

**INSIGHTS INTO LANDFORMS AND SOILS FOR EXPLAINING PLAGUE  
HOSTS-VECTORS INTERACTION IN WESTERN USAMBARA MOUNTAINS,  
TANZANIA**

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**A THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR  
THE DEGREE OF DOCTOR OF PHILOSOPHY OF SOKOINE UNIVERSITY OF  
AGRICULTURE. MOROGORO, TANZANIA.**

**2014**

## **EXTENDED ABSTRACT**

Western Usambara Mountains in Lushoto District, Tanzania, are highly populated owing to favourable climatic conditions for production of both cash and food crops such as coffee, tea, maize, beans, potatoes and assorted fruits and vegetables. Some areas in the district are also potential as tourist destinations. However, clusters of villages in the district are reported to be hot-spots of plague recurrence that has caused deaths of thousands of people. Plague outbreaks in some villages of Lushoto District show a high frequency (on average, more than 1 year out of three) while other villages, very nearby (<10 km) have low plague frequency (less than once in 10 years). In these areas, plague has persisted for over 20 years in some villages. It is not known why plague has persisted for years in some villages but is not observed in others in the neighbourhoods. Also the irregularity of the disease outbreaks (both in time and space) pose a serious risk to communities. Earlier studies show that this persistence and the foci of the disease could not be explained by differences in fauna composition or human domestic behaviour. Hence, it was thought that a critical analysis of landscape factors at farm scale could provide explanations for plague occurrence. This study attempted to establish a landscape ecological framework in which the importance of factors of landforms, soils and soil microclimate linked to rodents, fleas and rodent burrows can be analysed as proxy for plague risk prediction. Specifically the study was aimed to i) analyse landforms and associated soil properties in relation to occurrence of small mammals (rodents) and fleas, ii) investigate the status of soil micronutrients with respect to landforms and small mammals; abundance in the plague risk area, iii) investigate the influence of landform characteristics and surface attributes at farm scale on rodent burrows, and iv) examine the influence of soil physical properties and soil microclimatic attributes on rodent burrows'

abundance, portals' orientation and burrows' use. The study employed standard field survey and mapping of landforms, surface attributes and soils using remote sensing and GIS techniques. Soil samples were analysed in the laboratory for physical and chemical properties following internationally accepted methods. Trapping of small mammals was conducted on purposely selected sites using traps of different types and sizes. The trapped small mammals were counted and recorded, and treated with ethanol for further analysis. Fleas were removed from the animals by brushing the fur using ethanol, counted, recorded and stored. In the field, rodent burrows were surveyed systematically in the mapped landforms at farm scale. Data were explored using correlation and descriptive statistical analysis while regression analysis was carried out by generalised linear models (GLM) and boosted regression trees (BRT) in the framework of R statistics and Geographic Information System (GIS). The results show that phosphorus, base saturation, elevation and slope aspect are soil and landform characteristics which favour diversity of rodents ( $p < 0.001$ ); with Shannon Diversity Index increasing with elevation with values of 1.58, 1.62 and 1.69 for Plain, Escarpment and Plateau respectively. Fleas abundance was discouraged by hill-shade and magnesium while it was favoured by available phosphorus and organic carbon ( $p < 0.001$ ). The studied DTPA extractable Fe, Mn, Cu and Zn were variable. Fe ranged from 2.13 to 399.4 mg/kg soil, with a mean of 65.3 mg Fe/kg soil across the geomorphic units. Mn ranged from 0.59 to 266.28 mg Mn/kg soil while Cu ranged from 0.25 to 8.19 mg/kg soil with a mean of 2.98 mg/kg soil. Results show that Zn ranged from 0.08 to 19.6 mg/kg soil. Higher concentrations of Mn and Zn occurred mostly in the topsoils which also contained relatively high organic matter. Iron and Cu showed more or less equal distribution with soil depth but generally micronutrients declined with soil depth. Iron was found to significantly ( $p < 0.01$  and  $p < 0.05$ ) influence abundance of plague hosts and vectors. It is concluded that micronutrient levels vary in

function of soil types and geomorphic units. Whereas higher concentrations were found in the plateau and upper part of escarpment, lower levels were in the plain. Fe had positive influence on abundance of plague hosts and vectors. Landforms in the studied plague frequency landscapes vary significantly in terms of elevations and slopes ( $p < 0.05$ ). Abundance of rodent burrows varies significantly ( $p < 0.05$ ) with different landform characteristics in the studied plague frequency landscapes, with high abundance in the high plague frequency. Surface cover favoured rodent burrowing in high plague frequency areas. Elevation and slopes interactively provided a favourable environment for rodent burrowing. In the medium plague frequency landscape, slope length and slope aspect were the dominant landform characteristics favouring rodent burrows. Hence high elevations and vegetation cover favoured rodent burrowing; thus, these attributes should be considered in future plague research. It has been established in this study that topsoil depth, a natural Ap/Ah horizon was an important soil physical property ( $P < 0.05$ ) which influenced the abundance of rodent burrows with a relative influence of 39.5 percent. The results further showed that there was no statically significant influence of soil physical properties and soil microclimate attributes ( $P > 0.05$ ) on burrow port orientation. The results showed that both soil depth and temperature encouraged burrow use in the high plague frequency landscape ( $p < 0.05$ ). Soil depth, dry soil consistence and subsoil relative humidity (RH (%) within 30 cm depth) significantly ( $p < 0.05$ ) could explain the burrow abundance in the medium plague frequency landscape. The use of burrows depended on the resistance of burrow to collapse, a characteristics which is dependent on the compaction of topsoil. However, dry subsoil consistence discouraged burrowing. Subsoil dry consistence had a significant ( $p < 0.05$ ) negative influence on burrow portal orientation in the medium plague frequency area, something attributed to compaction of the soils. It is concluded that soil physical and soil microclimate in the high plague

frequency landscape encourage burrowing, a phenomenon correlating with the reported human plague contact risks. The information obtained from this study could be applied for surveillance, monitoring and control of rodent populations before they reach outbreak levels, not only in the Western Usambara Mountains, Lushoto District, but also in similar ecological settings with rodent problems.

**DECLARATION**

I, Joel Loitu Meliyo, do hereby declare to the Senate of Sokoine University of Agriculture that the work that is reported in this thesis is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any institution.

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## ACKNOWLEDGEMENTS

Many thanks are due to our heavenly Father JEHOVAH GOD for HIS mercies that endure forever and for HIS love to me. Thank you Father for life and for enabling me to pursue the work presented in this thesis.

I express my appreciation to many people who helped me to accomplish my PhD thesis work. Foremost, sincere gratitude are due to my supervisors, Prof. B.M. Msanya of Department of Soil Science, Sokoine University of Agriculture, Prof. D.N. Kimaro of the Department of Engineering and Land Planning, Sokoine University of Agriculture, Prof. L.S. Mulungu of Pest Management Centre, Sokoine University Agriculture and Prof. J. Deckers of Catholic University of Leuven, Belgium for their encouragement, guidance and constructive comments which enabled me to complete this work successfully.

I greatly appreciate the scholarship offered to me by the Government of Tanzania through the Ministry of Agriculture, Food Security and Cooperatives. Without this scholarship, surely my study could not have been undertaken. I also thank my employer the Permanent Secretary of the Ministry of Agriculture, Food Security and Cooperatives for granting me study leave. I give my vote of thanks to Director of Research and Training, Dr. F. Myaka and Assistant Director, Support Services, M. Lutkamu, for their regular follow ups of my progress and their words of encouragement. I also thank the Training Officer, Mr. J. Banzi, for his quick responses regarding logistical support and funding.

My sincere appreciations are due to Prof. H. Gulinck (Department of Earth and Environmental Sciences, Catholic University of Leuven, Belgium) for his professional

input and provision of free licence software (GRASS, QGIS) and training me on the use of GRASS.

I greatly appreciate the logistical and material support to me by Landscape-ecological Clarification of Bubonic Plague Distribution and Outbreaks in the Western Usambara Mountains, Tanzania (LEPUS) project under the leadership of Prof. D. N. Kimaro. I deeply appreciate the three months' study at the Catholic University of Leuven, Belgium, that was organized and facilitated by LEPUS via VLIR-Own Initiative project and for sponsoring me to attend the Soil Science Society of East Africa biannual conference in Nakuru, Kenya. I also sincerely appreciate the partial scholarship given to me by the LEPUS project to assist me to finish up the thesis writing. I appreciate and thank very much Dr. S. Neerinckx for sparing time for my proposal, his invaluable comments and discussions we held when I was in Belgium. Thanks to all friends I met in Belgium, and shared coffee and barbecue together.

My vote of thanks is due to the entire LEPUS project team in Tanzania and Belgium for the professional inputs during field workshops and annual planning meetings which steered the course of my PhD work. This magnificent team composes professors: B.M. Msanya, D.N. Kimaro, N. I. Kihupi, L.S. Mulungu, Dr. P. Mtakwa from Tanzanian side and Profs: J. Deckers, H. Gulinck, J. Poesen and H. Leirs from Belgium. Thanks to you all very much.

My field station was situated in the former Sebastian Kolowa University College of Tumaini University, now Sebastian Kolowa Memorial University (SEKOMU). I record

my appreciations to all SEKOMU leadership, in particular Dr. Rev. Anneth Munga for the logistical support she provided during the entire period of my field research.

I am grateful to my two Heads of the Department of Soil Science who served at different times during my study, Professors J. J. Msaky and F.B. Rwehumbiza, for their frequent encouragement and follow ups on my progress. I am grateful to all academic members of staff of the Department of Soil Science for their interaction throughout my study period from research proposal development to completion of PhD work. Many thanks to the laboratory and support staff of the Department of Soil Science for material and technical support during my study period.

Many thanks are due to many fellow students with whom I worked and enjoyed moral and academic support: Boniface J.H. Massawe., Ralaizafisoloarivony, N. A., Marianne Hubeau, Bernd Annaert, Matthias, V., Brabers L. and his wife Gitte, Bastiaan, V., Richard Temba, Heldelitha Msita, Catherine Senkoro, Hilda Ngazi, Hassan B. Shellukindo, Sibaway Mwango, Mweta Mjema and Soud Nahodha. My special votes of thanks are due to my friend and colleague Proches Hieronimo. We shared many things while in the Usambara Mountains from faith and prayers, to food and science, without forgetting mountain climbing.

My field work could have been difficult without hard working colleagues who were facilitating. I appreciate mentioning Michael Mnkande and Ramadhani Iddi for their devotion and hard work.

My special thanks go to my family members, brothers and sisters for understanding the difficult situation I was in for the last five years. Brother Mathew K. Meliyo: thanks for

introducing me to school and for sacrificing your little allowance to buy me a short and a shirt that I started school with. Your efforts and sacrifice have resulted in this academic undertaking. Dr. Michael Meliyo, Olarip Meliyo, Johnson Meliyo and Joseph Meliyo: thanks for your words of encouragement. Ngoo-Natosim, Ngoo-lomitu and Dada Meliyo: thanks for your understanding and words of encouragement. I missed a lot of family calls but you understood me, thank you.

My children Emmanuel and Neema: thanks to you for encouraging me and for struggling to climb an academic ladder. I wish you the best of luck in your new testing grounds of education. To Benjamin, Gloria and Joshua: thanks for being good children and for your prayers. To my wife Joyce I remain in debt. I do not have words to express my thanks. You are a determined fighter and struggler. Your material and moral support was enormous. To Prosper and Baraka, I enjoy to say that you are the reward of God to our family during of my PhD period; you have been a source of happiness and your presence inspired me to work even harder. To you all I say may Almighty JEHOVAH God bless you.

## **DEDICATION**

Commitment, determination, and devotion were fundamental elements for the completion of my doctoral thesis, but even more was the support of my family. I would remind my brother Mathew Meliyo that his call to go to school brought me this far. To my wife Joyce and our children Emmanuel, Neema, Benjamin, Gloria, Joshua, Prosper and Baraka, today I dedicate this work to them all because without their prayers, support and understanding I would not have achieved my goal.

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**APPENDIX**

Appendix 5.1: Correlation of burrow characteristics, soil physical properties and  
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**LIST OF ABBREVIATIONS AND SYMBOLS**

AAS	Atomic Absorption Spectrophotometer
AIC	Akaike information criterion
a.m.s.l.	above mean sea level
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BRT	Boosted regression trees
CDC	Center for Disease Control and Prevention, USA
CEC	Cation exchange capacity
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
CTI	Topographic compound index
Cu	Copper (cuprum)
DDT	Dichloro diphenyl trichloroethane
DEM	Digital elevation model
DTPA	Diethylene triamine penta-acetic acid
EC	Electrical conductivity (in soil solution)
FAO	Food and Agricultural Organisation of the United Nations
Fe	Iron (ferric, ferrous)
GDEM	Global Digital Elevation Model
GIS	Geographic Information systems
GUI	Graphical user interface
m	metres
Mn	Manganese
NDVI	Normalized differential vegetation index
SPI	Stream power index
UTM	Universal Transverse Mercator
VLIR	Vlaamse Inteunivestaire Raad

Zn

Zinc

## CHAPTER ONE

### 1.0 GENERAL INTRODUCTION

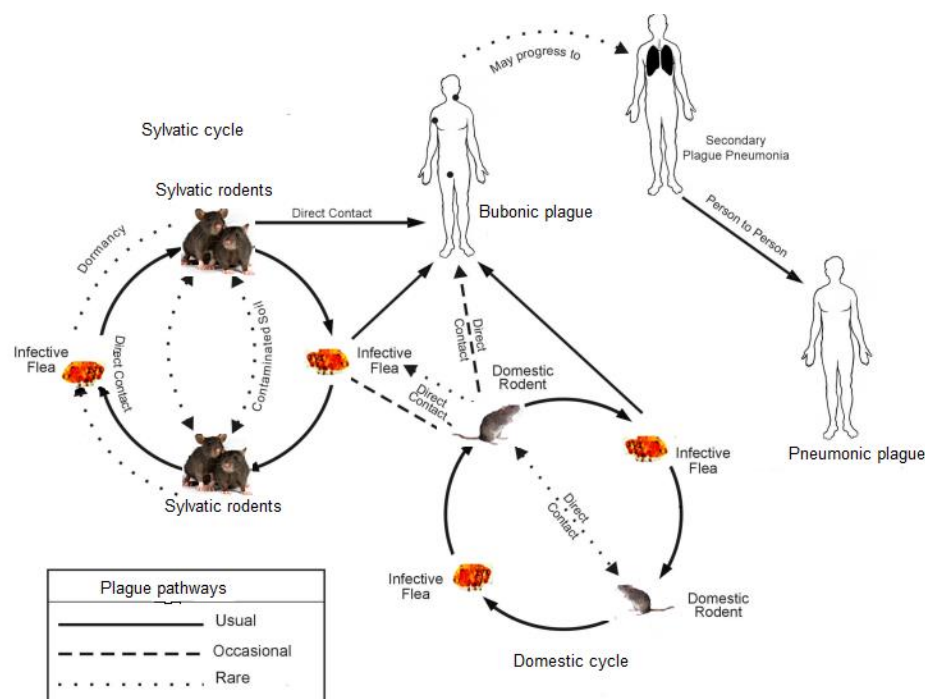
#### 1.1 Plague Ecology and Geographic Occurrence

Plague is caused by *Yersinia pestis*, which is a Gram-negative rod-shaped bacterium belonging to the family Enterobacteriaceae (Gage and Kosoy, 2005; Lowell *et al.*, 2005; WHO, 2003). It is a facultative anaerobic bacterium causing rodent zoonosis transmissible to humans by the bite of an infected rat flea, *Xenopsylla cheopis* (Gage and Kosoy, 2005; Eisen *et al.*, 2008) or other types of rat fleas (Kilonzo and Mhina, 1982). Other flea species that have been documented to be probable effective vectors of the bacterium include *Xenopsylla brasiliensis* and *Pulex irritans*, among others (Laudisoit *et al.*, 2007).

In humans the disease is called Bubonic, Septicemic, or Pneumonic plague, depending on the symptomatic pattern of distribution of the infection. Bubonic is the most common form causing fever and swollen tender lymph nodes called buboes. Pneumonic plague is the systemic plague mainly attacking lungs, whereas Septicemic plague is mainly blood poisoning plague (unpublished CDC, 2009). The plague bacterium can also be exposed to humans by direct contact with an infected animal or consuming an infected animal, and by coming into contact with a sick person's body fluids (Witmer, 2004; Kilonzo and Msangi, 1991).

Figure 1.1 presents a complex plague cycle showing key phases during enzootic and epizootic periods (Chamberlain, 2004). The figure shows that both domestic and sylvatic rats are important hosts for the plague bacterium *Yersinia pestis* circulation in the

different organisms. Also, it has been established that apart from rodents some warm blooded animals such as cats, camels, chipmunks, prairie dogs, rabbits and squirrels can as well be important plague bacterium reservoirs or hosts (Bizanov and Dobrokhotova, 2007).



**Figure 1.1: Plague disease spread between hosts - vectors – incidental hosts in enzootic and epizootic cycles in a natural environment**

(Source: Chamberlain, 2004)

Plague is characterised by quiescence and epizootic periods (Eisen and Gage, 2009; Gage and Kosoy, 2005). The enzootic phase occurs when there is no die-off of rodent while the epizootic phase is when it erupts and starts killing the hosts massively (Chamberlain, 2004; Witmer, 2004). As rodents die in large numbers the fleas seek alternative hosts, which are usually any nearby animals, including humans. Globally, there have been three massive plague pandemics in history, which are the “*Justinian Plague*” (540-542), “*Black Death*” (1345 – 1351) and “*Great Plague*” (1855-todate), which have claimed

over 200 million lives (Little, 2006; Tikhomirov, 1999). These were spread by commercial ships moving around world ports.

Following the old plague geographies, recent studies have established that plague foci are distributed in circumscribed areas assumed to be correlated with distributions of dominant hosts (reservoirs) and vectors and within their explicit ecology (Antolin *et al.*, 2008; Laudisoit *et al.*, 2007; Prentice and Rahalison, 2007).

Despite this knowledge, plague still remains an unpredictable threat in the natural foci around the world, including several countries in Africa, Central and South Asia, South America and Southwest United States of America (Eisen and Gage, 2009; Eisen *et al.*, 2008). This characteristic makes plague a horrific and dangerous disease. The natural active plague foci reported so far in Central Asia are found in Kazakhstan, Turkmenistan, Uzbekistan, Mongolia, China and India. In the South Americas they are found in Brazil, Bolivia, Ecuador and Peru. In North America the active plague foci are found in the United States of America (WHO 2010; 2005). Recent outbreaks have shown that plague may recur in areas that have long remained silent (Eisen and Gage, 2009; Makundi *et al.*, 2007; Kilonzo *et al.*, 2006; Lowell *et al.*, 2005).

Research carried out worldwide in most of the reported foci show that plague is still claiming over 3000 deaths each year. In the USA, it is reported that there are 10 to 15 human bubonic plague cases each year (unpublished CDC, 2009; Mary, 2011). Australia, which was initially assumed to be a plague free country, has reported annual cycles of plague outbreak among house mouse populations which reduce the density of rats from 3000 to 3 rats per hectare (CSIRO, 2012). This is a massive death of almost 100 % and when it happens it is usually associated with a potential plague eruption to humans,

although due to high awareness there have never been human cases in Australia. Reports from the World Health Organisation (WHO) show that about 90 % of the human plague cases notified in the world come from African countries (WHO, 2003). The most affected countries in Africa are the Democratic Republic of Congo, Madagascar, Mozambique, Uganda and Tanzania.

In Tanzania, accounts of plague history and geographical distribution have been outlined by Kilonzo (1981, 1992), Davis *et al.* (2006), Makundi *et al.* (2008), Laudisoit *et al.* (2007) and Neerinckx (2010). According to these authors the first plague outbreak reported shows that the incidence occurred at Iringa in 1886 (Kilonzo 1992; Neerinckx, 2010). The outbreak in Iringa was reported to have most likely originated from the old plague focus which existed around Lake Victoria in East Africa (Neerinckx, 2010). In the last decades of the 19<sup>th</sup> century several human plague outbreaks were recorded in various parts of Tanzania including Kiziba (Bukoba District), Ilembula (Njombe District), Gesani (Rombo District) and Mpwapwa (Dodoma District) (Kilonzo, 1992). Following these outbreaks the disease continued to recur repetitively and several regions were enzootically infected with plague (Neerinckx, 2010). The most important recorded and reported cases were in the Geseni District on the eastern side of the Kilimanjaro Mountain in 1912 whereby 58 human cases were reported (Lurz, 1967). There were also reports from Mwanza District and the eastern Lake Victoria area in 1913 and in Mbulu District in 1917 (Msangi, 1969).

From the 1950, few foci like those in Bukoba District, Iringa and Shirati in Tarime District became quiescent while others like in Singida and Mbulu Districts were active up to 1979 (Kilonzo, 1981). Other areas where human plague was reported for the first time

during that period include the Pare Mountains, located south-east of Mount Kilimanjaro. From the same period Same, Hai and Rombo Districts, situated in Kilimanjaro region, experienced regular recurrence of plague which was observed for about 30 years (Kilonzo and Msangi, 1991).

In 1980, the human plague epidemic was for the first time reported in a new location, namely Lushoto District in north-eastern Tanzania (Kilonzo and Mhina, 1982). Between 1980 and 2003, several hundreds of people were infected yearly in Lushoto District and in 2003, which was the last reported outbreak, 7 600 human cases were recorded (Davis *et al.*, 2006). In 1996-97 a total of 186 human cases were reported in Karatu District and in 2007 and 2008, eight and 27 human plague cases were reported in Mbulu District, respectively, after a period of almost 30 years (Makundi *et al.*, 2008). In view of this account, plague today remains a significant public health concern in Tanzania.

## **1.2 Plague and Environmental Factors in Tanzania**

In Tanzania, plague cases generally occur in seasonal cycles, and show clear and well defined geographical foci that are considered to be correlated with distributions of dominant hosts and vectors, particularly rodents and fleas, and their ecological interactions (Makundi *et al.*, 2008; Laudisoit *et al.*, 2007; Davis *et al.*, 2006). For example, in Lushoto District, a cluster of three villages seems to be a hot-spot of plague. Some other villages also show a high frequency of plague (on average, more than one year out of three) while other villages, very nearby (<10 km) have low plague frequency (less than once in 10 years) (Neerinckx, 2010; Davis *et al.*, 2006).

