enumerator 1 (S_1)…………………………………...Shrubs

Enumerator 2 (S_2)…………………………….……Shrubs

Average number of shrubs= $\frac{S_1+S_2}{2}$ ……………………Shrubs

13. Off-mound lianas abundance

Enumerator 1 (L_1)…………………………………...Lianas

Enumerator 2 (L_2)…………………………….……Lianas

Average number of lianas= $\frac{L_1+L_2}{2}$ ……………………Lianas

14. Off-mound grass abundance

Quadrat 1(Q_1) ……………………………………

Quadrat 2(Q_2) ……………………………………

Quadrat 3(Q_3) ……………………………………

Average = $\frac{Q_1+Q_2+Q_3}{3}$ ……………………………………

Off-mound grass abundance= $\frac{Average \times SurfaceArea}{0.09}$ =……………

APPENDIX 2: Mound radii spatial distribution

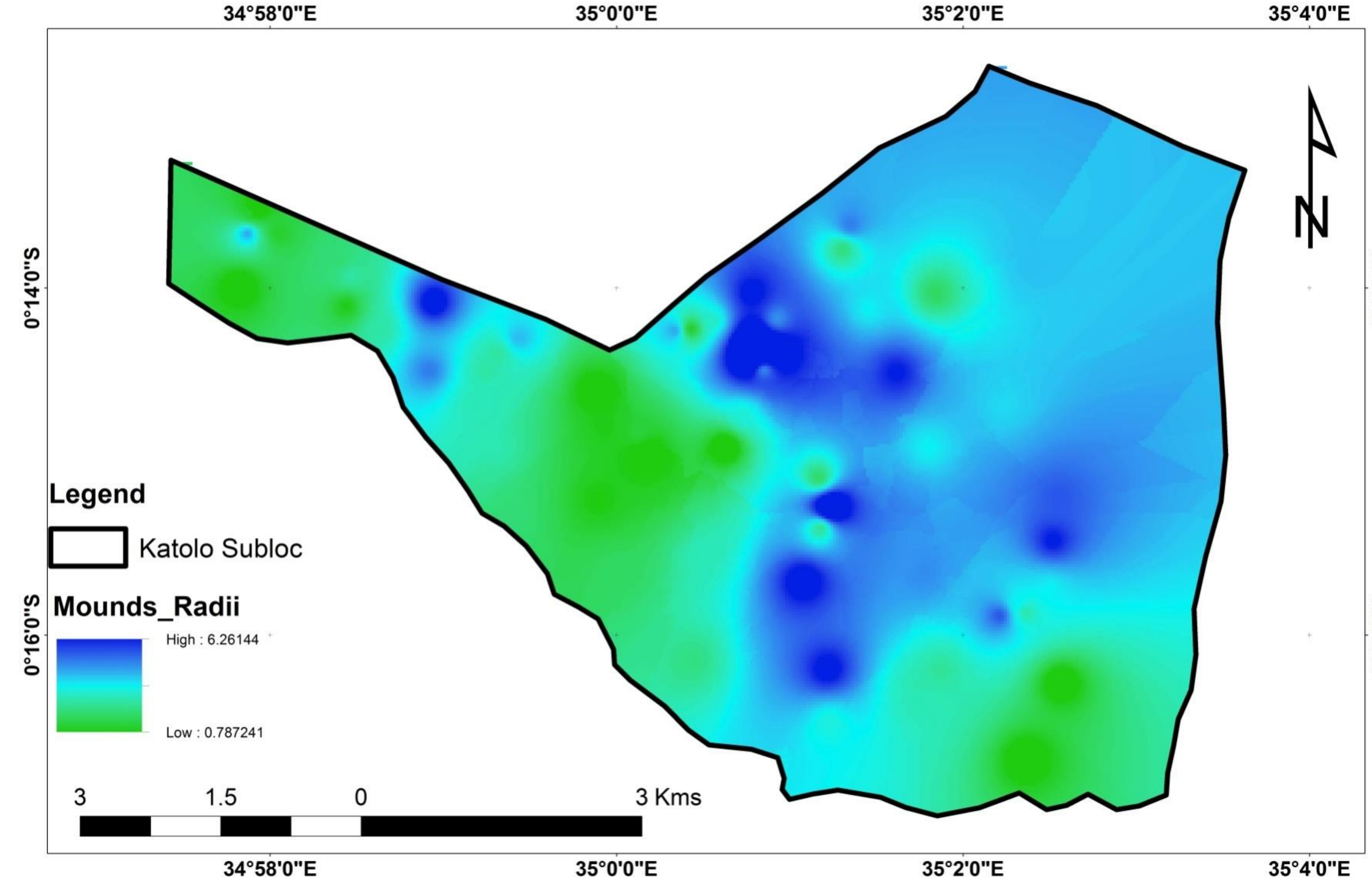


Plate 1: Spatial distribution of termite mound radii

APPENDIX 3: Mound height spatial distribution

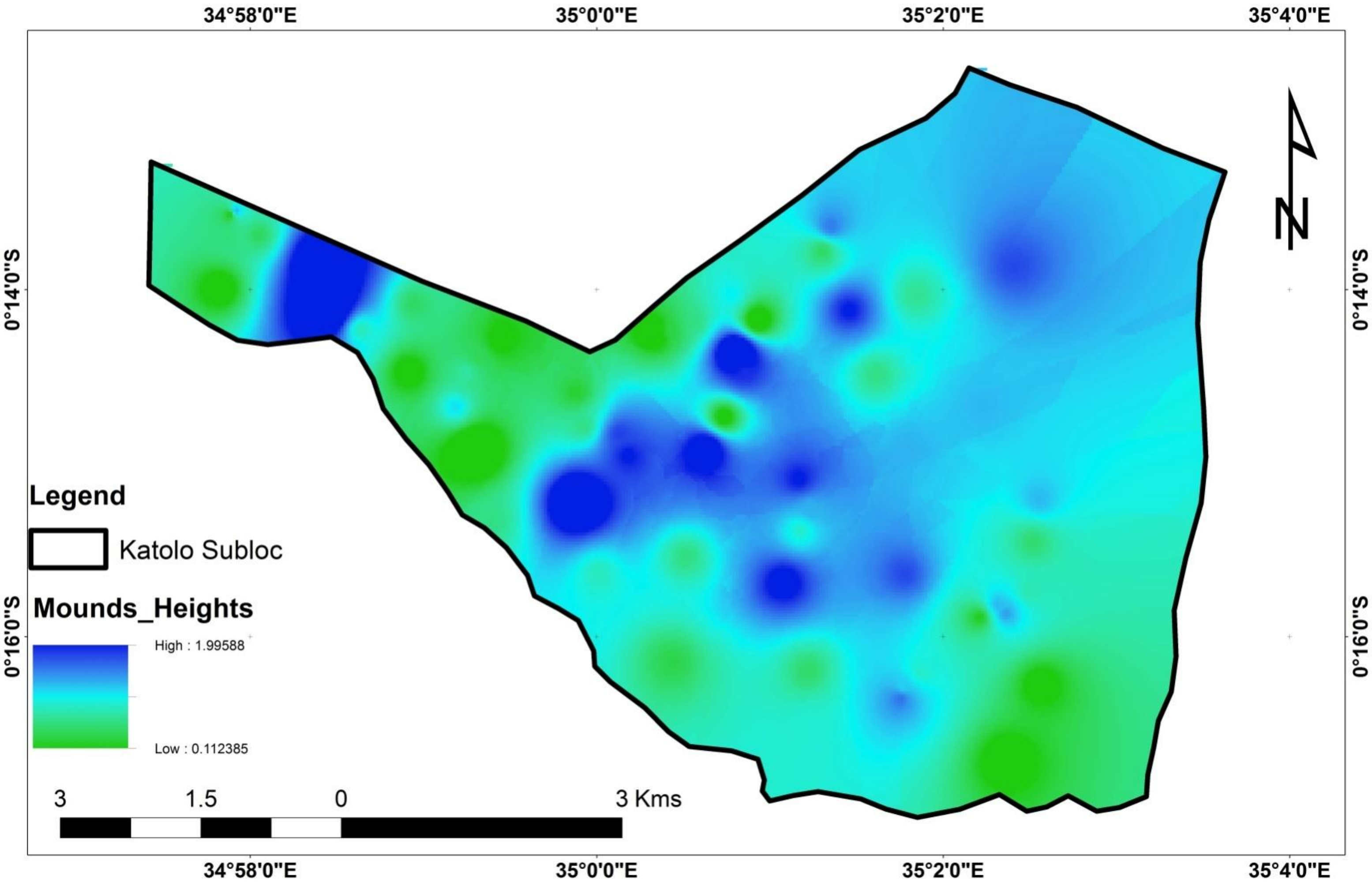


Plate 2: Spatial distribution of termite mound heights

APPENDIX 4: Interpolated Elevation Model of the study area based on 60 GPS points