Many studies conducted in Lushoto District and in many parts in Africa on plague have generally focused on examining host-vector-parasite systems and human social activity

patterns in the plague foci (MacMillan *et al.*, 2011; Hubeau, 2010; Ralaizafisolariovony, 2010; Neerinckx *et al.*, 2010; Neerinckx *et al.*, 2008; Laudisoit *et al.*, 2007). Most of these studies were aimed to help in identifying the hosts/vectors involved and in evaluating human risk behaviour in a particular focus. However, studies have so far not been able to explore the ecological factors determining the pattern of plague's geographic distribution at fine scales (Neerinckx *et al.*, 2010; Massawe, 2010; Davis *et al.*, 2006).

Furthermore, earlier studies have shown that patterns of plague in a geographic focus could have been explained by differences in fauna composition or human domestic behaviour, but this proved not to be the case (Hubeau 2010; Laudisoit *et al.*, 2007; Davis *et al.*, 2006). Therefore, consideration of abiotic, environmental and landscape factors in the interplay is of paramount importance. It has also been noted that most studies that were carried out earlier to examine the distribution patterns of plague and potential links with environmental factors were done at macro-scale and many of them were done elsewhere and not in Africa (Ben Ari *et al.*, 2011; Stenseth *et al.*, 2008; Neerinckx *et al.*, 2008; Gage and Kosoy, 2005). For example, in the United States, spatial patterns in plague transmission were evaluated in view of changing climates (Holt *et al.*, 2009; Ben Ari *et al.*, 2008; Nakazawa *et al.*, 2007). In these studies it was clearly observed that temporal patterns in plague distribution were consistent with changing climates (Ben Ari *et al.*, 2011; Snall *et al.*, 2008; Nakazawa *et al.*, 2007). Also, other recent studies in the United States, demonstrated that the geographic distribution of 13 flea species (potential plague vectors) could be predicted and explored (Adjemian *et al.*, 2006). In many of these studies positive relationships were established between human plague incidence, and winter-spring rainfall and elevation (MacMillan *et al.*, 2011; Brown *et al.*, 2010).

There were also other studies that attempted to establish relationships between landscape features and the distribution and occurrence of various diseases, including plague (Nakazawa *et al.*, 2007). It is clear from these studies that the contribution of environmental factors in relation to patterns and geographic distribution of plague can provide insights into the focality of plague (Holt *et al.*, 2009; Winters *et al.*, 2009; Foley *et al.*, 2007). But still it is so far unknown why plague has been able to persist for over 20 years in some villages in the Lushoto District. At the same time, it is puzzling that plague does not seem to spread from this existing focus. Therefore, finding the ecological factors that could explain the spatial patterns of plague asks for a detailed analysis of landscape factors including landforms, soil types, soil physical and chemical properties and soil microclimate at farm scale.

### **1.3 Justification**

By the year 2004, more than 7600 human plague cases were reported in Lushoto District, Tanzania (Laudisoit *et al.*, 2007; Davis *et al.*, 2006). In this area the plague disease has been able to persist for over 20 years in some villages. It is unknown why plague has been able to persist for years in some villages but was not observed in other nearby villages in Lushoto District. Also the irregularity of the disease outbreaks (both in time and space) pose a serious risk to communities (Davis *et al.*, 2006).

Earlier studies have shown that plague persistence and the foci of the disease could not be explained by differences in fauna composition or human domestic behaviour (Hubeau, 2010; Davis *et al.*, 2006; Kilonzo *et al.*, 1997; Kilonzo *et al.*, 1992). Therefore, a critical analysis of landscape factors at farm scale could provide an explanation for the plague occurrence in the area. This study attempted to establish a landscape ecological

framework in which the importance of factors of landforms, soils and soil microclimate linked to rodents, fleas and rodent burrows can be analysed as proxy for plague risk predicting behaviour.

The threat of plague in Tanzania remains given the mystery of factors governing its severity, contagiousness and re-emergence in some foci after over 30 years of dormancy (Makundi *et al.*, 2008; Kilonzo *et al.*, 2006; WHO, 2003; Kilonzo *et al.*, 1992; Kilonzo and Msangi, 1991). The Tanzanian Government is spending about one million euro (€) per annum to combat the problem of plague, mostly through clinical treatment of infected persons and control of host and vector outbreaks (Neerinckx, 2010). This action is a mere patching-up operation and does not prevent the disease to break out, as is currently the case in the Mbulu District (Makundi *et al.*, 2008). A study that explores some underlying factors of plague occurrence and distribution is necessary and soil factors are deemed significant at this juncture.

Experiences of earlier outbreaks of plague show that apart from human losses, the disease has been endemic in most areas with high agricultural potential that are also heavily populated. For example, plague has historical outbreaks in Iringa, Bukoba, Mbulu, Rombo and Lushoto in Tanzania (Kilonzo *et al.*, 1997). These areas are important for production of both cash and food crops such as coffee, tea, maize, wheat, beans, potatoes and assorted fruits and vegetables. Some areas like Lushoto are also a tourist destination which may affect not only the Tanzanian economy and people's livelihood but may also pose a global threat. Therefore, the results of this study are aimed to complement the Tanzanian Government National Health Policy of 1998, the Health Sector Reforms 1994-2004 and the World Health Organisation's efforts which support coordination of plague

outbreak response by making use of data available from research programmes conducted by other units and organisations.

## **1.4 OBJECTIVES**

### **1.4.1 Overall objective**

To establish a landscape ecological framework in which the importance of factors of landforms, soils and soil microclimate linked to rodents, fleas and rodent burrows can be analysed for guiding plague surveillance.

### **1.4.2 Specific objectives**

- i) To analyse landforms and associated soil properties in relation to occurrence of small mammals (rodents) and fleas.
- ii) To investigate the status of soil micronutrients in different landforms and their influence on plague hosts in the plague risk area.
- iii) To investigate the influence of landform characteristics and surface attributes at farm scale on rodent burrows.
- iv) To examine the influence of soil physical properties and soil microclimatic attributes on rodent burrows' abundance, portal orientation and burrow use.

## **1.5 Hypothesis**

Landforms, soils and soil microclimate linked to rodents, fleas and rodent burrows can explain the spatial patterns of plague risk behaviour at farm scale.

## **1.6 Conceptual Framework**

Figure 1.2 presents a conceptual framework tool that was used to structure and guide individual components of research to completion.

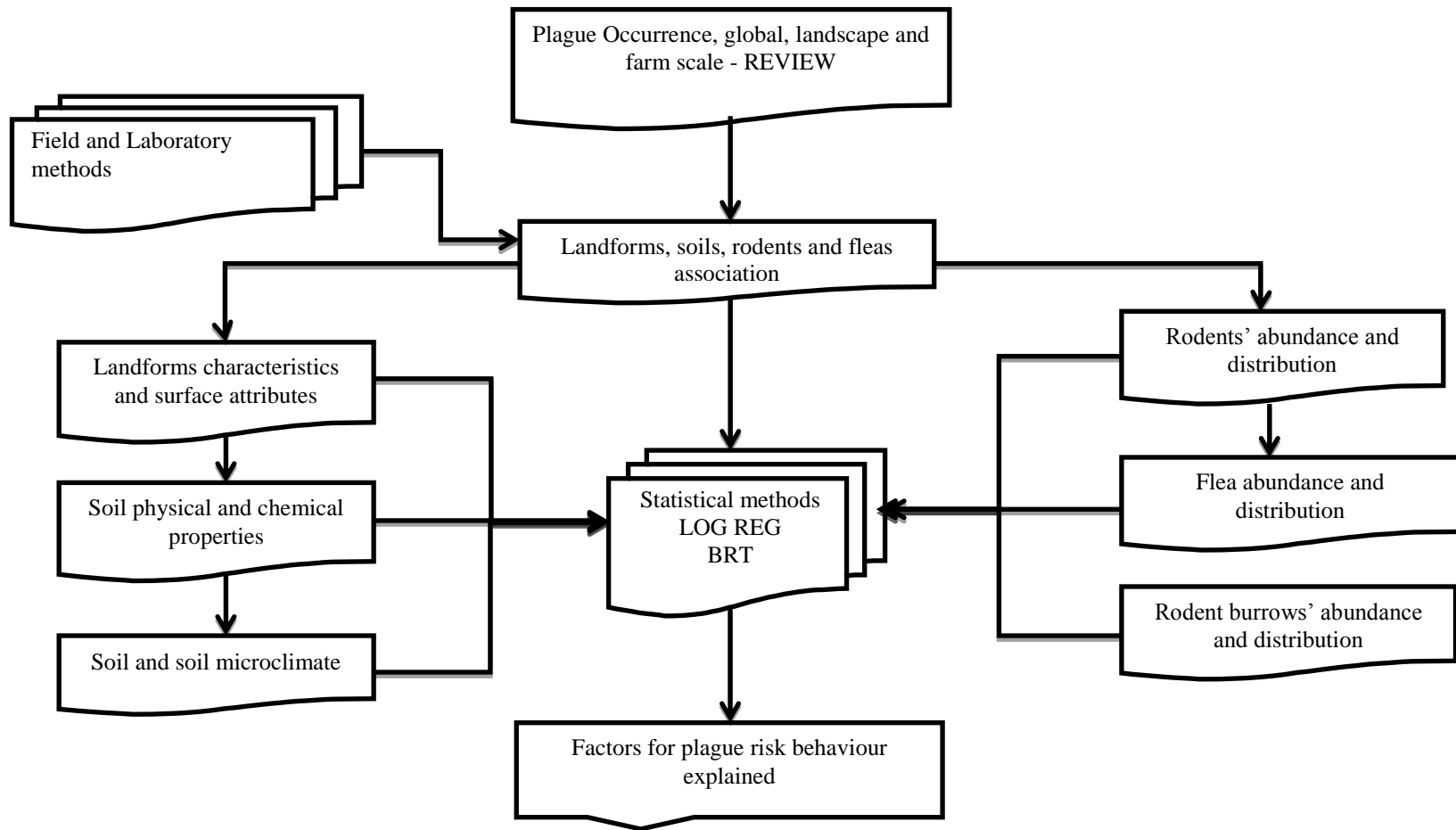


Figure 1.2: The conceptual framework

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## CHAPTER TWO

### 2.0 PREDICTING SMALL MAMMAL AND FLEA ABUNDANCE USING LANDFORM AND SOIL PROPERTIES IN A PLAGUE ENDEMIC AREA IN LUSHOTO DISTRICT, TANZANIA

#### ABSTRACT

A study was carried out in Western Usambara Mountains, Tanzania, to investigate small mammals and flea abundances, diversity and spatial distribution in relation to soils and landforms. A digital elevation model (DEM) analysis was carried out coupled with field surveys to examine in detail landform characteristics. Soil was studied on randomly selected landforms, the sites at which small mammals were trapped. Results showed that Shannon Diversity Index increased with values of 1.58, 1.62 and 1.69 for Plain, Escarpment and Plateau respectively. Small mammal species richness also increased with elevation. Flea abundance followed small mammal trends. The observed trend is attributed to a combination of factors such as elevation, landform heterogeneity, slope gradient, shape, forms and slope aspect which have been observed determine habitats' characteristics. A landform/soil model shows that available phosphorus ( $p < 0.001$ ), aspect ( $p < 0.01$ ) and elevation ( $p < 0.01$ ) are statistically significant predictors explaining richness and abundance of small mammals. Fleas' abundance and spatial distribution were influenced by hill-shade ( $p < 0.001$ ), available phosphorus ( $p < 0.01$ ), and base saturation ( $p < 0.01$ ). This study shows that landform and soils influence small mammals and fleas abundances and their spatial distribution along the landscape. This improves our understanding of relationships between landforms, soils and abundance of small

mammals and their fleas in a plague focus and will ultimately help surveillance and control of plague hosts.

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Key words: Landforms, soil properties, rodents, fleas, plague hosts

## **2.1 INTRODUCTION**

Small mammals (particularly rodents) are considered the primary natural hosts and reservoirs of *Yersinia pestis* that infect about 203 rodent species (Sternest *et al.*, 2008; Gage and Kasey, 2005). Several studies carried out in the Western Usambara Mountains have shown a diversity of small mammals and fleas implicated as plague hosts (Laudisoit *et al.*, 2007; Kilonzo and Msangi, 1991).

Furthermore, Neerinckx *et al.* (2010) and Kamugisha *et al.* (2007) have found that plague reported cases were correlated with landforms, particularly in elevations above 1500 metres above mean sea level (a.m.s.l) in Lushoto. Similar results were reported by Eisen *et al.* (2012) and MacMillan *et al.* (2011) that plague cases in the Uganda were common above 1300 m a.m.s.l. The above studies agree with Pavlovsky (1966), Rotshild (1978) and Meade and Earickson (2000) who associated the occurrence of plague disease with landform factors, which are envisaged to influence the presence, reproduction of hosts and vectors and their interactions with humans.

In addition, soil may be an important reservoir, with burrowing animals acting as the first link in transmission to other animals and humans through flea bites (Drancourt, 2006). Some literature indicated that plague persistence in natural foci has a root cause in soils (Breneva *et al.*, 2006; Eisen *et al.*, 2008). The above hypothesis was supported by the evidence that *Y. pestis* survived in natural soil conditions from 24 days (Eisen *et al.*,

2008) to 40 weeks (Ayyadurai *et al.*, 2008). Additionally, there is a long standing hypothesis linking enzootic and epizootic plague cycles with soil micro-organisms like amoeba and with soil organic matter (Anisimov, 2002) which come in contact with burrowing rodents. Through interaction of sylvatic and commensal rodents they exchange the disease pathogens through the vectors, such as fleas (Witmer, 2004). Although there was no established direct link between plague and soil types, some research suggests a spatial distribution of small mammals and fleas in relation to landform and soils. Hence their aspect could enlighten the description of plague foci and possibly explain the nature of re-emergency of plague disease after several decades of quiescence (Neerinckx, 2010; MacMillan *et al.*, 2012).

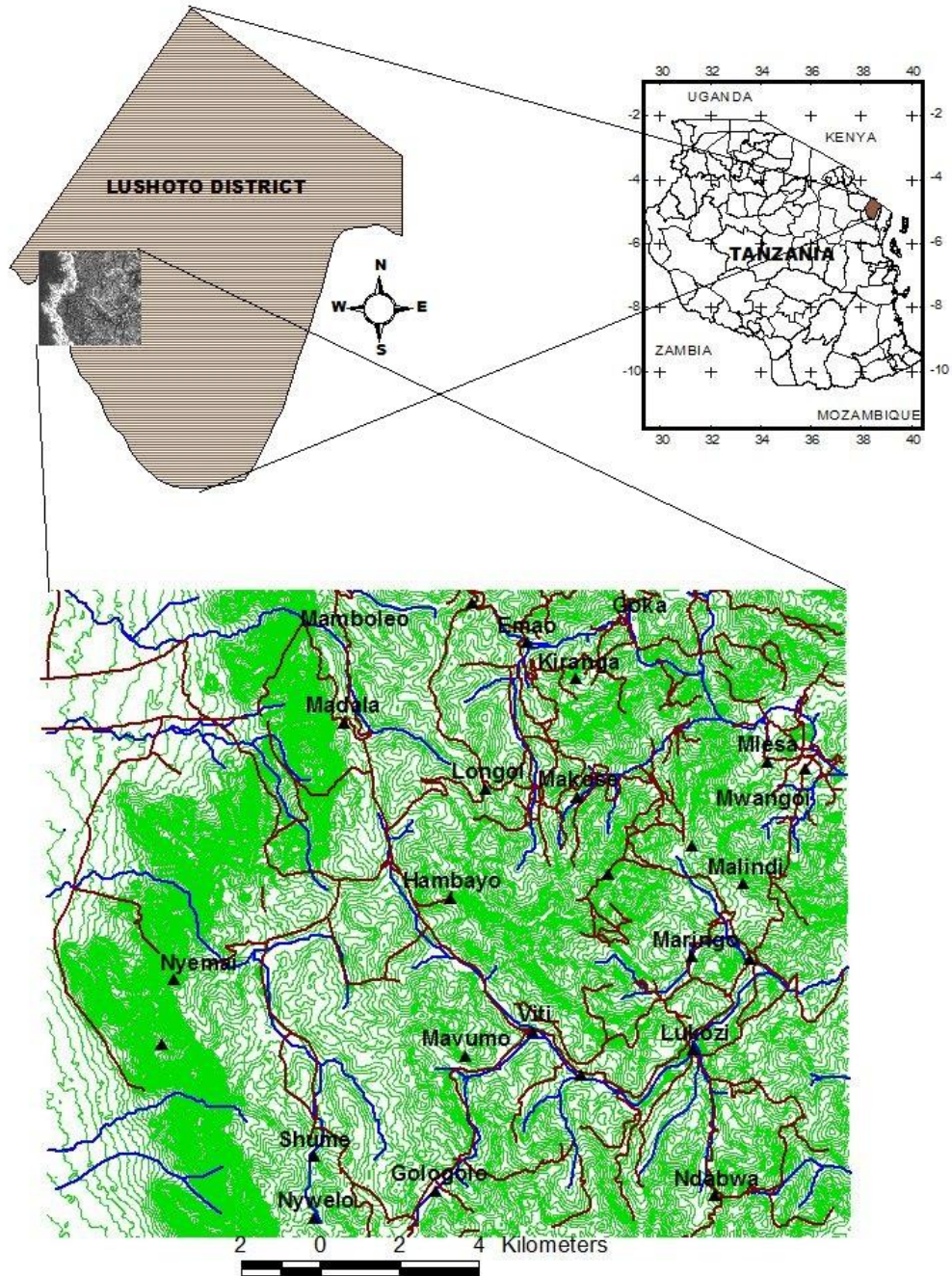
Nevertheless, studies relating landforms and soils to abundance of plague hosts and vectors are limited. It is envisaged that understanding landforms and soil properties in the Western Usambara Mountains plague focus may provide an insight into plague foci, with respect to rodents as plague hosts, and hence explain the difference of plague occurrence between neighbouring villages.

Therefore, this study aimed to examine landforms and associated soil properties with respect to occurrence of potential small mammals (rodents) and fleas in order to contribute information that would help to explain the presence and persistence of the plague focus in Western Usambara Mountains, Lushoto District, Tanzania.

## **2.2 MATERIALS AND METHODS**

### **2.2.1 Description of the study area**

The study area is located between UTM 9 474 965.2 and 9 502 528.6 N and 389 060.2 and 472 276.1 E (Figure 2.1). Altitude ranges from 418 to 2273 m a.m.s.l. The plains portion of the study area is located at 440-700 m a.m.s.l., and in the rain shade of the Usambara Mountains. The area receives a bimodal rainfall pattern with two peaks between October-December and March-May for short and long rain seasons, respectively. The Plain experiences less than 600 mm of rainfall per year, hence it has limited agricultural activities apart from sisal cultivation and overgrazing. The dominant vegetation cover is woody and thorny shrubs. From the plain follows an escarpment, situated between 700 and 1700 m a.m.s.l., with annual rainfall which ranges between 600 and 800 mm. It is mainly characterised by steep slopes of over 90 % and more than 50 % of the escarpment has vertical cliffs and boulders. Some places have canyons with relatively steep slopes but can support diverse vegetation including trees, shrubs and grasses. In view of the difficulty of accessibility, the escarpment can be considered the safe shelter for diverse small mammals, including Geneta which do not associate with humans. The upper part of the escarpment is exploited for cultivation in areas where the slope gradient allows. It is further characterised with deep soils in some places originating mainly from colluvial materials from higher steep slopes by gravity and surface run-off. The upper slopes harbour big trees and diverse woody shrubs.



**Figure 2.1: Location of the study area indicating villages**

The Plateau is situated between 1700 and 2273 m a.m.s.l., and is in the rain shadow of the Magamba ridge, which divides the plateau into a wet cold zone to the east and a cold dry

zone in the west of the ridge. The area receives an annual rainfall that varies between 600 and 800 mm during the short and long rain seasons, respectively. It is characterised by a heterogeneous landscape composed of Mountains (relief intensity of >300 m) with narrow to broad rocky crests, rocky/stony upper slopes, steep to very steep sloping ridge sides and U-shaped valley bottoms with seasonal or permanent streams.

The valley bottoms are famous for production of assorted irrigated vegetables, whereas round potatoes and cereals are produced on the sloping ridge sides. The area is also famous for Plantation Forest for commercial timber production, Natural Forest Reserve, and scattered woodlots. *Miraba* (rectangular structures) planted to different grasses such elephant grass, *Guatemala* or herbaceous plants are the main soil conservation structures all over the West Usambara highlands.

## **2.2.2 Methodology**

### **2.2.2.1 Landform characterization**

#### ***Determination of landform attributes***

A digital elevation model was obtained from Advanced Spaceborne Thermal Emission and Reflection Radiometer, Global Digital Elevation Model (ASTER-DEM) with 30 m ground resolution. It was used to derive landform attributes i.e. elevation, slope gradient, slope aspect, slope curvature (plan, profile, tangential, cross-section and general curvatures), and hill-shade. Continuous surface flow direction and flow accumulation were computed using *Algorithms* available in ArcGIS 9.3 Tool Box. The derived maps include different types of curvatures which are continuous surfaces with grey scales depicting negative (low) to positive (high) values. The positive values indicate upwardly

convex surface, whereas negative values indicate upwardly concave surfaces (Lindsay, 2005). Intensive field verification was done. Sites at which soil sampling and trapping of small mammals were carried out were superimposed and point data from individual landform characteristics (i.e. elevation, slope gradient and curvatures e.t.c.) were extracted using ArcGIS 9.3. The point data were used as landform variables in regression analysis. These characteristics were used together with soil properties to establish relationships between landforms and occurrence of small mammals and fleas.

#### ***Determination of soil properties***

A map was derived from a digital elevation model and topographic map with GPS adjusted points of the area at the scale of 1:50 000 was enlarged to produce a working map at scale of 1:10 000. This working map was used to select sites for soil sampling. From each representative landform (plain, escarpment and plateau) features soil samples were taken from topsoils at a depth of the 0 - 45 cm which was considered the maximum depth for most rodent burrows (Brabers, 2012). A total of 57 soil samples were collected from corresponding 57 georeferenced sites. The soil samples were analysed in the Laboratory for texture, pH<sub>water</sub>, EC, Total N%, Organic C%, CEC, exchangeable bases and micronutrients as per procedures described by Moberg (2000).

#### **2.2.2.2 Determination of occurrence of small mammals and fleas**

Trapping of small mammals was conducted twice at sites where soil samples were collected, between December 2009 and March 2010. Traps of different types and sizes were employed to capture diverse small mammal sizes and species in the field (Mengak and Guynn, 1987). The traps used were (i) Sherman live trap (23 x 9.5 x 8 cm) traps, (ii)

locally made wire cages (for bigger sized small mammals like squirrel, genet) and (iii) Pitfall traps, which are 10-litre plastic buckets. The total number of traps used was 300, of which 270 were Sherman, 15 wire cages and 15 pitfalls. The traps were arranged in lines each with 10 trapping stations placed 10 m apart and left open during the day and night for two consecutive nights (Mulungu *et al.*, 2008).

Traps were inspected every morning between 09.00 and 10.00 a.m whereby those with catches were replaced by spare traps and bait. The timing allowed capturing both diurnal and nocturnal small mammal species. Peanut butter mixed with maize bran, roasted maize grains and sardines were used as bait. The trapped small mammals were counted and recorded. The fleas were removed from the animals by brushing the fur using ethanol, counted, recorded and stored.

### **2.2.2.3 Data analysis**

Data were statistically analysed using generalized linear Model (GLM) the commonly used model in ecological studies, implemented in Deducer the R GUI (Fellows, 2012). The small mammals and fleas (dependent variables) and landform features and soil properties (independent variables) were subjected to regression analysis to establish occurrence of small mammals and fleas in the different landforms found in the study area. Several cycles of GLMs were run and the best five were selected using their Akaike Information Criteria (AIC) (Akaike, 1974). The GLM with low value of AIC is the best model. The occurrence of small mammals and fleas in different landforms was validated using model goodness of fit given by pseudo R-squared ( $R^2$  or  $D^2$ ).

Diversity statistics on small mammals' richness and evenness in respective landform units and flea abundances were assessed using the Shannon Diversity Index (Shannon, 1948), the most commonly used index in ecology for assessing diversity. The idea behind this index is that the diversity of a community is similar to the amount of information in a code or message or the *communication entropy* that was introduced by Shannon (1948), and it is stated as:

$$H' = - \sum_{i=1}^S \frac{n_i}{N} \ln \left( \frac{n_i}{N} \right) \dots \dots \dots (1)$$

Where:

$H'$  = is the Shannon diversity index,

$S$  = species richness (number of species), and

$n_i$  = is the number of individuals in the  $i^{\text{th}}$  species,

$\frac{n_i}{N}$  = proportion abundance contributed by the  $i^{\text{th}}$  species to the total

$N$  = is the total number of individuals.

Typical values are generally between 1.5 and 3.5 in most real communities' ecological studies, and the index is rarely greater than 4, and it increases as both the richness and the evenness of the community increase (Kerkhof, 2010; MacDonald, 2003; Reish, 1984).

Although the Shannon index is widely used to establish diversity in different ecological undertakings, there have been the criticisms that the "index" is not by itself 'diversity' (Jost, 2006, 2007). Therefore, it is suggested to use the effective number of species, which

are the diversity themselves, by converting the diversity index into effective number of species using the formula:

Shannon effective number of species =  $e^{H'}$  (which is equal to  $(\exp H')$ )..... (2) Jost (2006). However, the Shannon diversity index is affected by both the number of species (S) and their *equitability*, or *evenness*, whereby the greater the number of species and the more evenly distributed the species are, both increase diversity as measured by H'. The maximum diversity ( $H_{\max}$ ) of a sample is found when all species are equally abundant.  $H_{\max} = \ln S$ , where S is the total number of species. Therefore, the actual diversity value (H') is compared to the maximum possible diversity by using an evenness measure (J'), which is a measure of the homogeneity of abundances in a sample or a community.

The evenness of the sample is calculated by the formula:

$$J' = H'/\ln(S)..... (3)$$

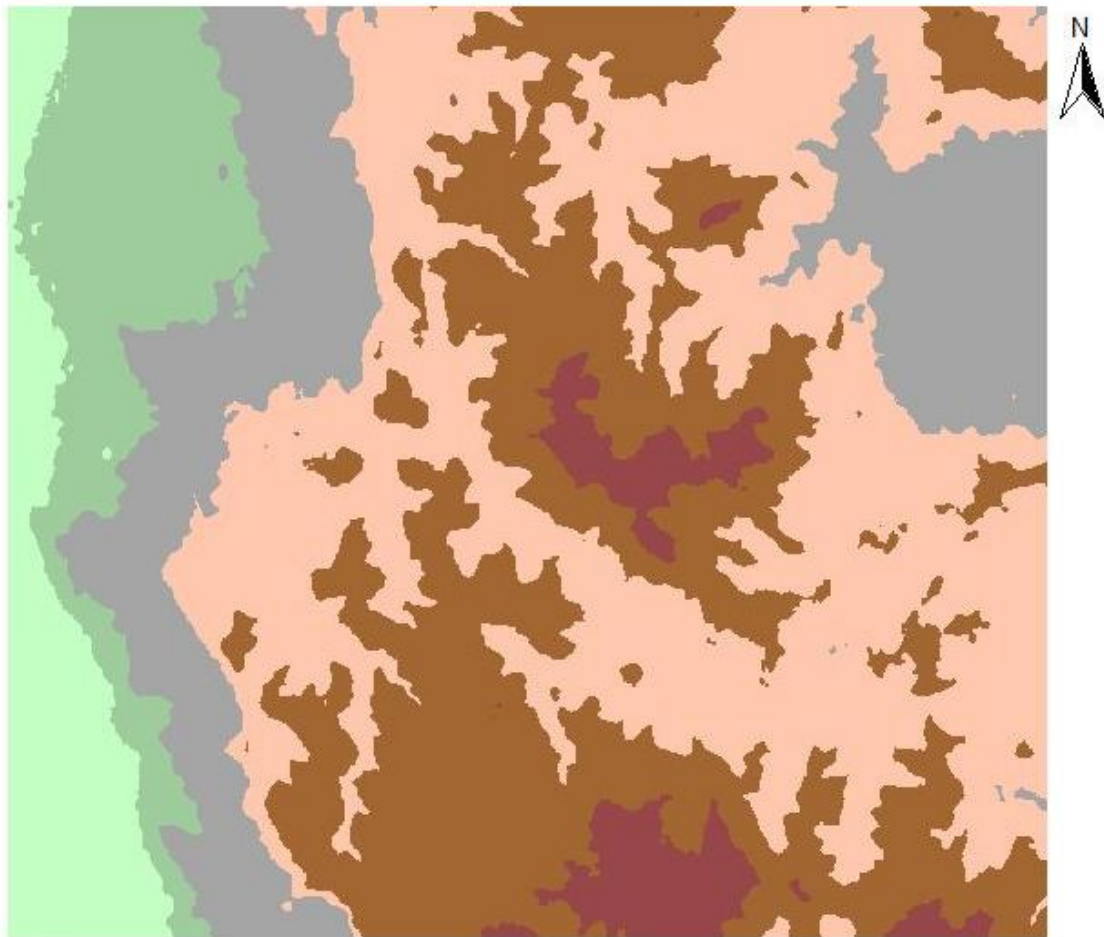
The assumption of species evenness (J') is that all species are represented within the sample, and values range between 0 and 1.0.

## **2.3 RESULTS AND DISCUSSION**

### **2.3.1 Landform characteristics in the study area**

Figure 2.2 presents the major landforms and their associated characteristics in the study area. Results show that the landforms are variable, with strong dissection and steep slopes of different curvatures. The dissection constitutes a complex system of elongated terraced ridges separated by narrow to wide drainage U-shaped valleys (converging hydrological

flows). The steep slopes and strongly dissected ridges are characterised by localized rock outcrops, scarps and, in places, landslide scars with shallow soils. The observed landforms in the study area are complex surface features with varying moisture conditions, vegetation and microclimates. These conditions are reported to influence the occurrence of small mammals, fleas and human activities (Randhir, 2007; Jake *et al.*, 1997; Monjeau *et al.*, 1997).



**Key**

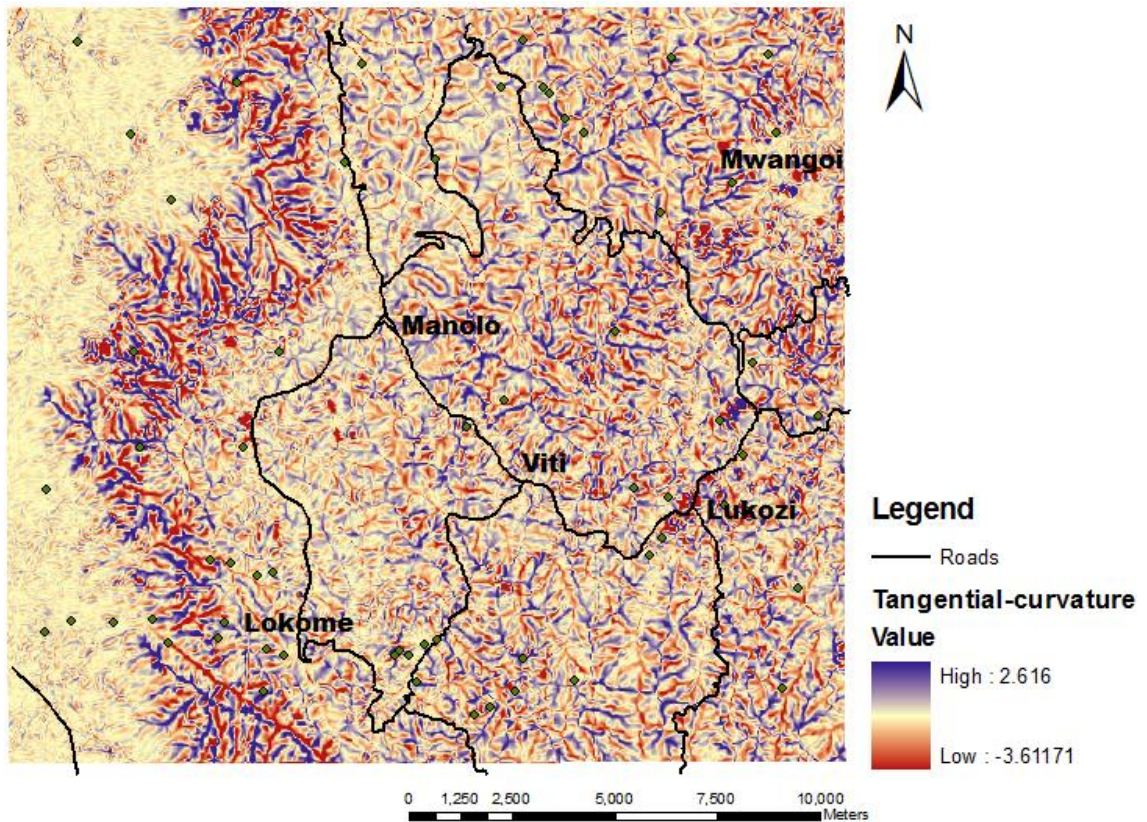
Elevation variation (m a.m.s.l)		
427 - 632	Almost flat plain	
633 - 837	Undulating to rolling plain	
838 - 1657	Escarpment and or depression	
1658 - 1862	Medium altitude broad crests ridges dissected plateau	
1863 - 2067	Medium altitude strongly dissected plateau	
2068 - 2273	High altitude dissected plateau with rock outcrops narrow crests	

1 0 1 Kilometers

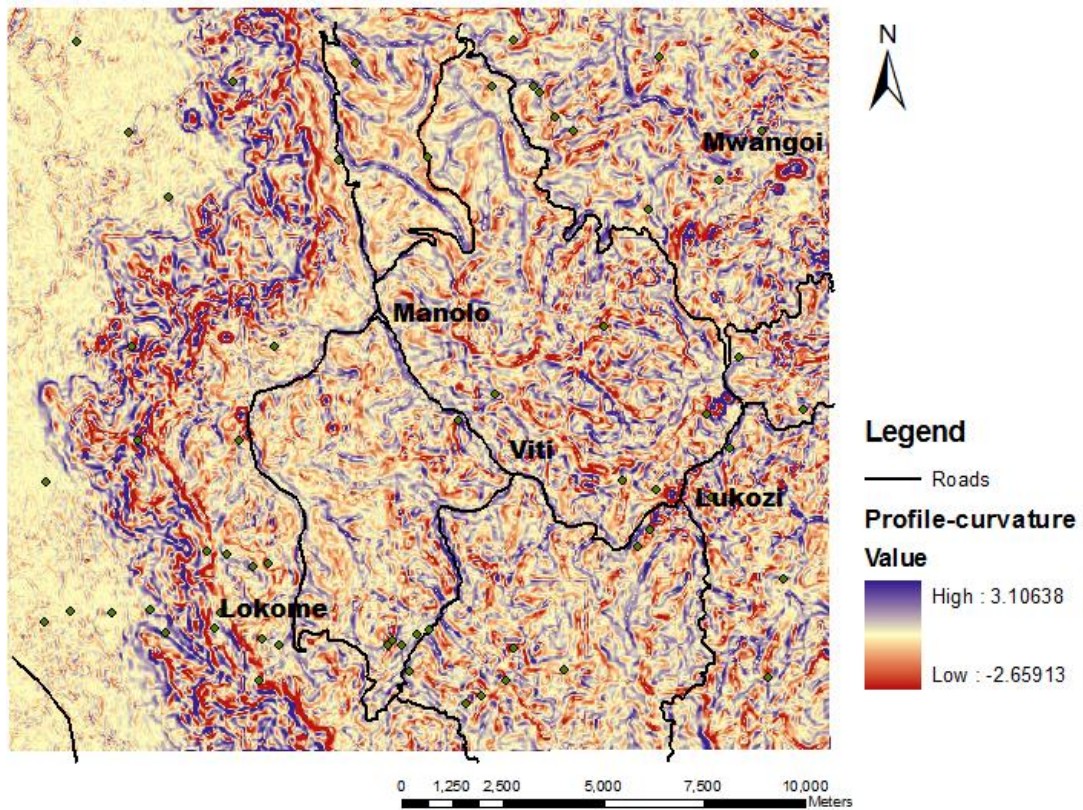


**Figure 2.2: Landform characteristics in the study area**

Figures 2.3 and 2.4 present results on surface curvature. Both profile and tangential curvatures show grey scales with high to low values. The observed values show the degree of concavity and convexity of the surface in the direction perpendicular to the direction of the steepest descent. The curvatures influence convergence and divergence of water flows, soil water content and soil water retention. These results are in line with various hydrological studies which show that slope facets on a landform influence water flows (Lindsay, 2005) and, therefore, food access and vegetation habitat for small mammals (Monjeau *et al.*, 1997).

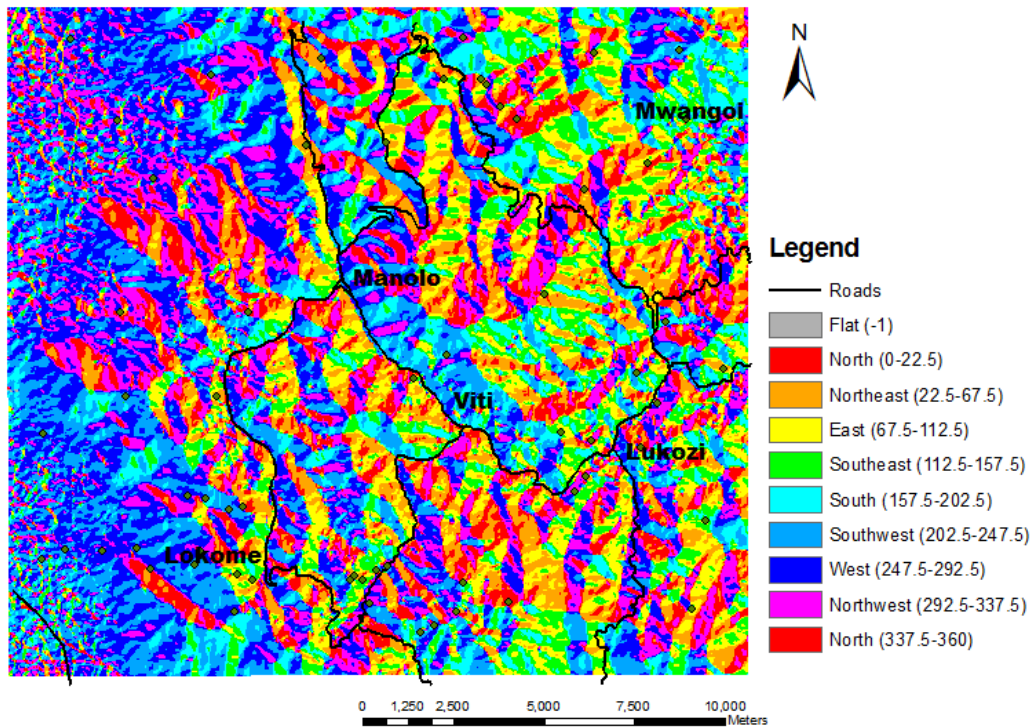


**Figure 2.3: Surface tangential curvature for the study area**



**Figure 2.4: Surface profile curvature for the study area**

Figure 2.5 presents results on slope aspect in the area which is multi-directional ranging clockwise from  $0^\circ$  (North),  $90^\circ$  (East),  $180^\circ$  (South)  $270^\circ$  (West). The aspect modulated by slope gradient influences slope local climate, especially solar radiation and exposure to winds (Warren *et al.*, 2013; Goudie, 2013). Slope aspect, therefore, impacts on vegetation habitat and differential soil development.



**Figure 2.5: Slope aspect for Western Usambara Mountains, Lushoto District**

### 2.3.2 Soil properties

The soil properties in the study area were strongly correlated with landforms. Table 2.1 presents results on dominant soil properties in the study area. The results show that soils are sandier in the plains but decline with elevation to clayey in the plateau. The OC % content shows variations with landform, with values ranging from 0.6 to 2.9 % for the plain and plateau, respectively. The studied micronutrients show an increase from low in the plain to toxic levels in the plateau for mainly Fe and Mn, considering agronomic critical levels reported by Deb and Sakal (2002) and Kang and Osiname (1985), respectively. These results agree with findings which reported that landforms greatly influence variability and distribution of soil macronutrients (Verma *et al.*, 2005; Jiang *et al.*, 2006).

The observed results conform to the findings by Moore *et al.* (1993) and Gessler *et al.* (2000) who reported that the development of catenary soil properties occurs as landscape response to the way water moves through and over the landscape, being governed by surface characteristics (convergence and divergence). Other works indicate that the soil-landscape pattern results in from an integration of shortterm and longterm pedogeographic processes (Van de Wauw *et al.*, 2008; Bockheim *et al.*, 2005).

**Table 2.1: Means of selected soil physico-chemical properties in the study area, in part of Western Usambara Mountains, Tanzania**

Landforms	(n=54)			Soil physico-chemical properties					
	Clay (%)	Sand (%)	Silt (%)	pH (water)	OC (%)	CEC cmol <sub>c</sub> /kg soil	Ca cmol <sub>c</sub> /kg soil	Mg cmol <sub>c</sub> /kg soil	K cmol <sub>c</sub> /kg soil
Plain	18.31	69.74	11.85	7.9	0.61	12.1	8.9	2.9	0.34
Escarpment	26.48	61.15	12.26	7.6	2.77	18.1	13.9	1.9	0.29
Plateau	52.48	38.7	8.82	5.7	2.91	18.3	7.1	2.2	0.15

### 2.3.3 Distribution of small mammals and fleas along the landforms

Table 2.2 – 2.4 presents diversity (richness and evenness) of small mammals and fleas' abundance in different habitats along the landforms in the studied landscape. Results show that the Shannon Diversity Index increased with increasing elevation. The species relative abundance shows that *Acomys wilson* and *Xerus erthropus* were dominantly found in the plains (Table 2.2) whereas *Aethomys chrysophilus* and *Lophuromys kilonzoii* dominated in the escarpment (Table 2.3) and *Praomys delectorum*, *Mastomys natalensis* and *Lophuromys kilonzoii* were the dominant rodent species on the plateau. Flea abundance also followed the trends of rodent species. The observed results could be

attributed to the theory of elevation diversity gradient (McCain, 2005) which takes into account integration of multiple ecological factors including elevation, heterogeneity of landforms, rainfall, temperature, habitat types and resources availability to account for the distribution of small mammals (Pavoine and Bonsall, 2010; Ackerly, 2003; Heaney, 2001; Sanchez-Cordero, 2001; Grytnes, and Vetaas, 2002; Rahbek, 1995; Rosenzweig, 1992).

Furthermore, results show that the slope aspect is among the strong predictors of small mammal abundance in the study area ( $p < 0.01$ ). This conforms to results by Urban and Swihart (2010) that species richness was influenced by slope aspect in Indiana, in the USA.

Small mammal habitats represented mainly by vegetation cover in the area varied with landform units. Shrubs dominated the plain and escarpment and natural forest, cultivation and plantation forests covered the plateau (Table 2.3 - 2.4). The results on small mammals' distribution could be attributed to soils, elevation and rainfall in an integrated way. According to Rosenzweig (1992), there are many mechanisms that operate together to influence biodiversity changes in communities. The mechanisms act together and in the ecosystem none works in isolation (McCain, 2005). The landform units in the study area have distinctive characteristics in terms of rainfall, which is low in the plains and increases gradually with elevation from 500 to 800 mm per year in the upper parts of escarpment and in the plateau. The soils are mainly Cambisols in the plain, Regosols and Leptosols in the escarpment while in the plateau there are more highly developed and weathered, very deep, well drained soils (Acrisols, Lixisols and Luvisols) which are

dominant in sloping lands whereas Gleysols are found in valley bottoms and depressions. So, the observed habitat types possibly were dictated by multiple factors namely climate, landforms and soils, among others.