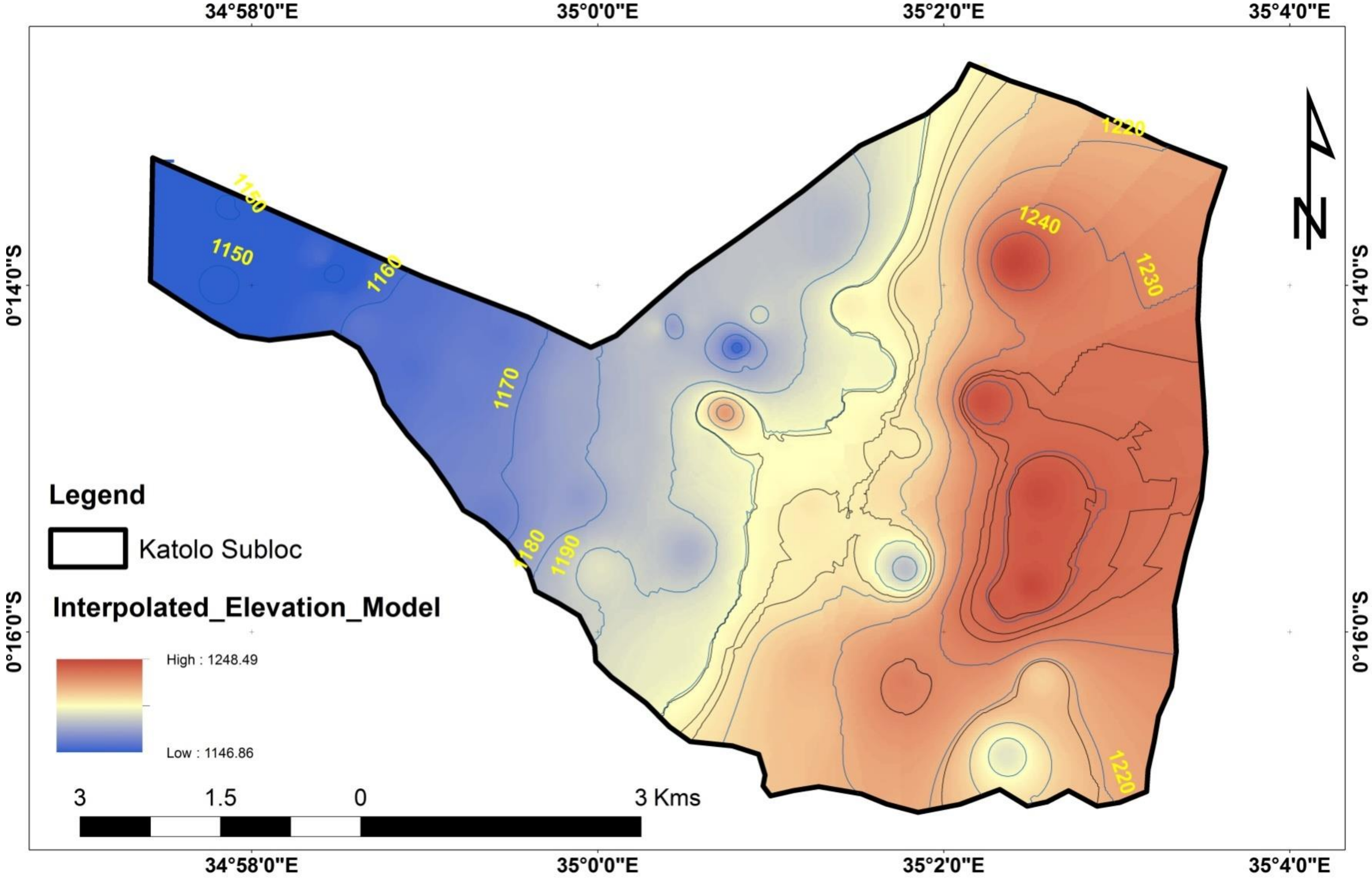


Plate 3: Interpolated elevation model of the study area

APPENDIX 5: Spatial distribution of off-mound grass abundance

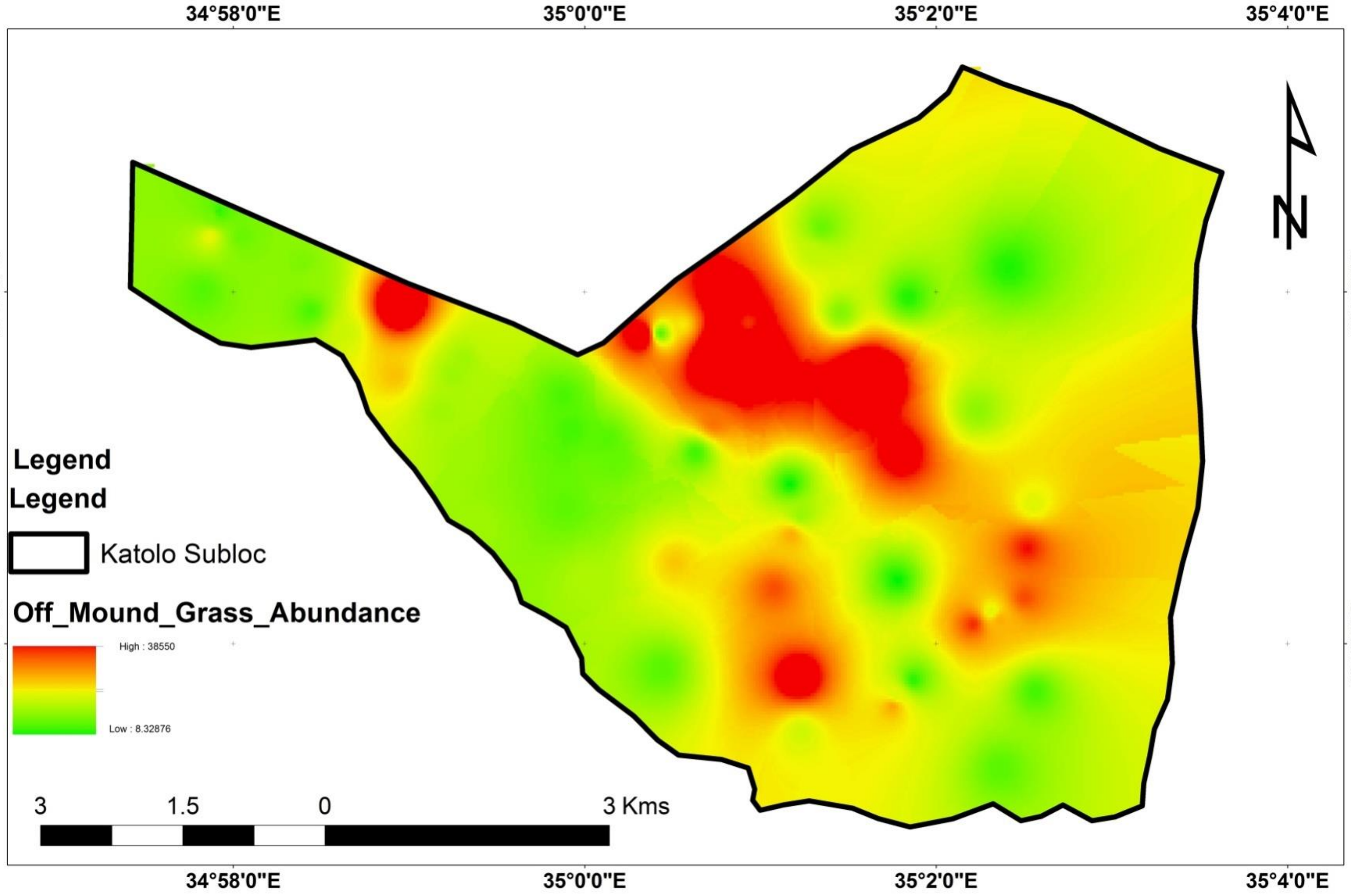


Plate 4: Spatial distribution of off-mound grass abundance

APPENDIX 6: Spatial distribution of off-mound lianas abundance

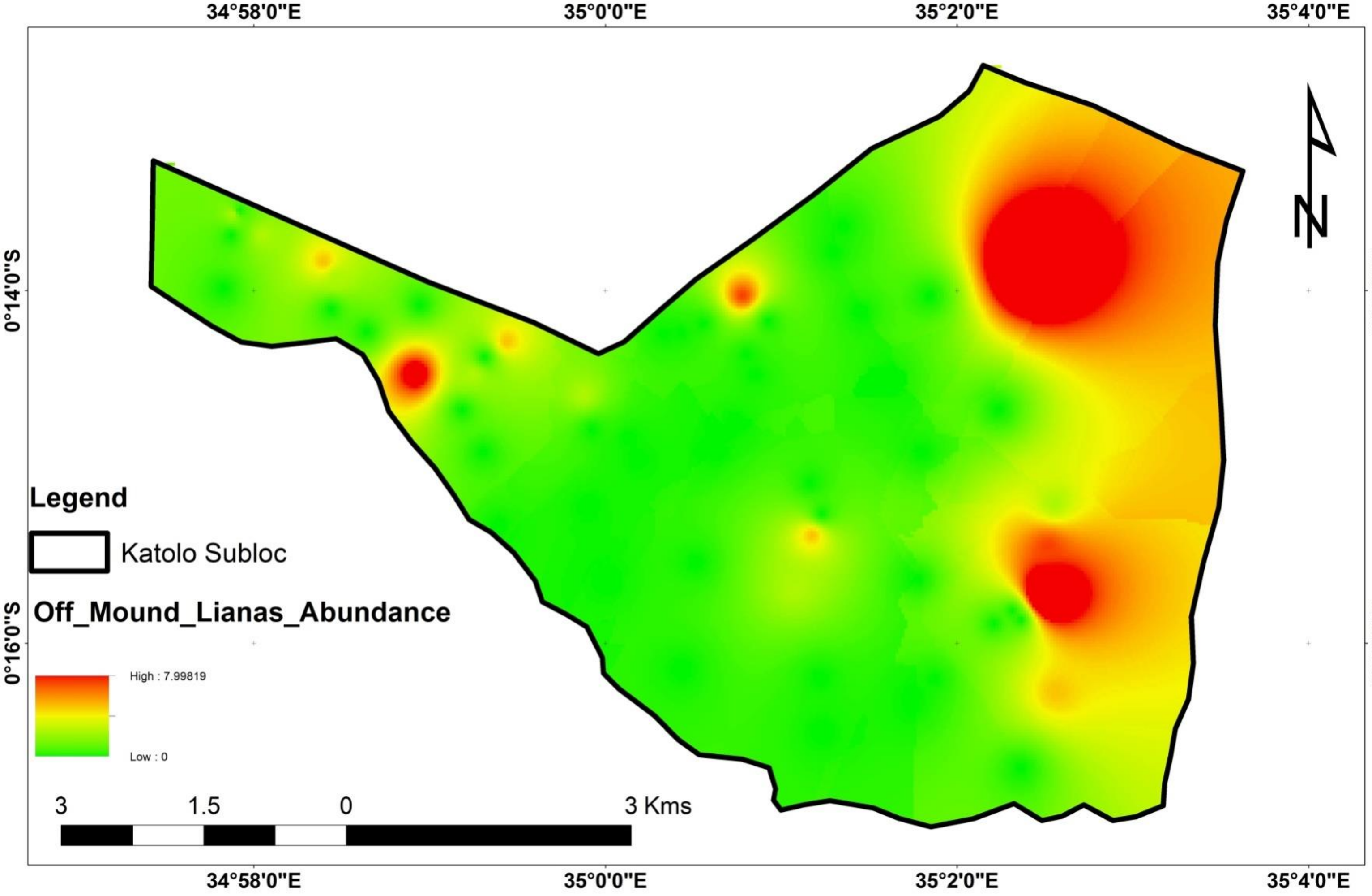


Plate 5: Spatial distribution of off-mound grass abundance

APPENDIX 7: Spatial distribution of off-mound shrubs abundance

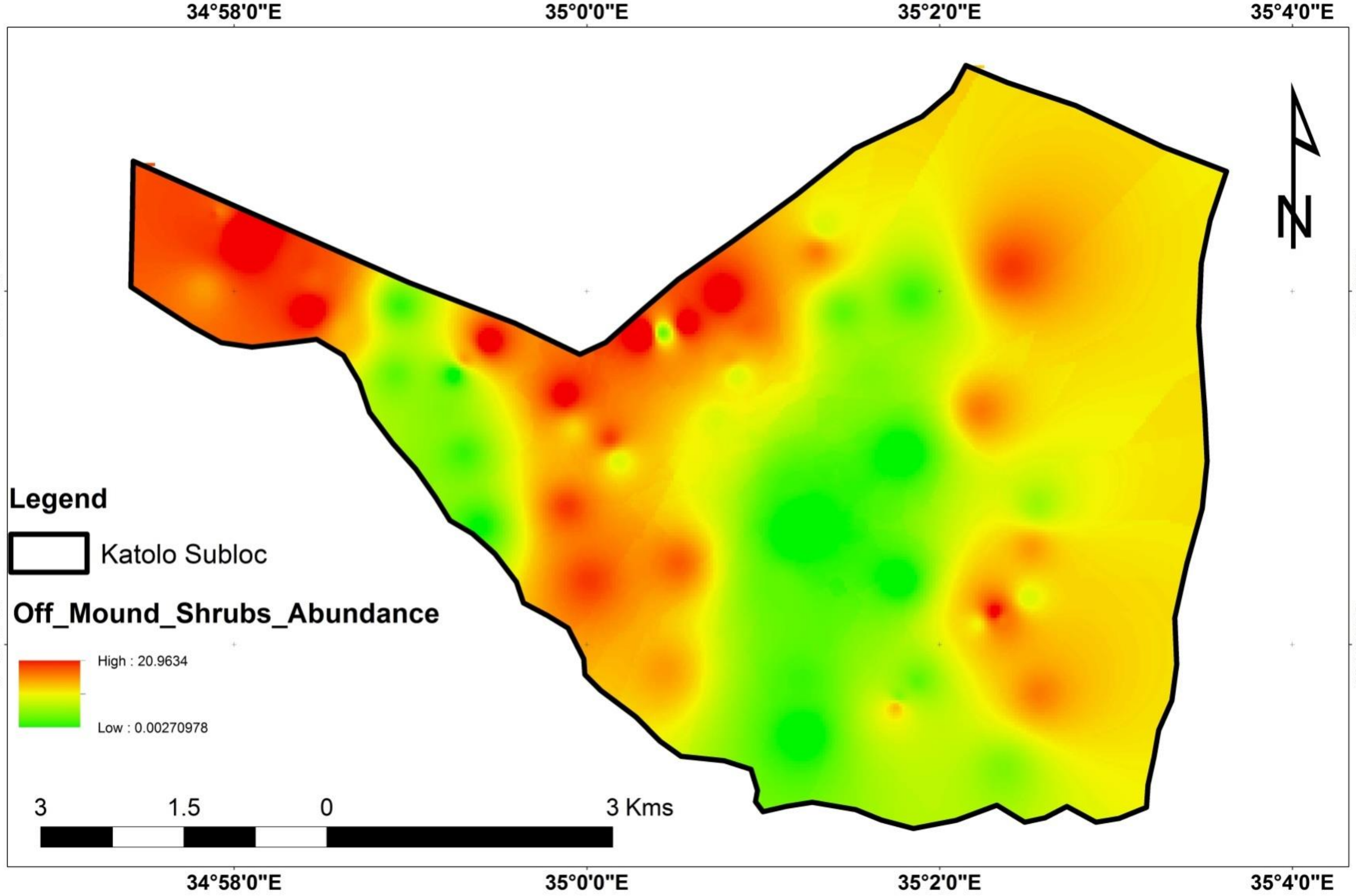


Plate 6: Spatial distribution of off-mound shrubs abundance

APPENDIX 8: Spatial distribution of off-mound trees abundance

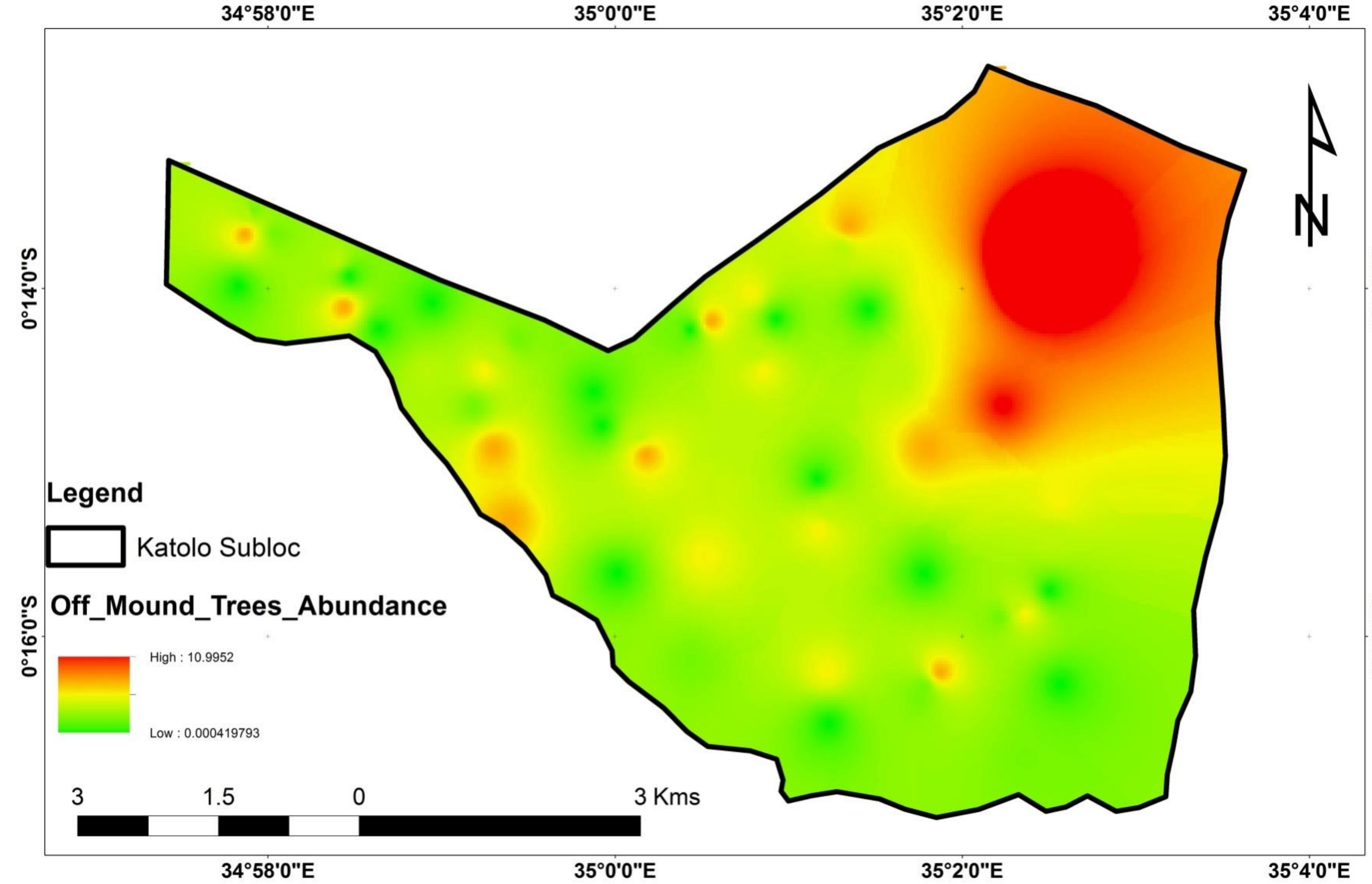


Plate 7: Spatial distribution of off-mound trees abundance