**Table 2.2: Landforms characteristics, soil types and small mammals' abundance and diversity and corresponding fleas' abundances within the undulating to rolling plain**

Landforms	Altitude range (m a.m.s.l.)	Slope gradient (%)	Dominant soils	Species' name	Small mammals abundance	Fleas' abundance	Small mammals' diversity index
Undulating plain	510-531	4-7	Fluvic Cambisols/Mollic Fluvisols	<i>Acomys wilson</i>	46.7	14	
Undulating plain			Fluvic Cambisols/Mollic Fluvisols	<i>Helogale parvula</i>	12.5	0	
Undulating plain			Fluvic Cambisols/Mollic Fluvisols	<i>Xerus erthropus</i>	16.7	0	
Rolling Plain	696	12-15	Mollic Leptosols/Cutanic Luvisols	<i>Genetta genetta</i>	9.1	5	<b>1.58</b>
Rolling Plain			Mollic Leptosols/Cutanic Luvisols	<i>Xerus erthropus</i>	21.4	1	
Rolling Plain			Mollic Leptosols/Cutanic Luvisols	<i>Acomys wilson</i>	50.0	0	
Rolling Plain	704	12 -15	Mollic Leptosols/Cutanic Luvisols	<i>Praomys delectorum</i>	33.3	0	

**Table 2.3: Landforms characteristics, soil types and small mammals' abundance and diversity within the escarpment**

Landforms	Altitude range (m a.m.s.l.)	Slope gradient (%)	Dominant soils	Species' name	Small mammals' abundance	Fleas' abundance	Small mammals' diversity index
Lower escarpment	765-807	15-30	Rocky/cliffs, Regosols/Lithic Leptosols	<i>Aethomys chrysophilus</i>	16.7	15	
Lower escarpment	878	56	Rocky, cliffs, Regosols/Lithic Leptosols	<i>Acomys wilson</i>	12.5	0	
Upper escarpment	1159-1604	32-80	Rock outcrops/Regosols/Lithic Leptosols	<i>Aethomys chrysophilus</i>	43.8	5	
Upper escarpment	1123-1604	45-55	Rocks/Regosols/Lithic Leptosols	<i>Grammomys dolichurus</i>	50.0	1	
				<i>Luphoromys kilonzoi</i>	50.0	4	<b>1.62</b>
				<i>Mastomys natalensis</i>	50.0	0	
				<i>Otomys angoniensis</i>	50.0	0	
				<i>Praomys delectorum</i>	25.0	0	

**Table 2.4: Landforms characteristics, soil types and small mammals' abundance and diversity within the plateau landscape**

Landforms	Altitude range (m a.m.s.l.)	Slope gradient (%)	Dominant soils	Species' name	Small mammals' abundance	Fleas' abundance	Small mammals' diversity index
Plateau	1885	23	Ferralsic Cambisols/Cutanic Acrisols	<i>Aethomys chrysophilus</i>	50.0	2	
Plateau	1887		Lithic Leptsols/Regosols	<i>Crocidura hirta</i>	60.0	0	
Sloping ridge of Plateau	1771-1918	20- 90	Cambisols/Alisols	<i>Grammomys dolichurus</i>	68.6	40	
Sloping ridge of Plateau	1887	20-90	Cutanic Acrisols/Alisols /Cambisols	<i>Lophuromys kilonzoii</i>	71.8	19	
Sloping ridge of Plateau	1739	20-90	Cambisols	<i>Mastomys natalensis</i>	110.8	32	1.69
Plateau, sloping/valleys	1739	7-70	Mollic Fluvisols/Gleysol	<i>Mouse legeda</i>	36.4	0	
Sloping ridge of Plateau	1771-2011	20-90	Acrisols/Alisols /Haplic Cambisols	<i>Praomys delectorum</i>	100.0	44	
Sloping ridge of Plateau	1900-1904	20-90	Acrisols/Lixisols/Haplic Cambisols	<i>Rattus rattus</i>	40.0	2	
Sloping ridge of Plateau	1753-1903	20-70	LithicLeptsols/Mollic Regosols	<i>Mus munitoides</i>	33.3	0	

These also influence the distribution, richness and evenness of small mammals and accompanying fleas (McCain, 2005), because they impact resource availability including food, water and shelter (Heaney, 2001; Pavoine and Bonsall, 2010) in ways that affect the distribution of the hosts and vectors.

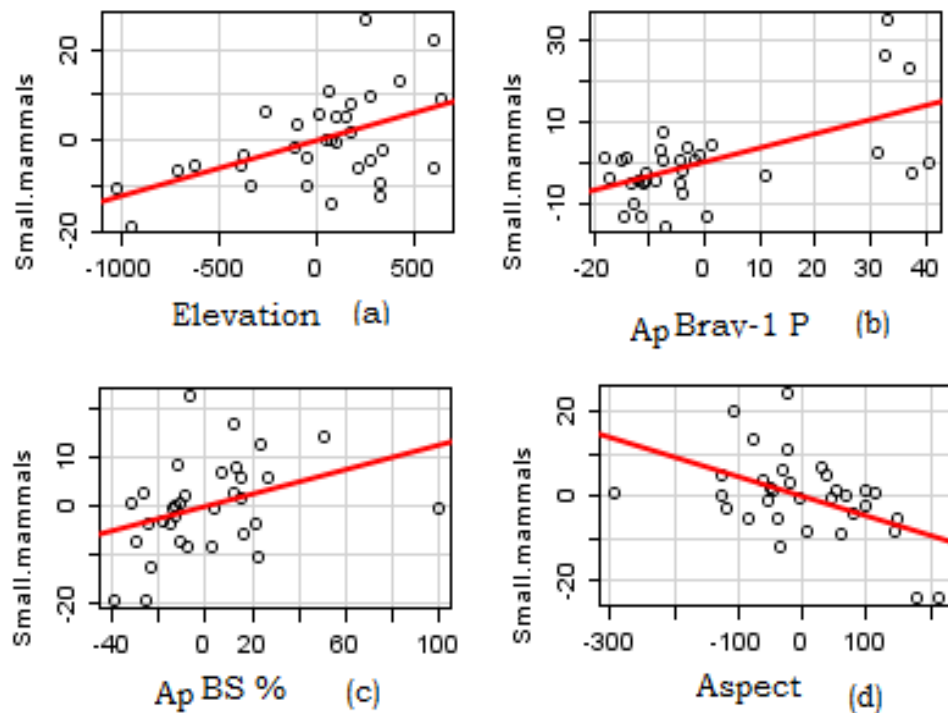
### 2.3.4 Influence of landform attributes and soil properties on small mammals and fleas

A landform-soil properties model for the quantification of small mammals and fleas' results is presented in Table 2.5. The results demonstrate significant relationships between occurrence of small mammals and fleas' with landform features, namely elevation and aspect. Among the studied soil chemical properties, Bray-1 extractable phosphorus (P) showed a significant correlation with the occurrence of small mammals and fleas.

**Table 2.5: Soil and landform predictors for small mammals' distribution along the landforms Western Usambara Mountains, Tanzania**

Selected GLM model	Akaike Information criteria (AIC)	Pseudo R-squared	Statistically significant predictors
1	247.1	55.2	Aspect ** Ap base saturation* Elevation ** Bray P ****
2	250.3	61.2	Aspect* Ap base saturation . Elevation** Bray P****
3	255	49.4	Elevation** Ap-Sand . Bray P****
4	256.6	50.2	Elevation** Bray P****
5	257.5	42.4	Elevation * Bray P .

Results identify elevation as the most influencing landform factor, with a strong positive correlation, whereby number of small mammals increased with increasing elevation (Fig. 2.6a). The large number of small mammals in high elevations in the Western Usambara Mountains corresponds with plague reported cases in the high plague frequency landforms. Previous work in the area has shown that every plague outbreak was preceded by rodent outbreaks (Kamugisha *et al.*, 2007). Similar results have been reported by Eisen *et al.* (2012) in Uganda, showing that plague cases were found on an altitude above 1300 m a.m.s.l. Also, Neerinckx *et al.* (2010) reported a high correlation between plague outbreak and elevation and vegetation cover.

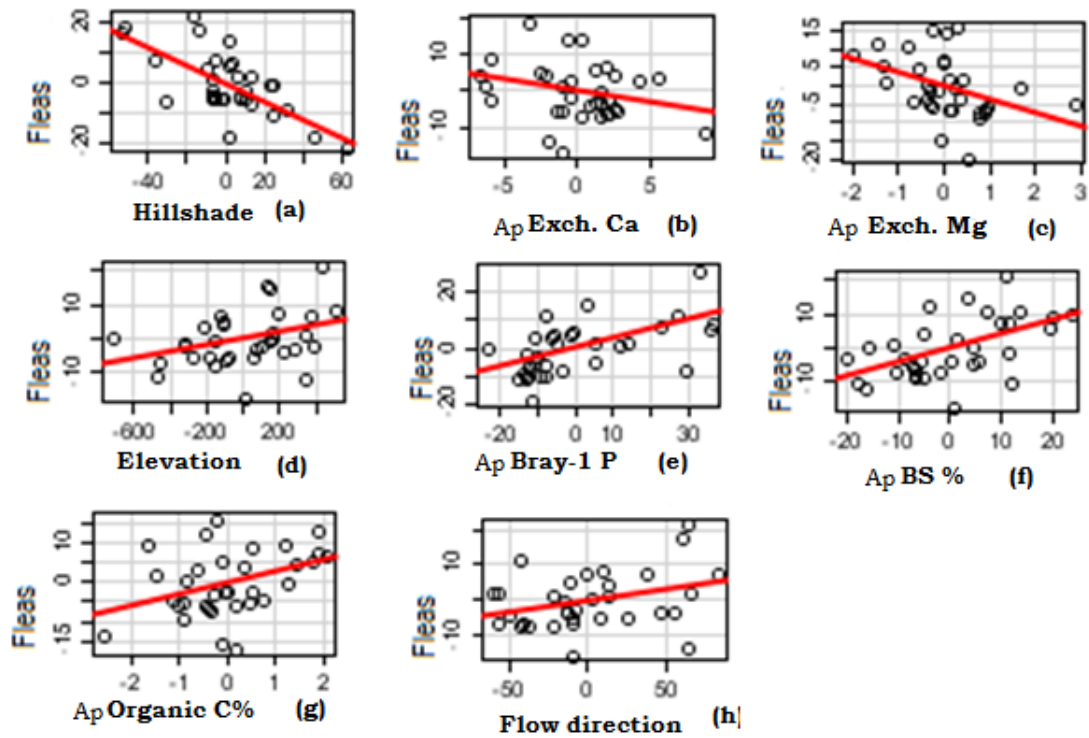


**Figure 2.6: (a-d): Influence of landform and soil properties on the occurrence of small mammals in Western Usambara Mountains, Tanzania**

Furthermore, results show that there was positive correlations between extractable phosphorus, base saturation percentage and the number of small mammals (Fig. 2.6 b and c), the result that could be attributed to the role of extractable phosphorus in soil fertility and establishment of vegetations while high base saturation percentage also shows a high proportion of bases in the soil implying good fertility for vegetation including habitats.

However, there was a negative correlation between small mammal numbers and slope aspect in the studied area (Fig. 2.6 d) and this could be attributed to the influence of aspect on climatic factors that negatively affect vegetation habitat, food and water resources, which are important for small mammals' habitation (Busch *et al.*, 2000). The best two models explained between 55 to 61 % (Table 2.5) of the variance observed in the prediction of small mammals' abundance. Phosphorus indicated a strong influence on small mammals probably because of its availability in adequate levels, which favours vegetation growth, hence providing cover and habitat to rodents (Mulungu *et al.*, 2008) but also food and herbage (Krebs, 2001).

Figure 2.7 (a-h) and Table 2.6 present results on the influence of landforms and soil properties on fleas' abundance. Fleas' abundance declined with increased hill-shade (Fig. 2.7a), exchangeable calcium (Fig. 2.7b), and magnesium (Fig. 2.7c) while their abundance increased with increasing elevation (Fig. 2.7d), extractable phosphorus (Fig. 2.7e) and base saturation (Fig. 2.7f). Results further showed increased fleas abundance with increasing soil organic carbon (Fig. 2.7g) and flow direction (Fig. 2.7h). Table 2.6 indicates the significance levels of influence of the above outlined factors on fleas' abundance.



**Figure 2.7: (a-h): Influence of individual landform-soil properties on abundance of fleas**

**Table 2.6: Landforms and topsoil predictors of fleas' abundance**

Variables	Coefficient Estimate	Std. Error	t value	Pr(> t )
(Intercept)	20.889	12.493	1.67	0.1075
Elevation (m a.s.l.)	0.0097	0.005	1.82	0.0821.
Hill-shade	-0.3039	0.066	-4.63	0.00011***
Flow direction	0.0665	0.038	1.74	0.0950.
Org C (%)	2.9399	1.409	2.09	0.0477*
Available Bray P	0.3319	0.094	3.55	0.0016**
Exchangeable Ca	-0.6331	0.465	-1.36	0.1856
Exchangeable Mg	-3.6939	1.670	-2.21	0.0368*
Base saturation	0.4296	0.138	3.11	0.0048**

Signif. Codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for Gaussian family; Null deviance: 5524.2 on 32 degrees of freedom, Residual deviance: 1850.7 on 24 degrees of freedom. AIC: 246.53

The observed decrease in flea abundance could be attributed to energy, particularly from sunshine, which affects survival of fleas, which are ecto-thermic, hence susceptible to

temperature fluxes (Gage *et al.*, 2008). Although fleas' abundance has followed a similar trend with that of small mammals (Tables 2.2-2.4), literature show that flea survival and richness is dependent on local microclimatic factors like soil relative humidity fluctuations and temperature (Sternest *et al.*, 2006; Gage and Kasey, 2005; Ensore *et al.*, 2002, Krasnov *et al.*, 2001). Temperature has been reported to influence flea egg laying, egg survival and fleas' reproduction and development. Soil attributes are important because they influence moisture retention and humidity in burrows, and abrasive soils can damage the fleas' exoskeleton (Biggins, 2012). This could explain why there were few fleas in the drier plains and more in the moist plateau. Also, other studies have reported that the vectors encountered in a given area are related to specific locations and the host species (Kennedy and Bush, 1994; Caro *et al.*, 1997; Krasnov *et al.*, 2005) and these account for the observed correlation between fleas' richness of trapped small mammals, in the present study.

## **2.4 CONCLUSIONS AND RECOMMENDATIONS**

### **2.4.1 Conclusions**

It is concluded that landform and soils have a strong influence on the richness and evenness of small mammals and fleas' abundance. Elevation and aspect are strong landscape predictors whereas extractable phosphorus and the base saturation are strong soil predictors for richness and evenness of both small mammals and flea abundance. Distribution of fleas was mainly influenced by hill-shade and extractable phosphorus, organic carbon and exchangeable magnesium.

The insights into small mammals and flea dynamics in relation to soils and landforms in the plague focus of Western Usambara Mountains have contributed to the debate on plague-host-vector relationships.

#### **2.4.2 Recommendations**

It was observed that most rodents which are implicated for being plague hosts were found in the upper parts of the escarpment, and their habitat was identified. It is recommended to step up surveillance of rodent populations in those habitats so as to check plague disease in the nearby villages.

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### CHAPTER THREE

#### 3.0 STATUS AND VARIABILITY OF SOIL MICRONUTRIENTS WITH LANDFORMS IN THE PLAGUE FOCUS OF WESTERN USAMBARA MOUNTAINS, TANZANIA

##### ABSTRACT

A study was carried out in Western Usambara, Tanzania to assess the status of soil micronutrients across three geomorphic units viz., plain, escarpment and plateau in order to provide essential information for on-going studies on plague epidemiology. Nineteen soil profiles were opened, described and 54 samples collected for laboratory analysis. Standard methods were employed to analyse soil physical and chemical properties. Micronutrients Fe, Mn, Cu and Zn were extracted by DTPA and quantities estimated spectrophotometrically. Spatial distribution of micronutrients along the geomorphic units and within pedons was studied using descriptive statistics, correlation, ANOVA and means separation was done by Tukey's test at 95% confidence interval in Minitab 14 software. Relationships between small mammal and flea abundance and micronutrients were established by regression analysis using R-software. Results showed that DTPA extractable Fe, Mn, Cu and Zn were variable. Fe ranged from 2.13 to 399.4 mg/kg soil, with a mean of 65.3 mg Fe/kg soil across the geomorphic units. Mn ranged from 0.59 to 266.28 mg Mn/kg soil while Cu ranged from 0.25 to 8.19 mg/kg soil with a mean of 2.98 mg Cu/kg soil. Results show that Zn ranged from 0.08 to 19.6 mg Zn/kg soil, with a mean of 1.16 mg Zn/kg soil. Generally, micronutrients declined with soil depth. The micronutrient levels were high in the geomorphic units with the trend: plateau > escarpment > plain. Iron was found to significantly  $P < 0.01$  and  $P < 0.05$

influence plague hosts and vectors. The study concludes that micronutrients vary with soils and geomorphic units. Iron had positive influence on plague hosts and vectors. Further research on the relationships between micronutrients, and plague hosts and vectors in different plague foci in the country is recommended.

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Key words: Geomorphic units, critical levels, trace elements, ecological research, iron, manganese

### **3.1 INTRODUCTION**

Previous research works by Eisen *et al.* (2008) and Breneva *et al.* (2006) have shown that plague persistence in natural foci has some root cause in soils. The work by Rotshild (2001) has indicated that plague outbreaks in the Altay Mountains in East-Central Asia was correlated with medium to high concentrations of iron and low concentrations of copper in soils. It was further reported that high levels of manganese, iron, copper, and zinc in soils influenced the progression of *Y. pestis* infections in three gerbil species (Mezentzev *et al.*, 2000). Thus, ecological factors in plague epidemiology, particularly landforms and soil characteristics (especially the concentrations of micronutrients) are important. However, researches which have been carried out in this direction were of small scales and addressed only a few soil properties like texture and few selected macronutrients (Neerinckx *et al.*, 2010) and/or were conducted only at laboratory experimental level (Eisen *et al.*, 2008). Generally, those studies confined their scope to whether or not the plague causing bacteria *Y. pestis* could survive in soils under natural environment.

Spatial distribution of micronutrients (also referred to as trace elements) in Western Usambara Mountains plague focus has not been adequately studied, although these

nutrients are important for small mammals' habitat and general plant growth (Nube and Voortman, 2006; Dickinson *et al.*, 2008; Thompson and Amoroso, 2011). It has been reported that, well established plants influence small mammals' habitation as they provide shelter and food resources (Busch *et al.*, 2000). These provisions include micronutrients, which are also important for biogeochemical functions in plants and animals (Rengel, 2003; Gao *et al.*, 2008). Therefore, there have been pragmatic limitations particularly in description of the plague focus in Western Usambara Mountains where there have been phases of plague ecology studies.

Following the inadequacy of the existing landscape scale studies, different authors (Annaert, 2010; Neerinckx *et al.*, 2010; Brabers, 2012) have suggested that to gain new insights on landscape-ecological factors affecting plague hosts' and vectors' abundance, diversity and dynamics, detailed scale landform and soil studies should be taken into account. Although, there were ongoing ecological studies on plague disease occurrence in Western Usambara Mountains, it is apparent that relationships between soil micronutrients and landforms, which are important factors for habitation of plague hosts and vectors, have not been explored adequately (Brabers, 2012). Therefore, this study attempted to investigate the status of soil micronutrients and their variability with respect to landforms in order to contribute to the on-going landscape-ecological studies on plague disease in the area.

## **3.2 METHODOLOGY**

### **3.2.1 Description of study area**

The study was conducted between September 2009 and June 2013 in Western Usambara Mountains, Lushoto District, Tanzania, situated between latitude 04°30' through 04°45'S

and longitude 38°00' through 38°45'E. The area is covering three geomorphic units, namely the Plains, Escarpment and Plateau. The plains are located within the altitude range of 381 – 591 metres above mean sea level (m a.m.s.l.), and topography rises from plain to the plateau at 2273 m a.m.s.l.). The Western Usambara Mountains are part of the East African Arc Mountains in Tanzania, which were tectonically uplifted with formation of the East African Rift during the Tertiary Epoch (Shackleton, 1993). The escarpment rises abruptly from the surrounding plain to over 1500 m a.m.s.l. It is characterised by steep slopes of over 100 per cent and in some areas the escarpment forms a series of vertical cliffs. The plateaux are strongly dissected into a network of terraced ridges characterised by relief with steep slopes and drainage patterns that follow fault-controlled troughs (Lundgren, 1980). The valleys which were originally V-shaped are now filled in with sediments, resulting in U-shaped, and/or flat valley floors. The main rock types consist of Precambrian metamorphic rocks such as pyroxene garnet-granulites and hornblende gneisses and schists, which form the substrates of the soils (Mutakyahwa *et al.*, 2003).

The study area receives a weak biannual mode of rainfall that ranges from 600 to 1200 mm/year. The mean annual temperature and relative humidity are variable depending on the relief. The temperatures in the plains are high ranging from 27 to over 30 °C. In the plateau temperatures are lower ranging from 15 to 19 °C during the cold season and over 25 °C during the dry warm season.

Crop cultivation takes place mostly on slopes and on narrow U-shaped valley-bottoms where traditional irrigation is used to grow mostly vegetables. Crops are mainly tropical cereals and legumes with limited use of fertilisers, although there have been annual

increases in the recent years of fertiliser use, mainly a mix of inorganic and farmyard manure.

### **3.2.2 Determination of spatial distribution of soils in the area**

Fieldwork was carried by selecting transects that could give diverse geomorphic units and soils. Auger hole boring was done along the selected transects. Auger holes were drilled to a depth of 150 cm where the soil was not obstructed by rock or coarse gravel. The geomorphic units and soil characteristics from the auger holes were described according to the guidelines for soil profile description (FAO, 2006). A total of 19 representative soil profile pits were dug, described, studied and samples collected from natural horizons for laboratory analysis. Fifty four soil samples were collected and used in the analysis of macro and micronutrients. Landform analysis was done using digital elevation model (DEM) to study elevation and slope gradient which are among geomorphic factors that influence soil formation and their properties (Brady and Weil, 2002; MacMillan and Shary, 2009).

### **3.2.3 Trapping of plague hosts and vectors**

Trapping of small mammals (plague hosts) was done twice in December 2009 and March 2010, on sites where soil profiles were located. In order to diversify small mammals' species captured, three types of traps were used: (i) Sherman live traps (23 cm x 9.5 cm x 8 cm) were used to capture smaller species, (ii) locally made wire cages for bigger species such as squirrel (*Xerus erthropus*) and genetta (*Genetta genetta*), and (iii) the pitfall traps (10-litre plastic buckets). Three hundred traps composed of 270 Sherman, 15 wire cages and 15 pitfalls were used in the trapping exercise. The traps were provided with bait which was peanut butter mixed with roasted maize grain bran and sardine. Traps were

arranged in lines of 10 traps and placed 10 m apart, left open during the day and night for two consecutive nights. Traps were inspected every morning between 08.00 and 10.00 hrs whereby those with catches were replaced by spare traps and bait. The trapped small mammals were counted, and identified to species level using the nomenclature by Kingdon (1997). Fleas (plague vectors) were removed from small mammals by brushing the fur using ethanol, counted and recorded. The data for small mammals and fleas were organised per specific landforms in a spread sheet for data analysis.

### **3.2.3 Laboratory analysis**

Chemical and physical soil properties were analysed in the laboratory following standard procedures outlined by Moberg (2000). Diethylene triamine pentaacetic acid (DTPA) extractable micronutrients Fe, Mn, Zn and Cu were determined using the method by Lindsay and Norvell (1978) and concentrations of Fe, Mn, Zn and Cu in the DTPA extracts were determined by Atomic Absorption Spectrophotometer (AAS).