APPENDIX 9: Spatial distribution of on-mound grass abundance

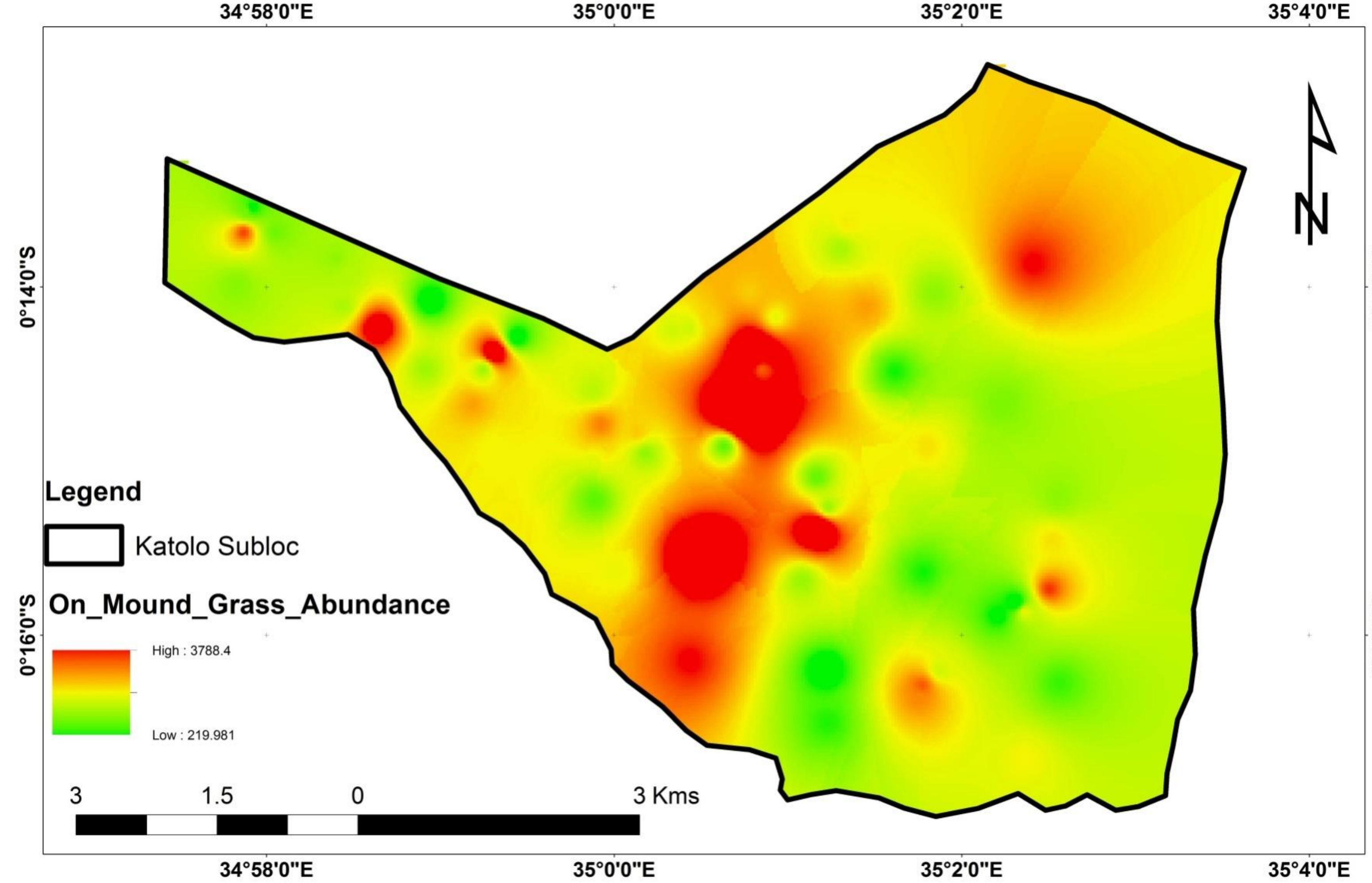


Plate 8: Spatial distribution of on-mound grass abundance

APPENDIX 10: Spatial distribution of on-mound lianas abundance

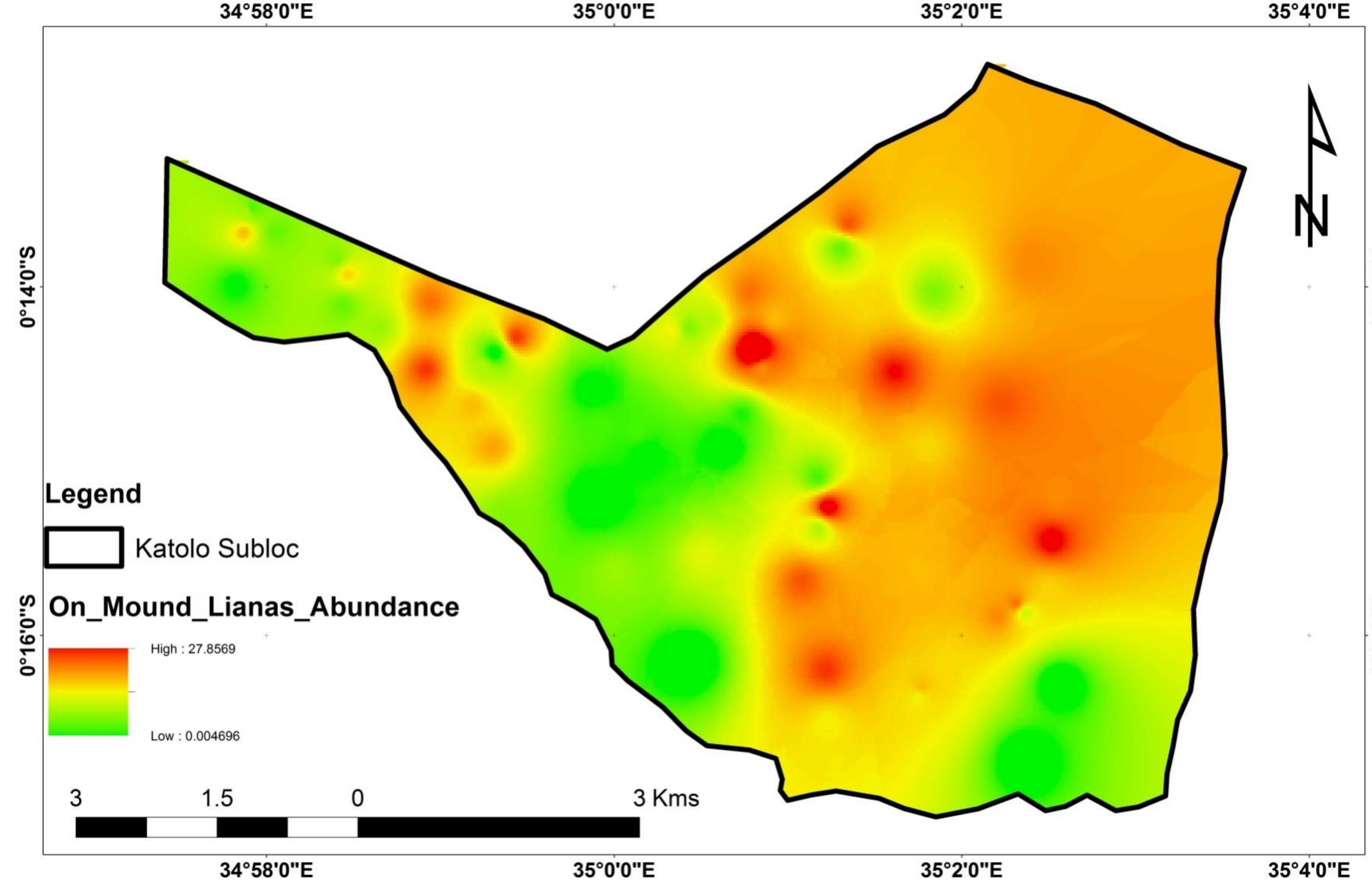


Plate 9: Spatial distribution of on-mound lianas abundance

APPENDIX 11: Spatial distribution of on-mound shrubs abundance

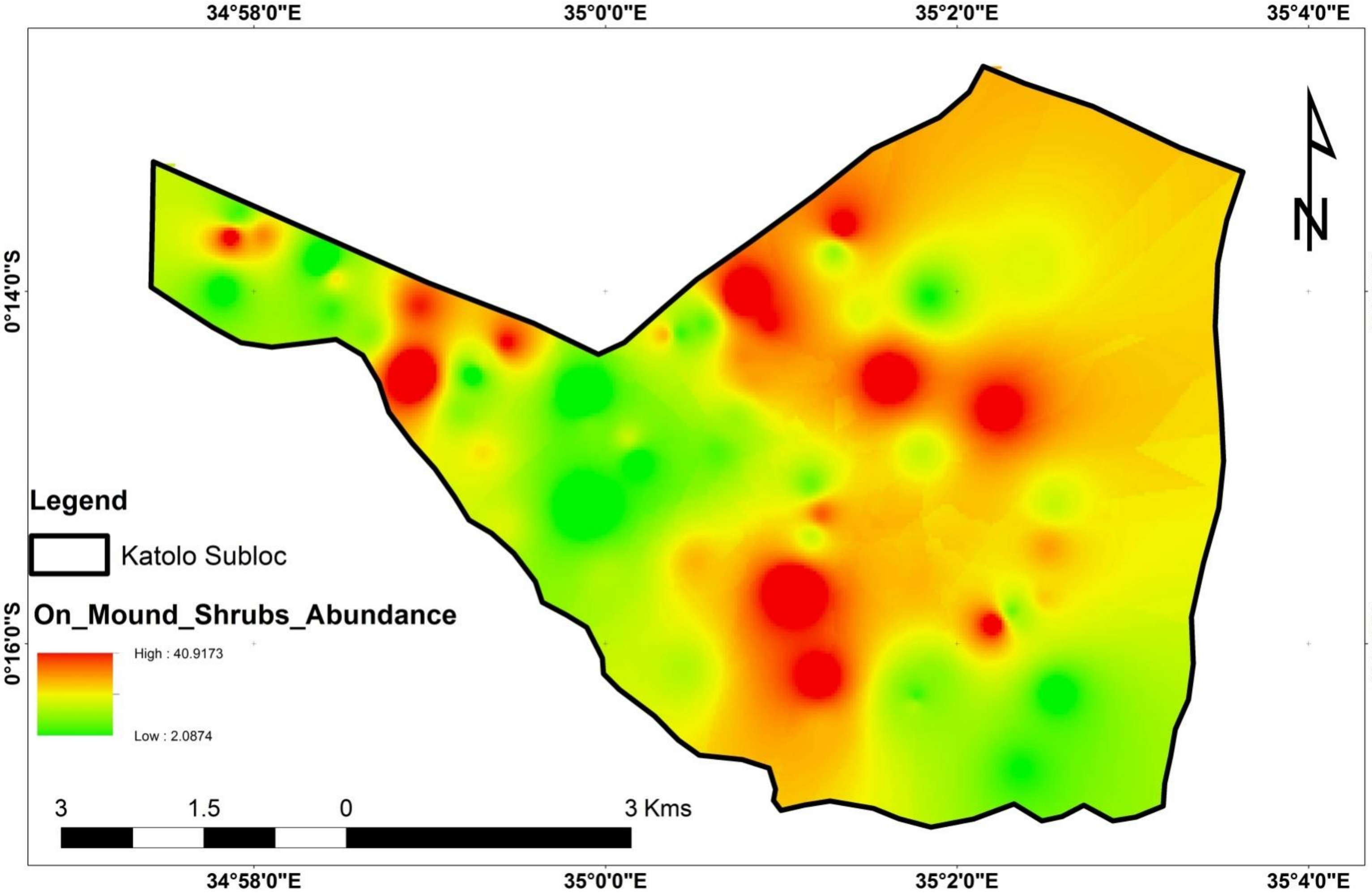