### **3.2.4 Statistical analysis**

Data on geomorphic unit characteristics (elevation, slope gradient, curvature), soils' physical and chemical properties were organised using Microsoft Excel. Spatial distribution of micronutrients along the geomorphic units was studied using descriptive statistics, correlation and ANOVA. Determination of statistically significant differences between geomorphic units and individual micronutrients was by means separation using Tukey's (Honest Significant Difference (HSD) test at 95% confidence interval in Minitab 14 software. Relationships between small mammals' and fleas' abundance, and micronutrients were established by generalized linear model (GLM) (McCullagh and Nelder, 2007) using R software (Williams, 2009). Small mammals and fleas were

dependent variables (y) while the micronutrients values were the independent variables (x). A simplified formula of the GLM used is as follows:

$$\hat{y} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_n x_n + \varepsilon$$

Where:  $\hat{y}$  = represents small mammals or flea abundance (dependent variable).

$\beta_0$  = is the regression coefficient for the intercept.

$\beta_1 - \beta_n$  = values are the regression coefficients (for variables 1 through n) computed from the data.

$X_1 - X_n$  = represent DTPA extractable micronutrient concentrations (independent variables).

$\varepsilon$  = represents residual/error.

The model was validated by portioning data, where 70% was used for training and 30% for modelling. Akaike information criteria (AIC) was used to select the best model among several repeats (Akaike, 1974).

### 3.3 RESULTS AND DISCUSSION

#### 3.3.1 Status and variability of micronutrients in different pedons

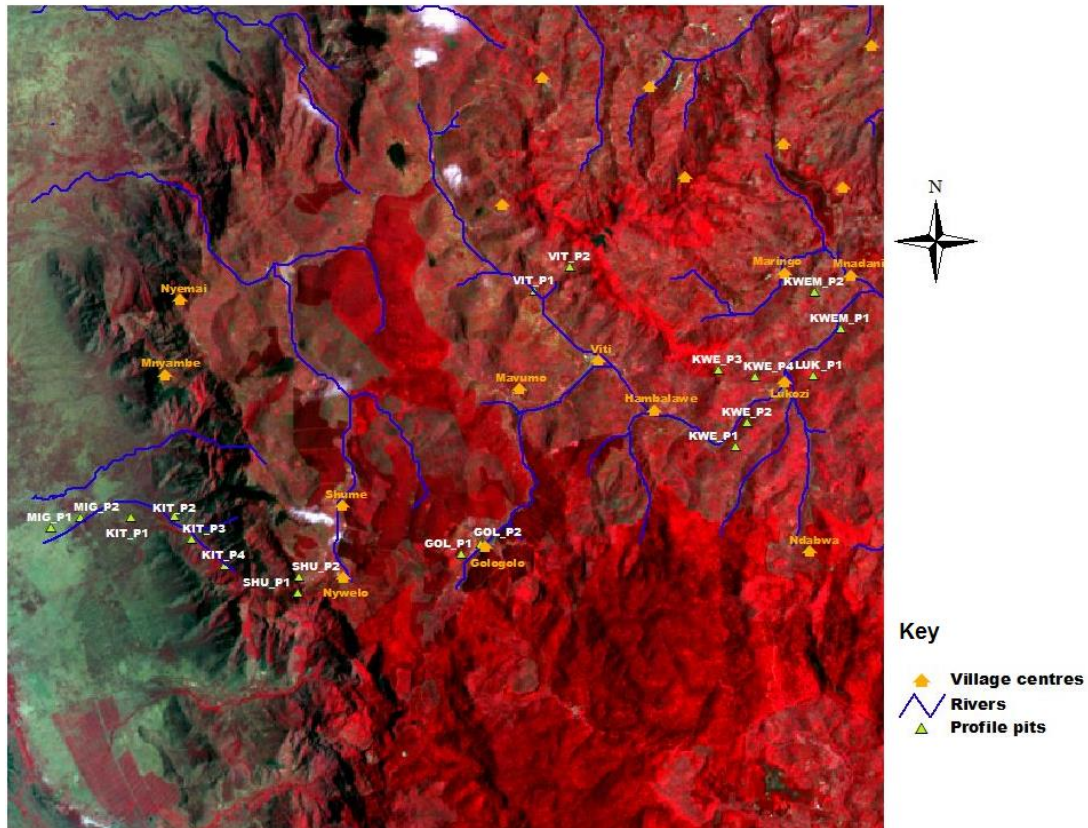
Figures 3.1 - 3.3 and Tables 3.1 - 3.3 present results on the status of DTPA-extractable micronutrients including Fe, Mn, Cu and Zn. Fig. 3.1 shows spatial distribution of studied profiles along the three geomorphic units while Table 3.1 indicates statistical significant ( $P < 0.05$ ) differences between individual micronutrients and their minimum and maximum contents in the studied soils. Table 3.2 shows that profiles Migombani (MIG<sup>1</sup>) P1, MIG P2, Kitivo (KIT) P2 and KIT P3, which are located in the plains, have low

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Abbreviations of local names in this paper: <sup>1</sup> MIG = Migombani, KIT = Kitivo, LUK = Lukozi, SHU = Shume, GOL = Gologolo, KWEM = Kwemunyu, VIT = Viti, KWE = Kwezizi

topsoil Fe with values that range from 12.33 to 16.29 mg Fe/kg soil, whereas the rest of the studied profiles have DTPA-extractable Fe greater than 20 mg/kg soil. Fig. 3.2 depicts that the DTPA-extractable Fe in the intermediate depth (30 - 70 cm) ranges from 3.95 mg Fe/kg soil in profile MIG P2 to the highest value of 399 mg Fe/kg soil in profile Gologolo (GOL) P2. In the subsoil (>70 cm) the DTPA-extractable Fe ranges from 2.1 mg Fe/kg soil in profile KIT P2 to 222.5 mg Fe/kg soil in profile GOL P2. The pedons represented by profiles MIG-P1, MIG-P2, KIT-P1 and KIT-P2, which are located in the plains, have relatively lower DTPA-extractable Fe, when compared to values in the escarpment and the plateau. The observed DTPA extractable Fe, Mn, Cu and Zn values are comparable to those reported by Athokpam *et al.* (2013).

The results further show that the DTPA-extractable Fe status and variability may be attributed to mobility of Fe in the soil, which is dependent on its redox potential and on various soil properties including soil pH, organic matter, and moisture contents (Deckers and Steiness, 2004; Ayele *et al.*, 2013).



**Figure 3.1: Location of studied soil profiles in the plain, escarpment and plateau of Western Usambara Mountains, Tanzania**

Given the agronomic critical levels by Sillanpaa (1982) of 3 to 4.5 mg Fe/kg soil and those by Deb and Sakal (202) of 2.5 to 5 mg Fe/kg soil, these iron rich soil may pose soil fertility problems such as P-fixation, boron deficiency, Fe and Mn toxicity to plants (Kang and Osiname, 1985; Nicolas *et al.*, 2002; Singh, 2009).

**Table 3.1: Status and variation of DTPA extractable micronutrients in Western Usambara Mountains**

Variables	n	Mean	SD	Minimum	Maximum
Fe mg/kg soil	54	65.30a	86.40	2.13	339.4
Mn mg/kg soil	54	61.26b	70.17	0.59	266.3
Cu mg/kg soil	54	2.98c	2.11	0.25	8.2
Zn mg/kg soil	54	1.16c	2.74	0.08	19.6

Means followed by the same letter are not significant different at P=0.05

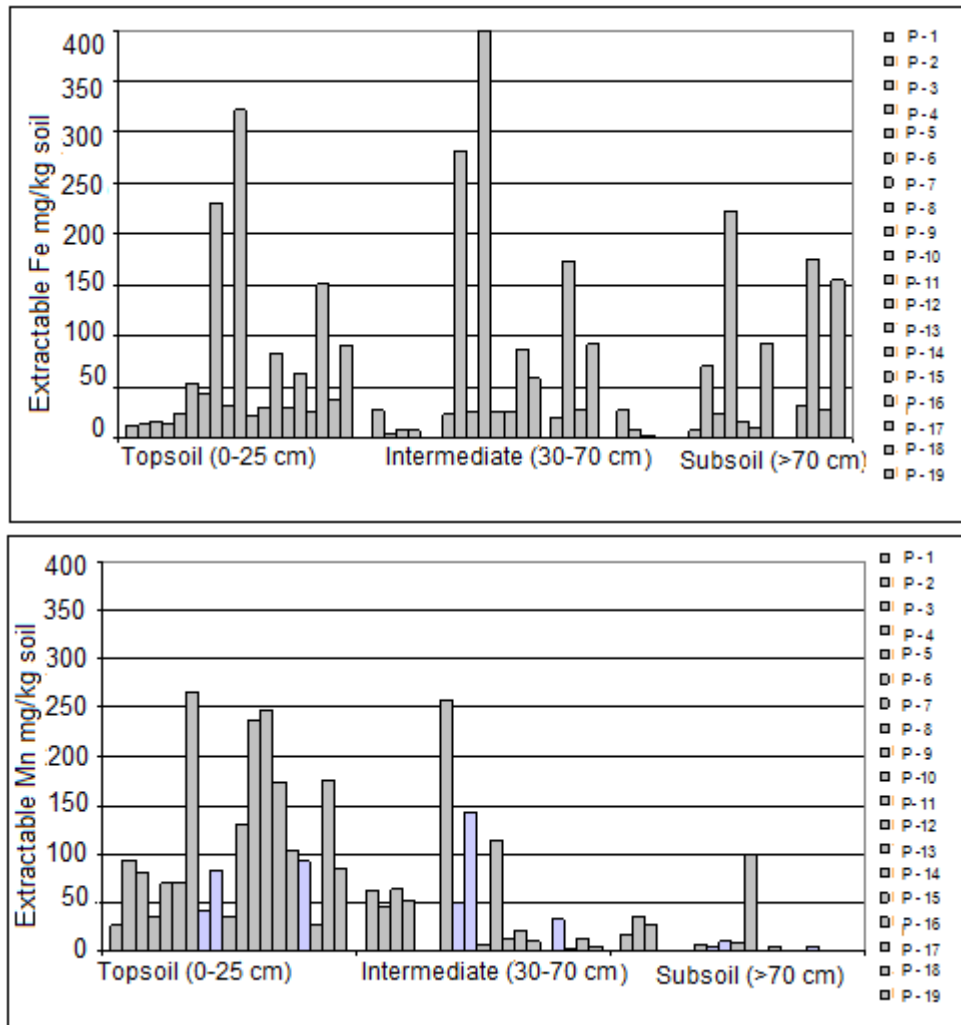
The topsoil Mn ranges from 26.6 to 266.3 mg Mn/kg soil for profiles Lukozi (LUK) P1 and Shume (SHU) P1, respectively (Table 3.2). The Mn in subsoils (>100 cm) ranges from 0.59 to 98.09 mg Mn/kg soil for profiles Kwemunyu (KWEM) P1 and Viti (VIT) P1, respectively. The high subsoil Mn values observed in some of the profiles are associated with presence of Fe/Mn concretions in the soils (Brady and Weil, 2002; Oyinlola *et al.*, 2010).

The DTPA-extractable Mn levels in the soils of plains ranges from 26.66 to 80 mg/kg soil for topsoils and between 26.21 and 29.04 mg/kg soil for subsoils of profiles MIG P1 and KIT P1, which shows a rather more equitable distribution with soil depth compared to the plateau soils. However, there is a general decline of Mn contents with soil depth for most of the studied pedons (Fig.3.2).

**Table 3.2: Topsoil micronutrients mean levels associated with different World Base Reference (WRB) Soil groups**

Soil profiles	Landform Unit	WRB soil names	Topsoil DTPA extractable micronutrients (mg/kg)			
			Fe	Mn	Cu	Zn
MIG-P1	<b>Plain</b>	Mollic Fluvisols (Hypereutric)	12.3	26.6	2.20	0.70
MIG-P2		Mollic Fluvisols (Hypereutric)	13.1	93.5	2.28	1.20
KIT-P1		Cutanic Luvisols (Chromic, Hypereutric)	16.3	80.1	1.98	0.20
KIT-P2		Haplic Umbrisols (Chromic, Arenic, Endoeutric)	13.2	36.0	1.07	0.56
KIT-P3	<b>Escarpment</b>	Mollic Leptosols (Epieutric, Humic)	22.8	69.3	2.96	1.67
KIT-P4		Mollic Leptosols (Epieutric, Humic)	53.5	69.5	3.64	3.73
SHU-P1	<b>Plateau</b>	Haplic Cambisols (Hypereutric, Humic)	42.5	266.3	2.18	2.78
SHU-P2		Ferralic Cambisols (Chromic, Hyperdystric, Humic)	231.4	40.8	0.76	0.70
GOL-P1		Cutanic Acrisols (Epiclayic, Hyperdystric, Humic)	31.6	83.8	5.17	0.87
GOL-P2		Mollic Gleyic Fluvisols (Epiclayic, Orthoeutric, Humic)	320.9	35.9	5.94	19.6
VIT-P1		Cutanic Vetic Acrisols (Profondic, Hyperdystric, Humic)	21.0	129.6	5.82	0.22
VIT-P2		Cutanic Acrisols (Epiclayic, Profondic, Humic)	30.2	237.9	2.19	2.86
KWE-P1		Cutanic Alisols (Hyperdystric, Humic, Abruptic)	81.6	247.2	6.15	3.74
KWE-P2		Cutanic Alisols (Chromic, Humic, Abruptic)	30.0	173.0	2.19	2.12
KWE-P3		Haplic Regosols	63.4	103.2	4.06	0.66
KWE-P4		Luvic Ferralic Phaeozems (Chromic, Epiclayic, Abruptic)	26.1	91.6	1.97	4.28
LUK-P1	Cutanic Alisols (Profondic, Hyperdystric, Humic)	150.7	26.6	0.65	1.31	
KWEM-P1	Cutanic Alisols (Chromic, Profondic, Humic)	37.0	174.1	1.89	1.72	
KWEM-P2	Cutanic Alisols (Profondic, Hyperdystric, Humic)	90.5	85.3	0.63	0.77	

Abbreviations of local names in this paper: <sup>1</sup> MIG = Migombani, KIT = Kitivo, LUK = Lukozi, SHU= Shume, GOL = Gologolo, KWEM = Kwemunyu, VIT = Viti, KWE = Kwezizi



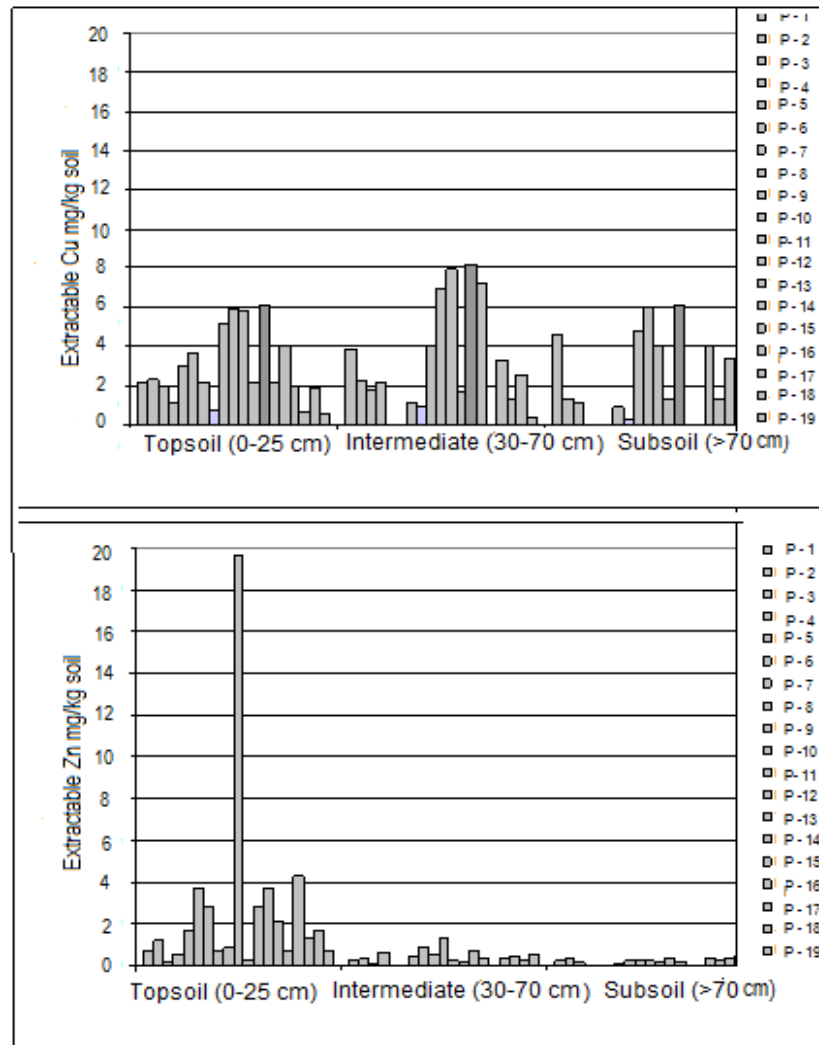
**Figure 3.2: Distribution of Fe and Mn between pedons and down the profile**

N.B. Pedons numbering starts from left to right (P1-P19) for each group of depth

The critical levels for Mn in soils ranges between 1 and 4 mg/kg (Smith and Johnson, 1991; Deb and Sakal, 2002), which suggests that the observed values are high and probably may cause phytotoxicity particularly in low pH (< 5.5) and in dynamic redox conditions due to moisture, and this is likely going to induce excessive Mn bioavailability in soils (Millaleo *et al.*, 2010). These results agree with those of Sillanpaa (1982) who reported high Mn values for acid soils of Tanga and Singida, Tanzania. Results further show that the DTPA-extractable copper in the studied soils ranges from 0.25 to 8.19 mg/kg soil with a mean of 2.98 mg/kg soil (Table 3.1). Table 3.2 shows that three out of

19 profiles, i.e. SHU P2, LUK P1 and KWEM P2, have less than recommended critical levels (1 to 3 mg Cu/kg soil) (Verm *et al.*, 2005; Oyinlola *et al.*, 2010; Pati and Mukhopadhyay, 2010). However, the distribution of copper in the study area is rather unique when compared with other micronutrients because the difference between topsoils and subsoils is not significant for most soils (Figs. 3.2 & 3.3). However, there are spatial differences between profiles located on different topographic positions, where the escarpment is statistically significantly ( $P=0.05$ ) different from the plateau and the plain. Three out of 19 profiles have Cu contents below the critical levels. However 6 profiles have values above critical levels, while the rest have adequate levels of Cu, implying that most soils in the study area are not deficient of copper (Table 3.2).

DTPA-extractable Zn levels (Table 3.1) range from 0.08 to 19.6 mg/kg soil, with a mean of 1.16 mg/kg soil. Profiles KIT P1 and VIT P1 have low levels of topsoils Zn (0.2 mg/kg) (Table 3.2). Profiles GOL P2, KWE P1, KWE P4 and KIT P4 have 19.6, 3.74, 4.28 and 3.73 mg Zn/kg soil, respectively (Table 3.2). Figs. 3.3 and 3.4 show the distribution of micronutrients with soil depth. It has been established in this study that seven of the studied soil profiles have Zn contents above 2 mg Zn/kg soil, while 4 profiles had Zn contents above 1 mg/kg soil with the remaining profiles having less than 1 mg Zn/kg soil. Given the established critical levels that range between 1 and 5 mg Zn/kg soil (Verma *et al.*, 2005; Oyinlola *et al.*, 2010) three profiles i.e. MIG P1, KIT P1 and KIT P2 which are located in the plains have contents that are lower than the critical levels of Zn. The results also show that Zn contents declined sharply with soil depth (Figs. 3.3 and 3.4). The observed phenomenon is attributed to poor Zn mobility accompanied by limited leaching to lower horizons.



**Figure 3.3: Distribution of Zn and Cu between pedons and with soil depth**

N.B. Pedons numbering starts from left to right (P1-P18) for each group of depth

Profile GOL P2 has higher levels of available Zn of 19.6 mg/kg soil, which could be attributed to localised land use practices coupled with poor drainage conditions (Jiang *et al.*, 2006; Alloway, 2008; Rutkowaska *et al.*, 2014). This profile is located in a plot where vegetables are grown and farmyard manure is applied seasonally, with frequent use of fungicides mainly copper sulphate. Both Zn and Cu are high in GOL P2. However, as indicated by the critical levels, the results show that some soils are severely

deficient while some had adequate soil Zn levels (Smith and Johnson, 1991; Deb and Sakal, 2002).

The observed results suggest that variations and bioavailability of micronutrients in the soils of Western Usambara Mountains are attributed to the pedogenic processes that replenish soil solution from solids through weathering of earth minerals in the soil (Verma *et al.*, 2005; Alloway, 2008). Moreover, the variations are attributed to differences in parent materials, topography, climate and biochemical and geochemical processes taking place in the soils (Basta *et al.*, 2005; Alloway, 2008; Loncaric *et al.*, 2010). In general, the results show a trend whereby higher values were observed in plateau, followed by escarpment and finally by plain. These findings agree with other researches that have shown that micronutrient distribution along profiles developed on different parent materials and geomorphic units are variable (Kabata-Pendias and Pendias, 2001; Jiang *et al.*, 2006). Also, it is crucial to note that, although the micronutrients particularly Fe and Mn were above established agronomic critical levels, the bioavailability to plants is largely dependent on the prevailing soil environment including soil texture, soil reaction, organic matter content, cation exchange capacity, phosphorus levels and tillage practices (Kabata-Pendias and Pendias, 2001; Nube and Voortman, 2006; Jiang *et al.*, 2006; Alloway, 2008; Loncaric *et al.*, 2010), the above factors were variable in the study area. Other factors that have been reported to affect the bioavailability of micronutrients to plants are soil water content, nutrient interactions and temperature (Millaleo *et al.*, 2010). Given the area which is very heterogeneous, bioavailability of micronutrients would be different not only on the major physiographic units but even within the major units like the plateau alone.

Our results show that topsoils which are rich in soil organic matter contain higher concentration of Fe, Mn and Zn than the subsurface soils. This implies that bioavailability of micronutrients increases with soil organic matter content, a fact which is attributed to the capacity of soil organic matter to form complexes with micronutrients and render them available for plant uptake. We also observed that the sandier plain soils with low organic matter had low DTPA extractable Zn (Ayele *et al.*, 2013).

### 3.3.2 Distribution of micronutrients with soil depth

Figure 4 shows the distribution of micronutrients with soil depth. High concentrations were in the topsoils, declining with increasing depth to low values in the subsoils. The trend of micronutrient content decline with soil depth has been observed in soils of India (Pati and Mukhopadhyay, 2010; Rutkowska *et al.*, 2014). The observed behaviour follows organic matter contents, particularly for Zn.

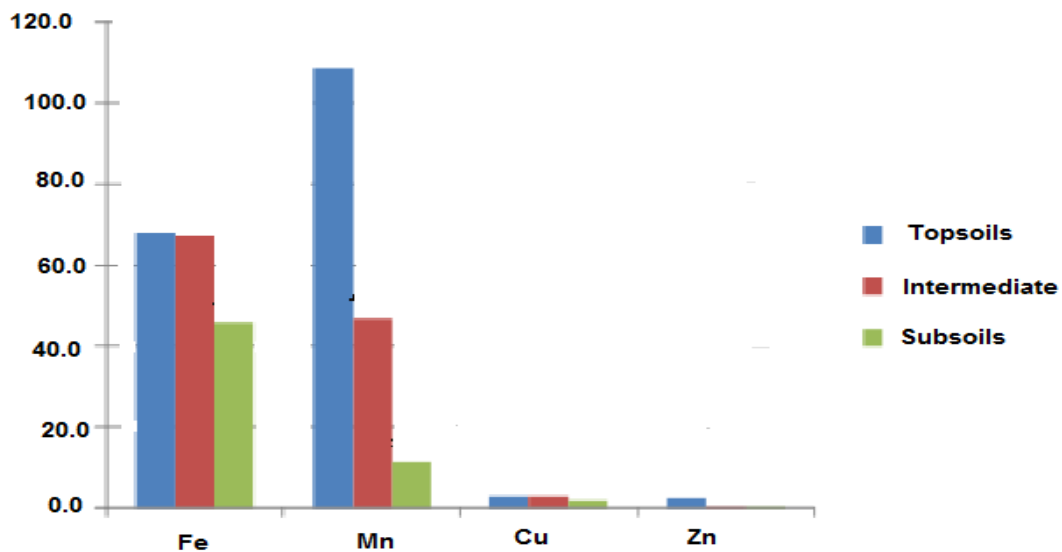


Figure 3.4: Average concentration of micronutrients as related to soil depth

It has been reported that organic matter plays an important role in biochemical and geochemical cycles of micronutrients and serves as their reservoir in the soil (Brady and Weil, 2002; Basta *et al.*, *et al.*, 2005). Correlation analysis indicates that the studied micronutrients are positively correlated with organic matter, but Fe and Zn had significant levels with  $r = 0.64$ ,  $P < 0.05$ , and  $r = 0.62$ ,  $P < 0.05$ , respectively.

### **3.3.3 Distribution of DTPA-extractable micronutrients with geomorphic units**

Table 3.3 presents results of distribution of micronutrients over geomorphic units. The results show that there are statistically significant ( $P < 0.05$ ) differences between Fe and Mn along the three studied geomorphic units. The increase of Cu is highest in the escarpment, but there is statistically significant ( $P < 0.05$ ) difference between the plain and the escarpment, while there is Zn increase from the plain to the plateau but the difference is not significant at  $P < 0.05$ . There are fluctuations of micronutrients but important to note is that even comparatively low values in the plateau were still higher than those in the plains in all studied micronutrients. These results agree with findings by several authors who reported variation of micronutrients across geomorphic units (Ali and Moghanm, 2013). The differences are attributed to parent materials, topography, climate and biochemical and geochemical processes in the soil (Kabata-Pendias, 2001; Basta *et al.*, 2005; Alloway, 2008; Loncaric *et al.*, 2010). Results from this study indicate that elevation and slope influence significantly the variability of micronutrients, except copper which appears to have similar values along the studied geomorphic units. The observed variation trend with geomorphic units, agrees with other research findings that have shown that DTPA extractable micronutrients Fe, Mn, Cu and Zn vary with some soil properties and topography and that in the higher elevation high concentration of micronutrients was reported (Sharma *et al.*, 2005; Ali and Moghanm, 2013).

**Table 3.3: Distribution of selected DTPA-extractable micronutrients with landforms**

Landforms	n	Fe		Mn		Cu		Zn	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Plain	6	13.5 <i>a</i>	1.4	70.5 <i>a</i>	31	2.0 <i>a</i>	0.48	0.84 <i>a</i>	0.42
Escarpment	11	41.3 <i>b</i>	2.32	60.1 <i>a</i>	26.7	19.23 <i>b</i>	36.2	2.05 <i>a</i>	1.44
Plateau	25	72.8 <i>c</i>	70.3	130.0 <i>b</i>	70.4	3.2 <i>a</i>	1.97	2.59 <i>a</i>	3.73

Means followed by the same letter in the same column are not statistically significant at  $P=0.05$

### 3.3.4 Correlation of micronutrients, elevation and selected soil physical and chemical properties

Table 3.4 present result of correlation of micronutrients, elevation and selected soil physical and chemical properties. The results show that DTPA extractable Fe was strongly correlated to most of the tested physical and chemical soil properties. Organic matter (OC %), total nitrogen (TN %) and CEC soil were positively correlated to Zn with  $r = 0.62$ ,  $r=0.76$  and  $r=0.71$  at  $P<0.05$ , respectively. Similar results have been reported that distribution of micronutrients Zn, Cu, Mn and Fe demonstrate correlation among them with  $r=0.4$  at  $P=0.05$  (Bassarani *et al.*, 2011).

**Table 3.4: Correlation of micronutrients to physical and chemical properties in Western Usambara Mountains, Lushoto, Tanzania**

Variables	DTPA-Fe	DTPA-Mn	DTPA-Cu	DTPA-Zn
Clay (%)	0.471*	-0.315*		
Sand (%)	-0.409*	0.357*	-0.347*	
Altitude (m a.m.s.l.)	0.638*	-0.216	-0.017	
A.W.C (vol/vol)	0.438*	-0.184	0.136	
O.C. (%)	0.641*	0.179	0.041	0.622*
pH (water)	-0.585*	0.352*	0.136	0.073
EC (dS/m)	-0.442*	0.163	0.089	0.235
Total N (%)	0.642*	0.371	0.091	0.763*
CEC $\text{cmol}^{(+)}/\text{kg}$ soil	0.454*	0.224	0.218	0.707*
Exch. Mg $\text{cmol}^{(+)}/\text{kg}$ soil	-0.363*	0.218	0.455*	0.172
Exch. K $\text{cmol}^{(+)}/\text{kg}$ soil	-0.304*	0.472*	0.247	0.492*
BS %	-0.505*	0.265	0.173	0.186

\*Correlation significant at  $P<0.05$

Further, our results show that copper is the most inert trace element having relatively weaker negative and positive correlations with sand per cent and exchangeable Mg with  $r = -0.35$  and  $r = 0.46$  at  $P < 0.05$ , respectively. The positive or negative correlations observed elucidate the fact that micronutrients in soils are influenced by soil properties such as pH, texture, cation exchange capacity and organic matter contents (Verma *et al.*, 2005; Pati and Mukhopadhyay, 2010; Bassarani *et al.*, 2011). The correlation results also demonstrate that interactions of multiple factors including soil reaction (pH), organic matter, TN %, CEC and exchangeable bases have had a strong influence on the distribution and status of micronutrients in the studied soils. Similar observations have been reported elsewhere and that most of these factors also influence bioavailability of micronutrients to plants (Verma *et al.*, 2005; Bassarani *et al.*, 2011; Ayele *et al.*, 2013).

### **3.3.5 Relationship of micronutrient distribution and plague hosts and vectors**

Table 3.5 presents a summary of correlation between plague hosts and vectors abundance and micronutrients along geomorphic units. The DTPA extractable Fe has a correlation with the plague hosts ( $r = 0.317$ ,  $P < 0.05$ ). The DTPA extractable Fe also has a strong positive correlation with fleas ( $r = 0.385$ ,  $P < 0.05$ ). There was no significant correlation that was observed between plague hosts and vectors abundance and DTPA extractable manganese, copper and zinc. Elsewhere research results show that plague outbreaks which is usually associated with abundance of plague hosts in the Altay Mountains was correlated with high concentration of iron in soils (Rotshild, 2001).

**Table 3.5: Associations of plague hosts and vectors and DTPA extractable micronutrients in landforms of Western Usambara Mountains, Tanzania**

Variable	Host abundance	Vector abundance (counts)	Altitude (m a.m.s.l.)	Slope gradient (%)	DTPA extractable micronutrients mg/kg soil		
					Fe	Mn	Cu
Vector abundance (counts)	.881*						
Altitude (m a.m.s.l.)	.281	.181					
Slope gradient	.062	.049	.196				
Fe mg/kg soil	.317*	.385*	.348*	-.171			
Mn mg/kg soil	.079	.02	.400*	.03	-.14		
Cu mg/kg soil	.028	-.022	.057	.372*	-.083	-.288	
Zn mg/kg soil	.026	.137	.163	-.02	.651*	.037	.002

\*Significant levels  $P < 0.05$

Tables 3.6 and 3.7 present regression results demonstrating the influence of micronutrients on plague hosts' and vectors' abundance. Table 3.6 shows that only Fe that has statistical significant ( $P < 0.01$ ) influence on plague hosts (rodents).

**Table 3.6: Influence of micronutrients on plague hosts' abundance**

Coefficients	Estimate	Std. Error	t value	Pr(> t )
(Intercept)	-0.33911	5.71202	-0.059	0.95320
DTPAFe	0.15843	0.04754	3.333	0.00302 **
DTPAMn	-0.01647	0.03819	-0.431	0.67056
DTPACu	0.07918	0.11392	0.695	0.49433
DTPAZn	3.00257	2.36240	1.271	0.21701

Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05

Iron also has statistical significant ( $P < 0.05$ ) influence on plague vectors (fleas) (Table 3.7). Although, the regression and correlation results could not show direct influence of Mn, Cu and Zn on plague hosts' and vectors' abundance, our results on DTPA extractable micronutrients indicated a trend of micronutrients being higher in the plateau and declined to the escarpment and then the plain in that order. These correspond with trapped small mammals and their fleas by abundance and pattern of their spatial distribution along the studied geomorphic units.

**Table 3.7: Influence of micronutrients on plague vectors' abundance**

Coefficients	Estimate	Std. Error	t value	Pr(> t )
(Intercept)	-0.930618	5.987056	-0.155	0.8778
DTPAFe	0.143970	0.052310	2.752	0.0113 *
DTPAMn	-0.016111	0.041276	-0.390	0.6999
DTPACu	0.004825	0.115861	0.042	0.9671
DTPAZn	2.618982	2.291286	1.143	0.2648

Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05

Further, research results by Ralaizafosoloarivony *et al.* (2014), who investigated the relationships between vegetation types and small mammals' abundance in the area

established that, the type of vegetation habitats strongly influenced abundance and type of species along the geomorphic units, where abundance increased from the plain to the plateau. Similar results were reported by Fricke *et al.* (2009) and Thompson and Gase (2013) who established that vegetation habitat characteristics influenced small mammals' abundance on the studied sites, in the USA. This implies that soils rich in micronutrients will have a better establishment of vegetation habitats which in turn favour small mammals' and fleas' abundance. On the other hand fleas' abundance has been established to follow small mammals' trends in this study. This could be the reason that DTPA extractable Fe influenced both small mammals and vectors. These results correspond with plague reported cases which were concentrated in high altitude villages and was associated with high population density of plague hosts and vectors (Davis *et al.*, 2006; Kamugisha *et al.*, 2007). Similar results were reported where plague cases were common in an altitude of 1300 m a.m.s.l. (MacMillan *et al.*, 2011; Eisen *et al.*, 2012). Therefore, plague hosts and vectors are probably being influenced by vegetation habitats that are influenced by multiple factors among them soil micronutrients.

### **3.4 CONCLUSIONS AND RECOMMENDATIONS**

#### **3.4.1 Conclusions**

- i. Studied micronutrients vary with soils and geomorphic units. Higher concentrations were in the plateau, then escarpment, and lowest in the plain.
- ii. Iron and Cu had more or less equal distribution with soil depth while Mn and Zn had higher concentrations in the topsoils signifying the effect of organic matter in holding the two trace elements.

- iii. Iron and Mn levels were by far greater than the established critical levels in the plateau and escarpment, hence may cause plant phytotoxicity or plant nutrition problems by fixing phosphorus and rendering it unavailable.
- iv. Zinc was deficient in most of soil profiles in the plains.
- v. Iron concentration had strong positive influence on both plague hosts and vectors in the study area.

### **3.4.2 Recommendations**

- i. It has been observed that soil micronutrients and their occurrence on the geomorphic units was a function of vegetation. It is therefore recommended to carry out research to establish relationships between micronutrients, vegetations, and plague hosts and vectors in different plague foci in the country.
- ii. The studied trace elements Fe, Mn and Cu had above agronomic critical values; however literature shows that bioavailability depends on various soil characteristics that this study did not work on. It is recommended to carry out research to establish possibilities of plant phytotoxicity.

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## CHAPTER FOUR

### 4.0 LANDFORM AND SURFACE ATTRIBUTES FOR PREDICTION OF RODENT BURROWS IN WESTERN USAMBARA MOUNTAINS, TANZANIA

#### ABSTRACT

A research was conducted in the Western Usambara Mountains, Tanzania to explore the influence of landform and surface attributes on rodent burrows presence. The study was carried out in three landscapes namely Lokome, Lukozi and Mwangoi corresponding to plague reported frequencies which are high, medium and low respectively. Data were collected from 117, 200 and 170 observation sites for Lokome, Lukozi and Mwangoi respectively using 100 m x 200 m quadrats. Remote sensing and field survey methods were used to collect data on landform (altitude, slope gradient, slope aspect, slope length) and surface attributes (rock outcrops, surface stones, surface gravels, sealing, erosion and vegetation cover). Rodent burrows were surveyed and quantified by counting the number of burrows in 20 m x 20 m grids demarcated on the main 100 m x 200 m quadrats. The collected data were analysed in R software using boosted regression trees (BRT) technique. Results show that rodent burrows were located above 1600 m a.m.s.l. whereby there were 397 and 92 rodent burrows respectively in the high and medium plague frequency landscapes. No burrows were found in the low plague frequency landscape which is below 1500 m a.m.s.l. Boosted regression tree analysis shows a significant relationship between landform characteristics (hillshade (16%), slope gradient (9.8%), elevation (8.8%), surface attributes (herb cover (9%), bare ground (8.9%) and rodent burrows in the high plague frequency landscapes. In the medium plague frequency

landscapes relative influence follows the trend slope length (15.6%), hillshade (13.2%), slope aspect (10.6%) and plan curvature (9.6%), with only bare ground (8.6%) representing the surface attribute. Interaction between hillshade and elevation demonstrated the strongest influence by a factor of 4.31 while longitudinal curvature and hillshade showed the lowest influence with a factor of 0.41 in both landscapes. On the overall, elevation and hillshade are the most important determinants of rodent burrow distribution in the studied landscapes. It is concluded from this study that high altitude landforms (hill-shade, slope, elevation) and land cover (herbs and bare ground) favour rodent burrowing.

Key words: Landforms, Western Usambara Mountains, surface attributes, rodent burrows, slope types

#### **4.1 INTRODUCTION**

Most studies which were carried out to explain the occurrence and incidence of plague have focused on the influence of climatic factors on vectors (Mills *et al.*, 2010) and vegetation and small mammal hosts (Ralaizafisoloarivony, 2010; MacMillan *et al.*, 2011). Others addressed biological factors particularly flea diversity and plague persistence (Amatre *et al.*, 2009; Eisen *et al.*, 2012), land use dynamics and trajectories (Annaert, 2010) and human activity flows and community behaviour (Hubeau, 2010). Few studies are available regarding environmental and behavioural risk factors associated with plague infection. Studies from Lushoto District, Tanzania (one of the plague foci), indicate that ecological factors comprising landform (elevation) and rainfall have influence on rodent population and fleas, which is linked to plague outbreaks (Kilonzo *et al.*, 1997; Kamugisha *et al.*, 2007).

Other studies carried out by Neerinckx *et al.* (2010) in Western Usambara Mountains, Tanzania, at landscape scale demonstrate that there is a high correlation between plague reported cases and elevation. Similar observations were made by MacMillan *et al.* (2011; 2012) in the West Nile Region of Uganda in a study meant to identify landscape and residential risk factors associated with historical human plague cases in the area.

Altitude also has been used to study the effect of topography on the risk of malaria infection in the Usambara Mountains, Tanzania (Ballsa *et al.*, 2004). In this study, logistic regression shows that altitude alone could correctly predict 73% of households with malaria infection. In another study by Neerinckx *et al.* (2010) in Western Usambara Mountains, it was observed at higher elevations that hamlets located in/or near valley bottoms had higher probabilities of being plague-positive than those far away. It was recommended, therefore, that since certain detailed scale environmental variables constitute meaningful predictors of plague risk areas, they could be applied in future research to predict plague risk areas; however, the detailed scale (farm level scale such as 1:5 000) ecological data is mostly lacking.

In this study, landform characteristics and surface attributes at farm scale were investigated to test their influence on rodent burrows, which are a proxy of rodent populations and hence useful for predicting plague risk areas. Rodent burrows have been studied to establish their abundance, portal orientation and burrow uses and the way they relate to landforms and surface attributes (Reichman and Smith, 1990; Goyal and Ghosh, 1993; Randall, 1993; Laundre and Reynolds, 1993; Davidson *et al.*, 2008; Mora *et al.*, 2010; Naderi *et al.*, 2011). Most of the research on rodent burrows has been related to

rodents' survival and soil suitability for burrowing (Laundre and Reynolds, 1993; Mora *et al.*, 2010). Rodent burrows, being places for nursing young rodents, could offer a better indication of rodent populations and hence could be a good proxy for prediction (Reichman and Smith, 1990; Randall, 1993; White *et al.*, 2008).

This work investigated at farm scale the influence of landform characteristics and surface attributes on rodent burrows presence as indicators of plague hosts abundance.

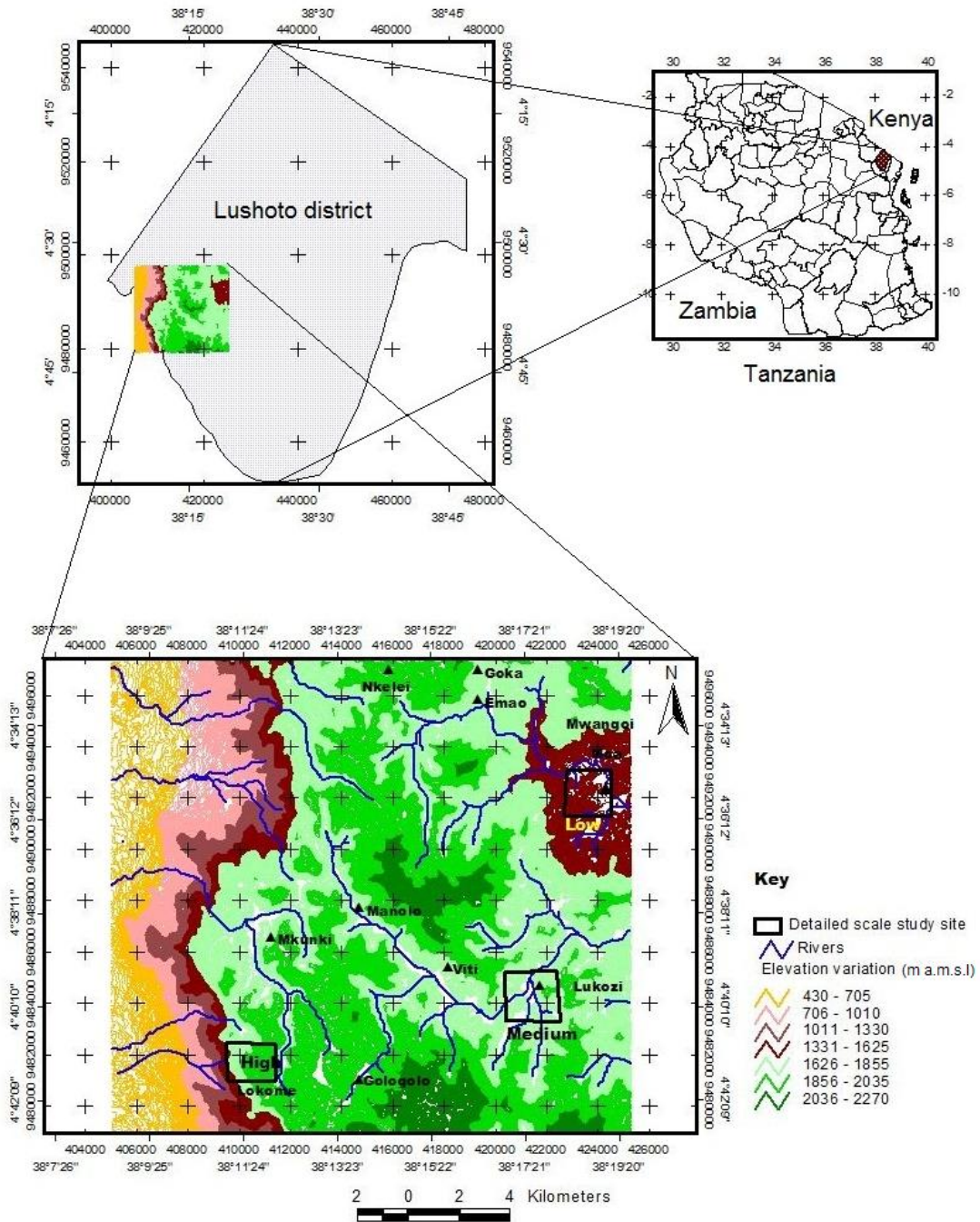
## **4.2 MATERIALS AND METHODS**

### **4.2.1 Description of the study area**

The study area is located in Western Usambara Mountains, Lushoto District, Tanzania (Figure 4.1). Three sample areas were selected based on diversity of landforms, climatic conditions and historical plague frequencies. The area is bounded between UTM Zone 37, UTM 9 474 965 N through 9 502 586 N and 444 532 E through 472 276 E covering an area of about 151 000 ha. Three sample areas (Lokome, Lukozi and Mwangoi) were selected representing historically high, medium and low plague frequency areas, respectively. The second criterion was differences in farming systems, climatic variability and landform heterogeneity.