Plate 10: Spatial distribution of on-mound shrubs abundance

APPENDIX 12: Spatial distribution of on-mound trees abundance

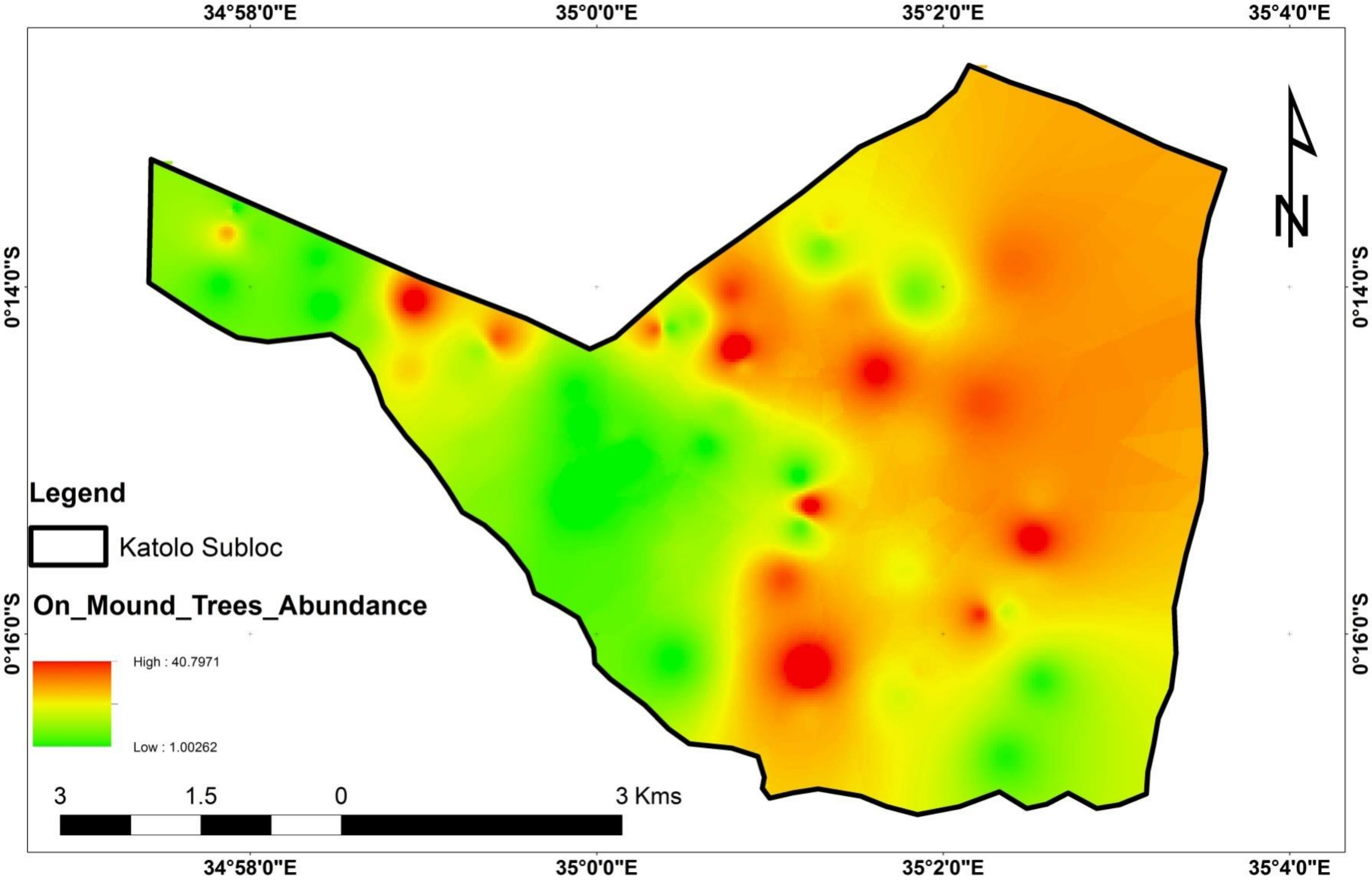


Plate 11: Spatial distribution of on-mound trees abundance

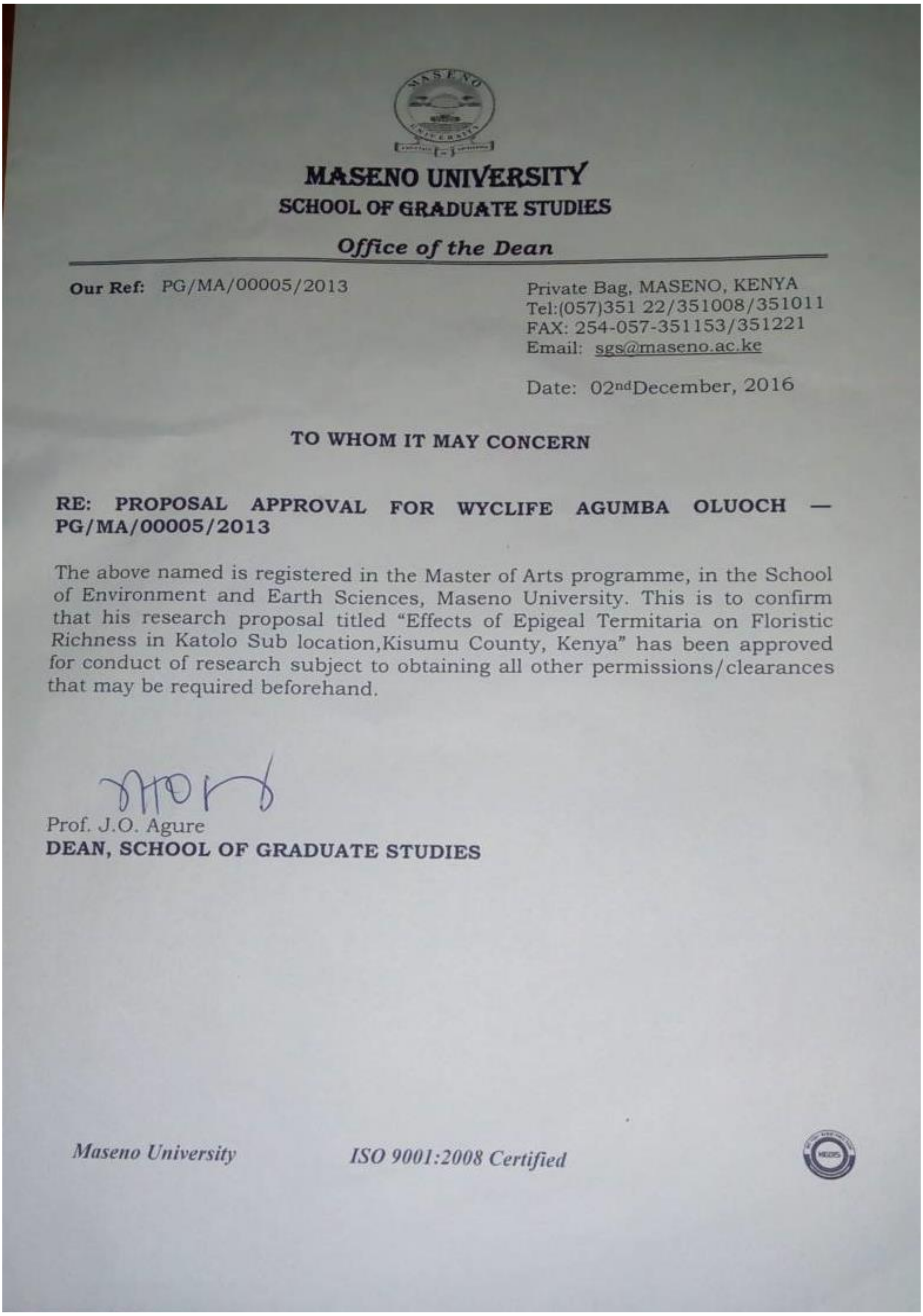
APPENDIX 13: Vegetation abundant termite mound

Plate 12: Termite mound with more abundant vegetation than off-mound site

APPENDIX 14: Termite mound showing vent, trees, shrubs and lianas

Plate 13: Termite mound showing various vegetation lifeforms

APPENDIX 15: Authority letter



MASENO UNIVERSITY
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Email: sgs@maseno.ac.ke

Date: 02nd December, 2016

TO WHOM IT MAY CONCERN

RE: PROPOSAL APPROVAL FOR WYCLIFE AGUMBA OLUOCH — PG/MA/00005/2013

The above named is registered in the Master of Arts programme, in the School of Environment and Earth Sciences, Maseno University. This is to confirm that his research proposal titled "Effects of Epigeal Termitaria on Floristic Richness in Katolo Sub location,Kisumu County, Kenya" has been approved for conduct of research subject to obtaining all other permissions/clearances that may be required beforehand.