The area receives rainfall in two seasons with annual rainfall varying from 500 to 1200 mm in the high plague frequency; 600 to 1200 mm in the medium plague frequency and less than 500 to 800 mm per annum in the low plague frequency area. While the high and medium plague frequency areas receive reliable rainfall during the long rain season between March and May annually, the low plague frequency area receives reliable rainfall

during the short rain season in October to December. The average annual temperatures are variable and increase from 17°C in the high and medium plague frequency landscapes to over 22°C in the low plague frequency landscape.



**Figure 4.1: Location map showing fine scale study sites**

### 4.2.2 Materials

Several materials and equipment that were used to carry out this study include GPS, compass, clinometers and altimeter. Other materials were a topographic map at scale of

1:50 000 (1983 - 1985), geological and vegetation maps at scale of 1:125 000; digital orthophotomaps at scale of 1:25 000 and 1:50 000 (1996) and satellite images for 1973, 1975, 1996, 2001, 2003, 2005, 2006 and 2008. The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Global Digital Elevation Model (GDEM) developed jointly by the Ministry of Economy, Trade and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA) with 30 m ground resolution and vertical resolution of 20 m at 95% confidence was also acquired. As for earth cutting equipment these included augers, shovels, hoes, machete knives and soil profile knives. Measuring tapes of different lengths i.e. 5, 10, 50, and 100 cm long were also used in addition to field note books and data recording forms.

#### **4.2.3 Methods**

##### **4.2.3.1 Determination of landform and surfaces characteristics**

Analysis of ASTER DEM was done using ArcGIS 9.3 to calculate continuous surfaces for elevation (m a.m.s.l.), slope gradient (degrees), slope aspect (radians), slope length (m), slope types (straight, convexity and concavity), flow accumulation, flow direction, topographic compound index (TCI), and stream power index (SPI). These were used to extract point values at each data collection site for modelling.

Surface characteristics including rock outcrops (%), surface stones (%), surface gravels (%), sealing (yes/no), erosion status (types) and degree, and vegetation cover (m<sup>2</sup>) were determined and quantified according to FAO Guidelines for Soil Profile Description (FAO, 2006).

#### **4.2.3.2 Rodent burrows**

Grids of 100 m down the slope and 200 m across the slope were used to identify and study rodent burrows. The sampling design was chosen in order to capture landform and surface characteristics. In order to capture maximum number of rodent burrows within a grid with minimal errors and bias smaller grids of 20 m x 20 m were located within the larger 100 m x 200 m grids for scanning and counting rodent burrows. Data collected included number of rodent burrows, number of used and non-used burrows, the burrows' portal orientation (down/up, perpendicular) and burrows' aspect, which was determined by a compass direction in degrees and presence or absence of the above ground nests (present/absent). Other data sets collected on burrows were presence of food (yes/no), faeces (yes/no) which establishes burrow use on non-use.

#### **4.2.3.3 Data analysis**

##### ***Data preparation***

Although the study involved three areas (Lokome, Lukozi and Mwangoi), the low plague frequency area (Mwangoi) was not included in the 'BRT' regression analysis process because it had no burrow data, but it was included in other analyses such as landform analysis e.g. slope curvature, slope gradient and cross-section of the study area. Field data were prepared in MS-Excel 2010 and an attribute table with 317 observation points was linked to GIS. Rodent burrow number, burrows' portals and burrow aspect were the dependent variable (y) and predicted by 26 landforms and surface attributes which formed the independent variables (x). Data examination for statistical compliance was done using partial scatter plots and correlation analysis using the Minitab 14 software.

### ***Determination of factors influencing rodent burrows by the BRT method***

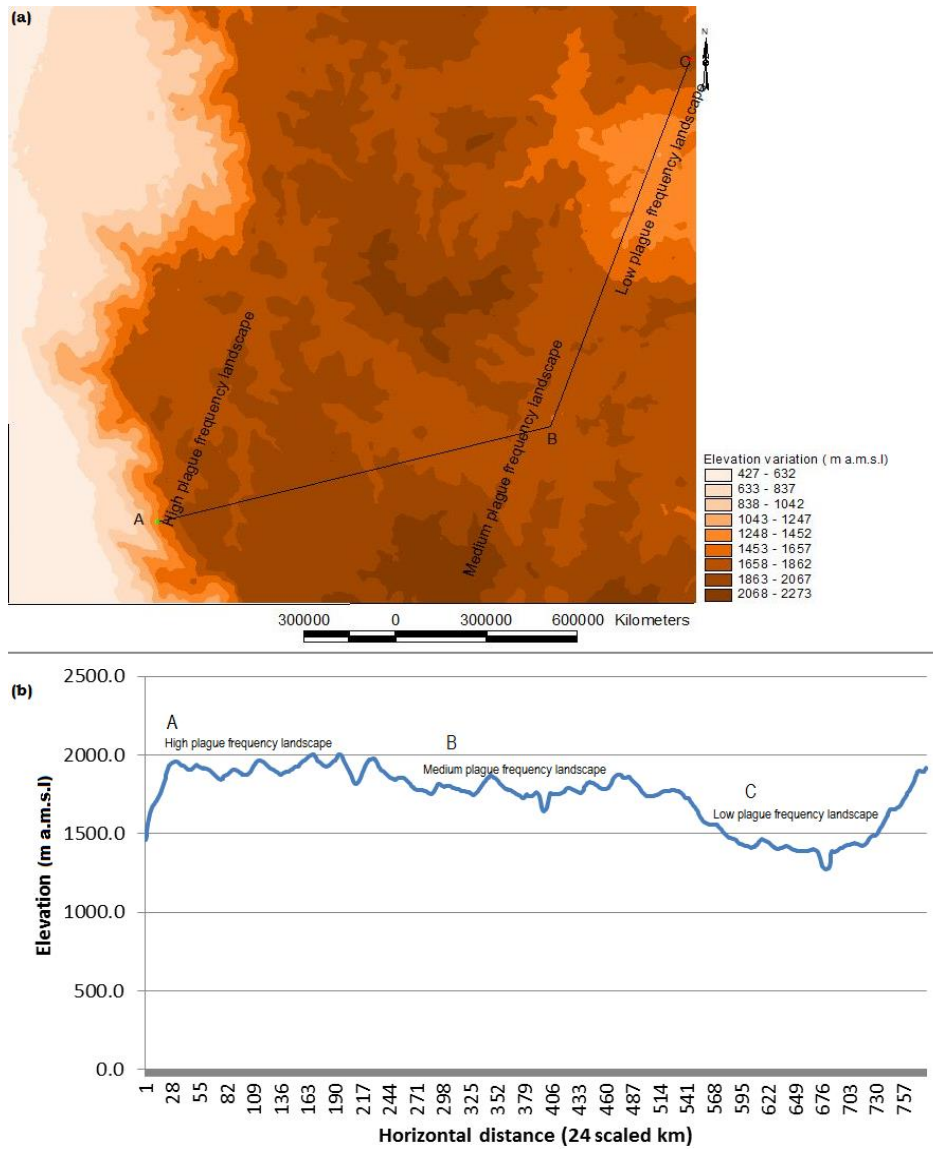
Identifying and rating ecological factors influencing rodents' burrowing in specific locations along the landforms positions was done using boosted regression trees (BRT) so as to assess individually high and medium plague frequency landscapes. The BRT are the statistical techniques composed of boosting and regression trees. Boosting is a machine learning technique comprising assembling and averaging of models resulting into several competing weaker models that are combined to stronger ones. Boosting uses a forward, stage-wise procedure, where tree models are fitted iteratively to a subset of the training data following the procedure outlined by Elith *et al.* (2008) after adjusting "bag fraction", "learning rate" and "tree complexity" to fit this study. The BRT script (Elith *et al.*, 2008) was run in R version i386 3.0.0., applying the package "gbm" library (Ridgeway, 2007). The BRT parameters used were *learning rate* = 0.005 and 0.0005 for high and medium plague frequency landscapes, respectively.

Other parameters of the model was tree *complexity*= 5 and cross-validation= 10-fold and the *bag fraction* was 0.5 (Elith *et al.*, 2008). The dataset in this case was setup such that the respondent variable was binary (0, 1), showing either presence or absence of burrows. Cross-validation by 10-fold process inbuilt in the BRT was used to assess the model performance. In the 10-fold cross-validation, the data were divided into 10 subsets of equal size. The regression techniques were then applied 10 times, each time leaving out one of the subsets and using that subset to complete the prediction (Elith *et al.*, 2008).

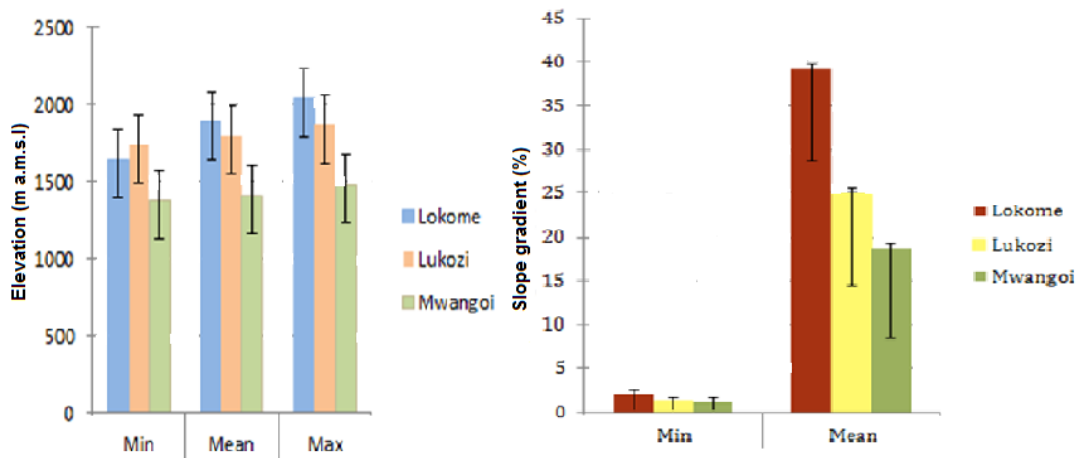
### **4.3 RESULTS AND DISCUSSION**

#### **4.3.1 Landforms' and slope characteristics' influence on rodent burrows**

Figures 4.2 – 4.4 present elevation, slope and slope characteristics variation between studied areas. Fig. 4.2 (b) shows topographic cross-section (ABC) indicating elevation heterogeneity. Results show that in the high plague frequency area the elevation range is from 1650 to 2040 m a.m.s.l. while the medium plague frequency area is from 1750 to 1900 m a.m.s.l. and in the low plague frequency area it is situated below 1500 m a.m.s.l. The heterogeneity of elevation, landforms and slope gradient, form and shapes have been indicated to have a marked influence on climate (rainfall and temperature) and lateral gradient in surface fluxes that affect convergences and divergences of surface water flow (Otto and Dikau, 2009) which, in turn, affect rodents' habitation including their burrows. Although there was no statistically significant difference in elevation between high and medium plague frequency areas, there was a significant difference ( $p=0.05$ ) between the high and low plague frequency areas (Fig. 4.3). Also, there was a statistically significant difference between slopes of high, medium and low areas but not between medium and low plague frequency areas.



**Figure 4.2: Elevation variability in the studied landscapes**



**Figure 4.3: Elevation and slope variation between studied landscapes in Western Usambara Mountains plague focus**

Plague outbreaks worldwide have been associated with high rodent populations (Witmer, 2004; Kamugisha *et al.*, 2007; Stenseth *et al.*, 2008). The plague foci in East Africa have been observed to be located in an elevation above 1000 m a.m.s.l. For example, Neerinckx *et al.* (2008, 2010) reported a positive correlation of high plague frequency and elevation above 1500 m a.m.s.l., in Western Usambara Mountains. Slightly similar results have been reported by MacMillan *et al.* (2012), who indicated a high correlation of plague host populations and rainfall above 1300 m a.m.s.l., in plague focus in Uganda. Also, elevation has been reported to influence plague host occurrence in Turkey (Yigit *et al.*, 2003). Although elevation alone could not be the decisive factor for plague outbreaks, the reports suggest that high elevation areas have favourable conditions for habitats of the plague hosting rodents, most of which are burrowers (Goyal and Ghosh, 1993).

Figure 4.4 (a-d) presents slope gradient and slope characteristics (aspect and curvature) variations of the study area. Slope gradients (Figure 4.4 a) ranging from 0 to 69.8 degrees,

appear to be the strongest topographic attribute influencing significantly landform forming process through its angle of inclination which speeds up overland and subsurface flows of water. This is in agreement with literature which shows that slope gradients and slope characteristics influence water movement on the land surface (Moore *et al.*, 1991), surface processes and landforms (Lopes, 1997; EasterBrook, 1999; Furian *et al.*, 1999; MacMillan and Shary, 2009). The aspect and curvature (Fig. 4.4 b-d) influence hydrological characteristics and the solar radiation the place receives, therefore, encourage resource availability such as water for growth of vegetation, which provides hiding places and food crops to rodents (Busch *et al.*, 2000).

Figure 4.5 presents the distribution of rodent burrows as influenced by slope position, where it shows that there are differences within and between areas. In high plague frequency landscapes (Lokome), upper slope positions had statistically higher numbers of rodent burrows compared to other positions, except for the mid-slopes. Similar observations were reported by Brabers (2012) when working on soils and soil microclimate and rodent preference for burrowing in the area.

The reasons for the observed rodent burrows distribution with landscape position in the high plague frequency landscape (Lokome) could be attributed to safe haven preferences by rodents (Lambin *et al.*, 2010; Piudo *et al.*, 2011). In the upper slopes of Lokome there were dead tree stumps from a harvested plantation forest.

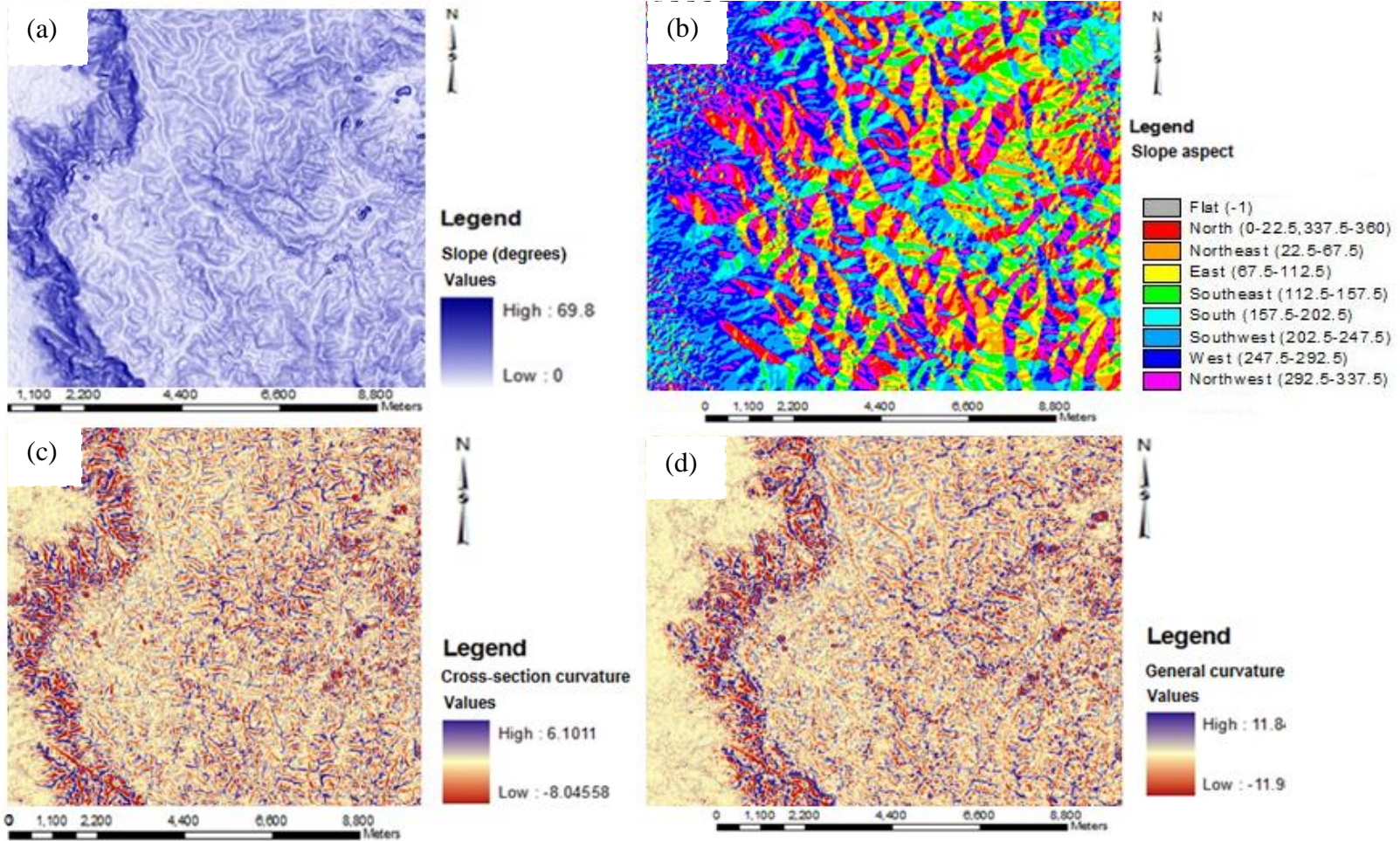
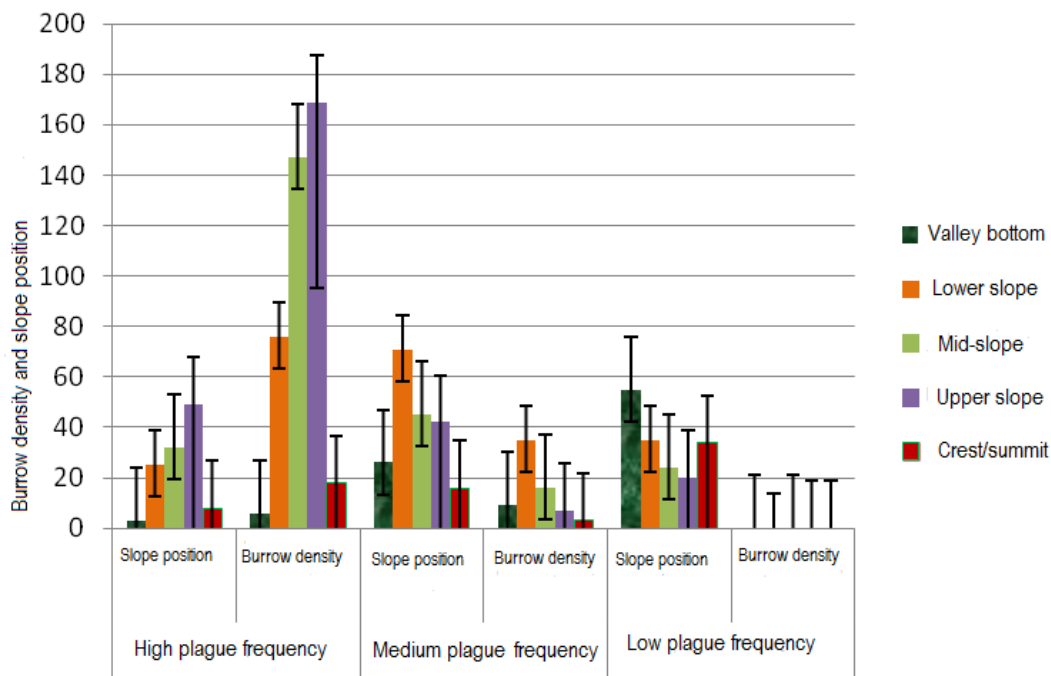


Figure 4.4: Slope characteristics in the study area

The upper parts of the escarpment had more surface stones and rock outcrops. In these environments (stumps and stones), rodents could make safer burrows from predators especially raptors and domestic animals. Also, in these positions, there were food crops intercropped with trees, which provided rodents' food on which they could live and multiply. Various results indicate that rodents require safe habitats where they can live and reproduce (Busch *et al.*, 2000; Davidson *et al.*, 2008; Lovy *et al.*, 2013).



**Figure 4.5: The influence of landform positions on burrow distribution in the studied areas, in Western Usambara Mountains, Tanzania**

The mid-slope of Lokome is also characterised by cultivation and rock outcrops, especially to the side which faces the escarpment, which also provide safe shelter and abundant food. The medium plague frequency landscape (Lukozi), has shown a rather different scenario, where lower slopes had larger numbers of rodent burrows although non-significantly different from other landform positions except for the ridge summits.

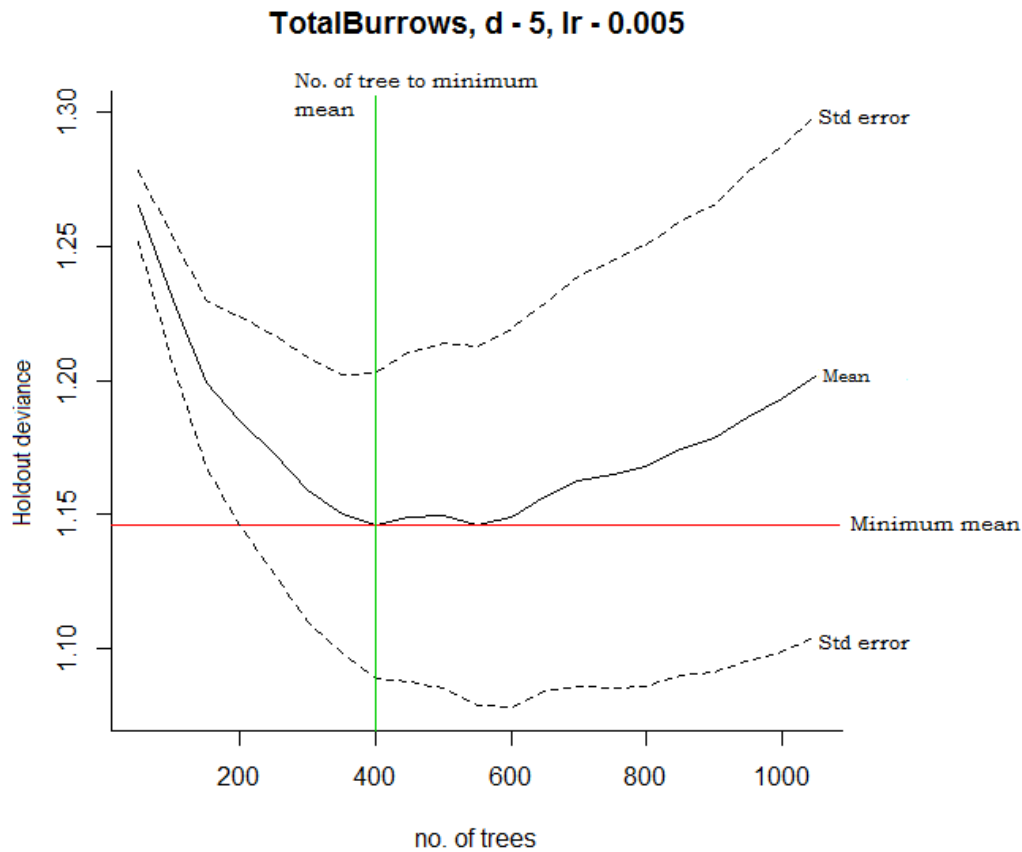
In Lukozi, the lower and middle slopes were the positions of preference for burrowing. Both landform positions were characterised by *miraba* (strips of live vegetation or residues arranged along the contour line) which provide good cover for burrowing. Also, the lower slopes had constant food supply from nearby valley bottoms which are continuously cultivated and are within rodents' home range (Mulungu, pers. comm. 2013) where they roam around for food and water resources. However, there were a limited number of burrows in valley bottoms, possibly because the hiding places were limited as there were no *miraba* and there was continual cultivation for irrigated agriculture. The present results are similar to those by Massawe *et al.* (2003) who indicated that methods of land preparation affect hiding places and therefore rodent population abundance and distribution patterns.