Prof. J.O. Agure
DEAN, SCHOOL OF GRADUATE STUDIES

Maseno University *ISO 9001:2008 Certified*

APPENDIX 16: Cathedral shaped termite mounds

Source: Dowuona *et al.,* (2012)

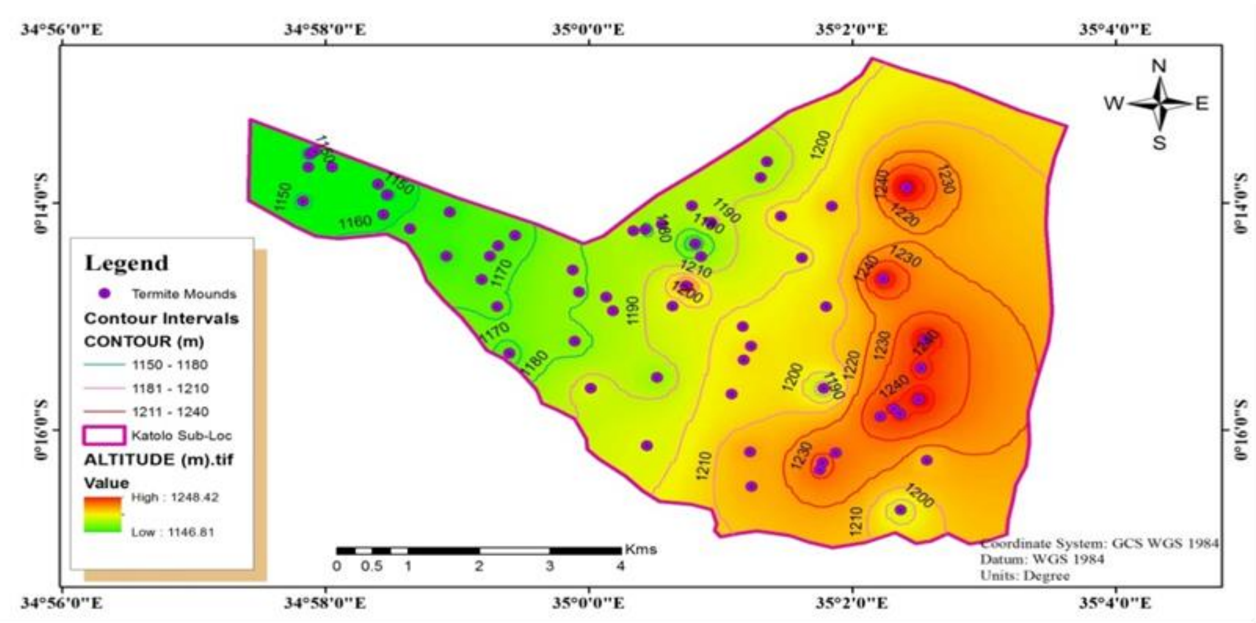
APPENDIX 17: Hemispherical shaped termite mounds

Source: Kirchmair *et al.,* (2012)

APPENDIX 18: Conical shaped termite mounds

Source: Yamashina *et al.*, (2010)

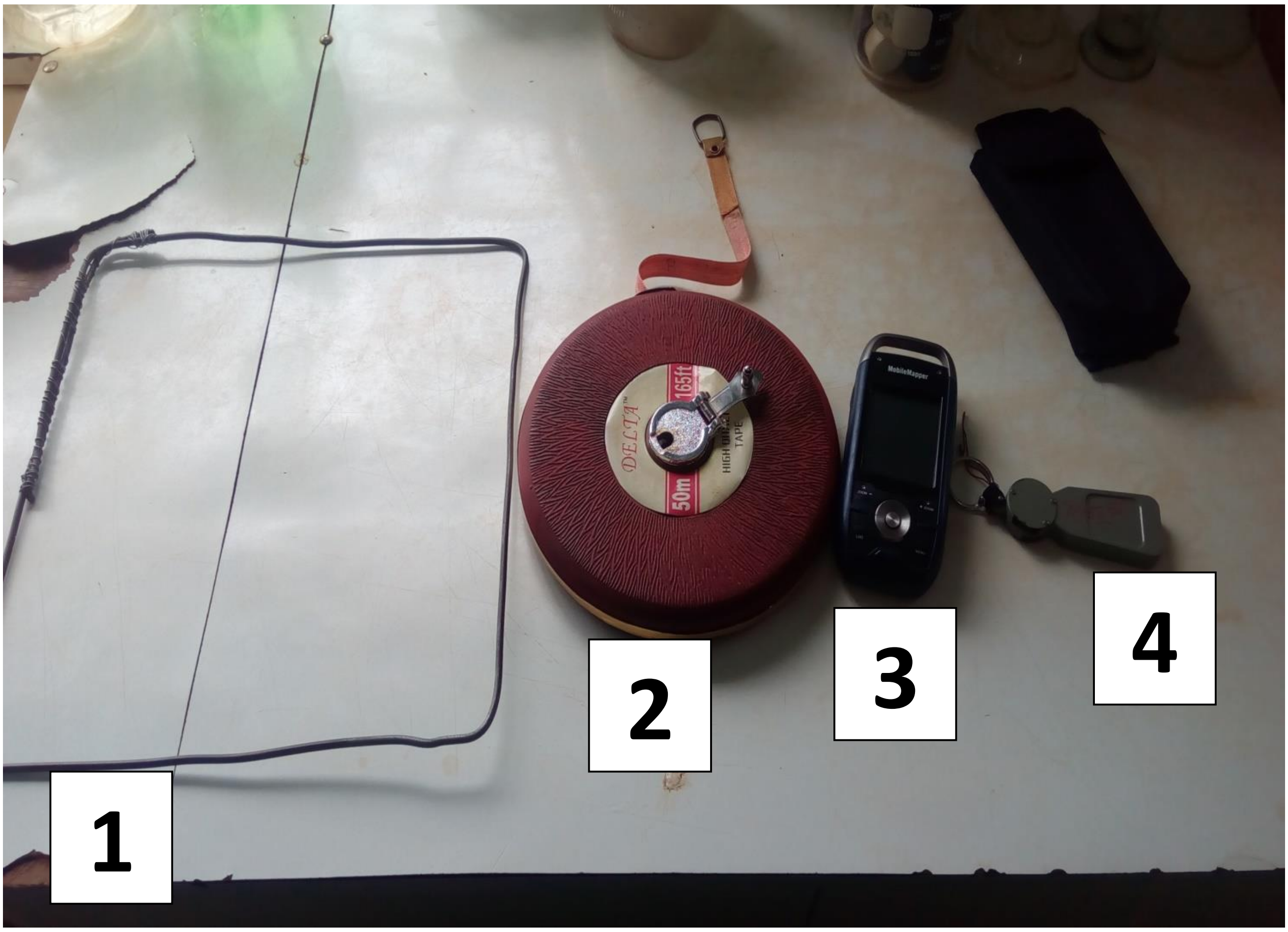
APPENDIX 19: Distribution of studied termite mounds



APPENDIX 20: Data collection instruments

(a) Front view of sliding Vernier calipers used in the study

(b) Hind view of sliding Vernier calipers used in the study



Label	Instrument	Use
1	0.3 X 0.3m Quadrat	Estimation of grass population
2	50m foot	Determination of heights and radii
3	Global Mapper GPS	Geo-locating termite mounds
4	Inclinometer	Estimating heights of taller mounds