Furthermore, results for the other two sites (Lokome and Lukozi) suggest that probably it may not be the landform position that explains the distribution of rodent burrows, but rather safe habitat for making burrows, and food availability, that would be found in the respective landform positions. The results could also be attributed to the rodents' use of resources that vary spatially and temporally. Therefore, rodent populations would be expected to vary in space and time accordingly (Busch *et al.*, 2000).

#### **4.3.2 Landform and surface attributes influencing rodent burrows in the high plague frequency landscape**

Figures 4.6 and 4.7 show the BRT model fit and partial plots of the predictors indicating the relative influence (in brackets) explaining presence of rodent burrows. Model parameters show a good model fit, which implies that the identified predictors were

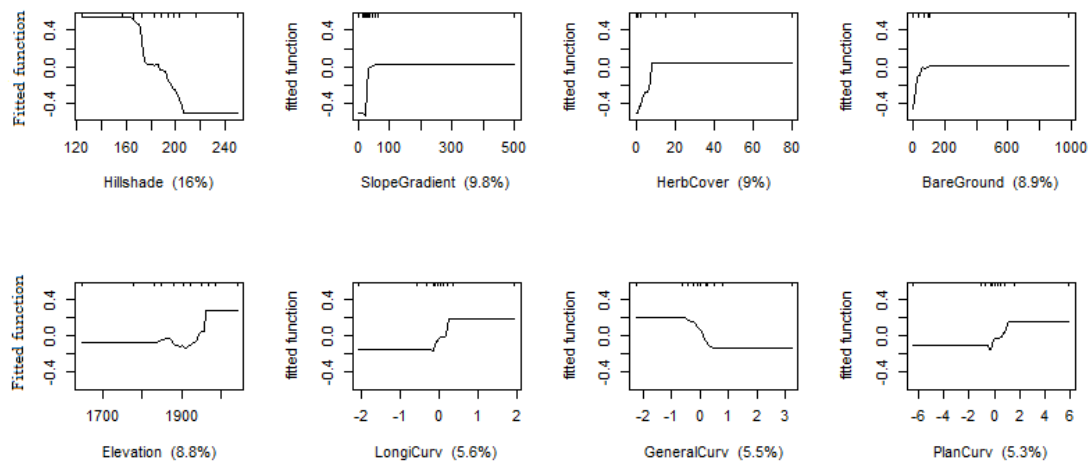
representative. It also suggests that the model is not explaining every aspect that influences rodent burrows in the area.



**Figure 4.6: Model fit for landform and surface attributes for high plague frequency area in Western Usambara Mountains, Tanzania**

Fitting final gbm model with a fixed number of 400 trees for TotalBurrows mean total deviance = 1.315; mean residual deviance = 0.763; estimated cv deviance = 1.146 ; se = 0.057; training data correlation = 0.824; cv correlation = 0.415 ; se = 0.075; training data ROC score = 0.971; cv ROC score = 0.728 ; se = 0.047

There were 26 predictors but only eight predictors with relative influence above 5.3% are presented by Figure 4.7. Predictors' variables are hillshade, slope gradient, herbs cover (herbcover), bare ground, elevation, longitudinal curvature (LongCurv), general curvature (GneralCurv) and plan curvature (PlanCurv) (Fig. 4.7).



**Figure 4.7: Partial dependence plots of the predictor variables explaining presence of rodent burrow in the studied landforms, in Western Usambara Mountains, Tanzania**

Results on ‘hillshade’, which is a hypothetical illumination of surface to enhance topographic visualisation and graphical display (Susam, 2002), suggest that it may be playing a role of meeting energy demand in the habitat by length of time and intensity of the solar energy exposure in a given location. Some research elsewhere (Goyal and Ghosh, 1993; Bogaart and Troch, 2006; Busch *et al.*, 2000) support the current results, whereby hillshade shows both the influence of topography and intensity of sunshine in different landform types in composing a rodent habitat for making burrows. The effect could be amplified by the reduced temperatures due to increase in elevation in the study area.

Slope gradient, with relative influence of 9.8%, is another predictor of rodent burrows in the high plague frequency landscape. The area is characterised by steep slope gradients, which probably influence land use through limiting accessibility within the habitats. It has been established that rodents (particularly the burrowing types) prefer inaccessible places

but with food supply (Jaksic, 1986; Abramsky *et al.*, 2000; Romanach, 2005; Nemati *et al.*, 2013).

The attribute 'herbs cover', with relative influence of 9 %, relates to the importance of cover for shelter and also for forage provision (Eileen *et al.*, 2000). It has been reported that cover provides protection, particularly from diurnal and nocturnal raptors (eagles, fowls) whose food source are rats (Taraboreli *et al.*, 2009). Research results in South and North America have shown that predators were effectively restricting spatial cavity patterns of their prey (rats) to the vicinity of protective cover of bushes, burrows and rock piles (Jaksic, 1986; Naderi *et al.*, 2011). It has been established that feeding habit changes in open insecure places and even in moonlight nights in open batches, the rodents were not freely feeding (Hodara *et al.*, 2000). Moreover, herbs and vegetation not only supply food but also affect patterns of ventilation and heat flow within burrow systems (Busch *et al.*, 2000; Naderi *et al.*, 2011). Therefore, presence of herbs cover in certain parts of the study area was a good predictor of rodent burrow density.

'Bare ground' had a relative influence of 8.9%. According to Bonsignore *et al.* (2008), rodents, in particular rats, have a tendency of avoiding open areas of high danger as their common strategy to minimise the risk in the environment. Therefore, presence of bare ground as comparatively high predictor in the model shows that there were no burrows in bare ground and this suggests that animals are forced to make burrows elsewhere for risk avoidance (Nemati *et al.*, 2013). The field work of the present study showed that burrows were located under herbs or suite of herbs around heaped stones, and under rocks or boulders, which are in agreement with the findings by Yigit *et al.* (2003) who reported that geographical distribution of rodents in Turkey was dependent on vegetation structure

and elevation, among others. Elevation was also picked by the model as important rodent burrow predictor.

Other accompanying studies have shown that most and diverse animals are found in the plateau compared to the low plains. This could be attributed to higher resources availability in the high elevation compared to the low lying areas. Within a plateau, the elevation is still important and this could be attributed to limited disturbance as compared to lower slopes where most residences and settlements are based. Similar observations have been reported in Turkey by Yigit *et al.* (2003), who established that variations of 9 to 17 rodent species were found in 20 localities studied and that vegetation structure, climate and elevation were the main factors affecting the distribution of rodent species.

Three types of curvature (planform, longitudinal and general) in the areas influence convergence and divergence of water flows, hence enrich soil water content and soil water characteristics which are important factors in rodents' selection of habitats (Rhodes and Richmond, 1985; Kumar and Pasahan, 1993). The curvatures influence the acceleration and deceleration of flow and, therefore, impact erosion and deposition (Bogaart and Troch, 2006; Lindsay, 2005; Moore *et al.*, 1991). Plan curvature in this case was important for hydrologic characteristics which influence vegetation (habitat), food availability and water resources, which are important requirements for habitat (Busch *et al.*, 2000; Hodara *et al.*, 2000; Mora *et al.*, 2010; Luiselli *et al.*, 2012).

### 4.3.3 Interaction of attributes influencing rodent burrows in the high plague frequency area

Table 4.1 presents a summary of interactions of landform and surface attributes in explaining the presence of rodent burrows. Results (Table 4.1) show that elevation and hillshade demonstrated a higher influence on the presence of rodent burrows, followed by herb cover and general curvature, and herb cover and longitudinal curvature and hillshade. The interacting attributes can be grouped into energy and cover provision. The hillshade interactions with elevation are central to solar energy influences in the habitat and herb cover and general and longitudinal curvatures encourages vegetation cover for food and security. Various research results suggest that habitat is a holistic place where multiple factors operate for the sustenance of occurrence of certain species (Jaksic, 1986; Naderi *et al.*, 2011).

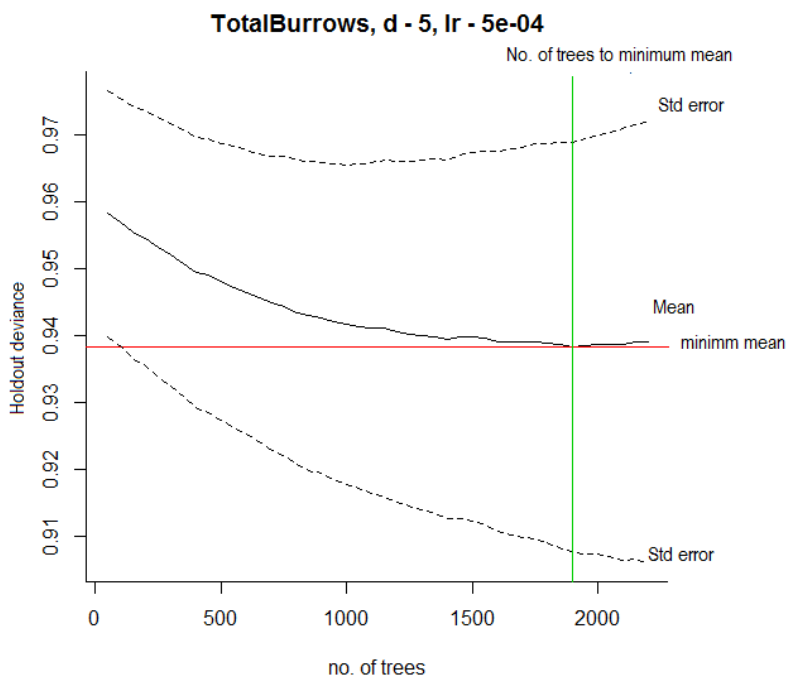
**Table 4.1: Interaction between predictor variables explaining the presence of burrows in high plague frequency landform in Western Usambara, Mountains, Tanzania**

No.	variable1 index	variable1 names	variable2 index	variable2 names	Interactions size
1	13	Hillshade	1	Elevation	4.31
2	22	HerbCover	17	GeneralCurv	0.48
3	22	HerbCover	18	LongiCurv	0.45
4	18	LongiCurv	13	Hillshade	0.41

Literature shows that predictors are operating in integration to create a habitat for rodents as indicated by their burrows presence (Eileen *et al.*, 2000). The most determinant predictors have been observed to be those factors for protection and food resource availability. If these basic requirements are not met, the species will not move to a place where risks are high and food resources are not available (Hodara *et al.*, 2000).

#### 4.3.4 Influence of landform and surface attributes on rodent burrows in the medium plague frequency landscape

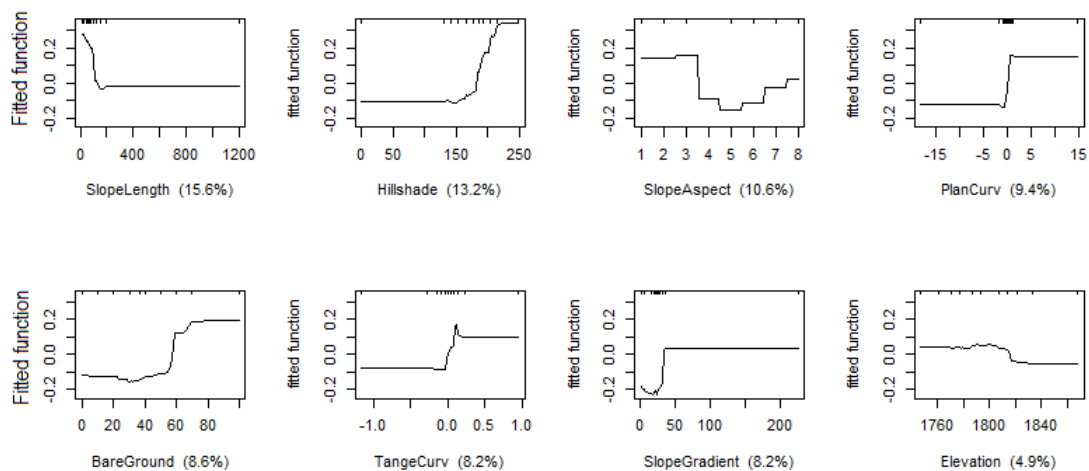
Figure 4.8 and 4.9 present a model fit and partial plots for predictor variables that explain presence of rodent burrows in the landscape. The attributes in Fig. 4.9: Hillshade, PlanCurv, BareGround, SlopeGradient and Elevation have been discussed under section 4.3.2 above. However, there are differences of influence particularly for elevation and plan curvature (Fig. 4.7 & 4.9).



**Figure 4.8: Model fit for landform and surface attributes in medium plague frequency landscape in Western Usambara Mountains, Tanzania**

Fitting final gbm model with a fixed number of 1900 trees for TotalBurrows:  
 mean total deviance = 0.961; mean residual deviance = 0.76; estimated cv deviance = 0.938 ; se = 0.031;  
 training data correlation = 0.706; cv correlation = 0.168 ; se = 0.066; training data ROC score = 0.957; cv  
 ROC score = 0.642 ; se = 0.037

The influence of elevation is 8.8 and 4.9% while plan curvature is 5.3 to 9.4 % for high and medium plague frequency landscapes respectively. The differences are attributed to topographic differences between the two landscapes. The elevation at the high plague frequency landscape is a stronger predictor than the same at the medium plague frequency landscape. This is attributed to difference in elevation and slope gradient and other slope characteristics (Fig. 4.5). It is not clear how slope length (15.6%) which is a dominant factor in medium plague frequency landscape influences burrowing compared to others, especially considering that every place is cultivated. Probably the length of slope may be restricting burrowing to specific slope positions as it has been established that in this landscape, rodent burrows are limited to lower slopes.



**Figure 4.9: Influence of landform and surface attributes on burrows in a medium plague frequent landform in Western Usambara Mountains, Tanzania**

Aspect like hillshade affects the solar energy an area receives which warms soils and influence burrowing. According Kumar and Pasahan (1993) and Goyal and Ghosh (1993) burrowing is influenced by many factors among them soil temperature which is an aspect

dependent in certain landscapes particularly in mountainous areas. Taraboreli *et al.* (2009) established that small mammal orient burrows portals to aspects where trap sun radiation into the burrows. Tangential curvature like plan, general and longitudinal curvature is related to the localised shape of landform and governs convergence and divergence of surface water flow which influence vegetation cover and top soil build up which in turn influence rodent burrowing (Moore *et al.* 1991; Goyal and Ghosh, 1993).

#### **4.3.5 Interaction of attributes influencing rodent burrows in the medium plague frequency**

Table 4.2 presents a summary of interaction between attributes in explaining burrow presence in the area. The attributes picked by the model are exactly the same as those observed in the high plague frequency landscape. The similarity of interaction results between the two studied areas (Table 4.1 and 4.2) signifies that elevation, hillshade, curvature and cover are the important predictors of rodent burrows for both landscapes.

**Table 4.2: Interaction between landform and surface attributes explaining the presence of burrows in medium plague landform in Western Usambara Mountains, Tanzania**

No.	Variable1 index	Variable1 names	Variable 2 index	Variable 2 names	Interactions size
1	13	Hillshade	1	Elevation	4.31
2	22	HerbCover	17	GeneralCurv	0.48
3	22	HerbCover	18	LongiCurv	0.45
4	18	LongiCurv	13	Hillshade	0.41

The results are in agreement with those of Bonsignore *et al.* (2008) who reported that rodent burrows help to avoid open areas of high danger as their common strategy to minimise the risk in the habitat. Therefore, ‘herbcover’ which is a comparatively high

predictor in the model shows that there were no or there were limited burrows in bare ground and this suggests that animals are forced to make burrows elsewhere for risk avoidance (Nemati *et al.*, 2013). The results are in agreement with Yigit *et al.* (2003) who reported that geographical distribution of rodents in Turkey was dependent on vegetation structure and elevation.

#### **4.4 CONCLUSIONS AND RECOMMENDATIONS**

##### **4.4.1 Conclusions**

The study on landforms and surface attributes for prediction of rodent burrows in Western Usambara Mountains has led to the following conclusions:

- i. Landform and surface attributes explain burrow presence and the differences in number of rodent burrows between high and medium plague frequency landscapes.
- ii. Specific landform characteristics such as steep slopes, rocky places and herb covers are likely to have high rodent densities.
- iii. There were slight differences between the same predictors in the two studied landscapes.
- iv. Rodent burrows were many in middle and upper slopes, and in middle and lower slopes in the high and medium plague frequency landscapes, respectively.
- v. There were no rodent burrows in Mwangoi that was located below 1500 m a.m.s.l.
- vi. Herb cover is the man-made good burrow predictor in the two areas.

##### **4.4.2 Recommendations**

The following management considerations are recommended:-

- i. Since most of the predictors identified in this study are natural landform characteristics, rodent burrow surveillance and application of rodenticide to control them on-site are recommended.
- ii. Herb cover is a strong predictor of burrows in both areas. It is recommended to manage herbs by clearing them.
- iii. Further research is recommended to find out why burrows were not observed in Mwangoi.

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## CHAPTER FIVE

### 5.0 THE EFFECT OF SOIL PHYSICAL PROPERTIES AND SOIL MICROCLIMATE ON RODENT BURROWS' CHARACTERISTICS IN WESTERN USAMBARA MOUNTAINS, TANZANIA

#### ABSTRACT

The present study was carried out between September 2009 and June 2013 in Western Usambara Mountains plague focus aimed to establish the influence of selected soil physical properties and soil microclimate on rodent burrows' abundance, portals orientation and use. Two landscapes with high and medium plague frequencies in Lokome and Lukozi villages were studied. In the two landscapes data were collected from 117 and 200 observation sites respectively, using 100 m x 200 m quadrats. At each quadrat crossing, a sample quadrat of 20 m x 20 m was demarcated for scanning rodent burrows whereby burrows encountered were counted and their portal orientation and burrow use described. Within each sample quadrat, selected soil physical properties including thickness of the soil genetic horizons, and soil dry consistence were determined. Soil samples were collected from each horizon for laboratory analysis of texture. Temperature (surface and subsurface to a depth 10 cm) and relative humidity at a depth of 10 and 30 cm were collected using infrared and thermo-couple thermometers, and *i*-Buttons. Descriptive statistics, ANOVA and logistic regression were used to analyse the data by R-software. There were significant ( $P < 0.001$ ) differences between the two landscapes regarding topsoil depth, infrared temperature, relative humidity and rodent burrows' abundance. In the high plague frequency landscape there was a significant

influence ( $P<0.05$ ) of topsoil horizon thickness on rodent burrows' abundance and use. Results also indicate that soil temperature to a depth of 10 cm was significantly ( $P<0.05$ ) correlated with rodent burrow use. Likewise, in the medium plague frequency landscape, soil physical properties and soil microclimate significantly ( $P<0.01$ ) discouraged rodent burrowing. It was concluded that soil physical and soil microclimate encouraged and discouraged burrowing in the high and the medium plague frequency landscapes, respectively. The landscape with high rodent burrows' abundance corresponded with high plague frequency records.

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Key words: Rodent burrows, burrows' abundance, soil microclimate, soil physical properties, plague focus

## 5.1 INTRODUCTION

Soils are a habitat for rodents, which are burrowing mammals (Stenseth *et al.*, 2001). Soils are important for burrow making by most fossorial and subterranean small mammals (Reichman and Smith, 1990; Biggins, 2014). Soil types and soil microclimate are reported to determine burrows' density in certain areas (Kumar and Pasahan, 1993; Goyal and Ghosh, 1993). Research conducted in Morogoro, Tanzania, has shown that soil texture influences population growth of *Mastomys natalensis* in agricultural farms (Masawe *et al.*, 2008). Other studies have shown that soil and soil microclimate influence distribution of rodents through their influence on habitats and food resources distribution (Busch *et al.*, 2000).

It has been established that most rodent habitats are determined by multiple factors, among them being vegetation cover (Groert, 1971), food availability (Busch *et al.*, 2000)

soil types (Massawe *et al.*, 2008), topography and slope gradient (Kaufman *et al.*, 2005; Wilschut *et al.*, 2012), and soil and microclimate (Mantilla-Contreras *et al.*, 2011). Soil and soil related factors like texture and moisture have been reported to be strong determinants of rodent burrowing (Desy, 1998). Rodent burrows are the proxy of rodent populations which have been linked to human plague outbreaks in Western Usambara Mountains (Kilonzo *et al.*, 1997; Kamugisha *et al.*, 2007). Similar observations were reported when studying relationships between climate and the frequency of human plague in the South-Western United States of America (Enscore *et al.*, 2002).

Rodent burrows offer a favourable environment for growth and increased rodent populations due to availability of supportive conditions for harbouring and safeguarding of young rodents. Literature indicates that burrows provide security and encouraging environment for population growth of both rodents and fleas (Busch *et al.*, 2000; Kaufman *et al.*, 2005). Abiotic factors have been reported to influence burrows' abundance. The key abiotic factors established to influence abundance of rodents include soil temperature, soil moisture and soil organic matter (Reichman and Smith, 1990; Witmer, 2004). Literature indicates that rodents have a number of preferences in relation to abiotic components for the specific location of their burrows; soil type has a significant influence on the spread and abundance of rodents (Kaufman *et al.*, 2005; Wilschut *et al.*, 2012; Brabers, 2012).

The soil microclimate, which is a function of soil type and micro-geographical features, is another important influencing parameter on the distribution of rodent burrows. Climatic variables affecting soil properties, such as temperature and soil moisture, will change the

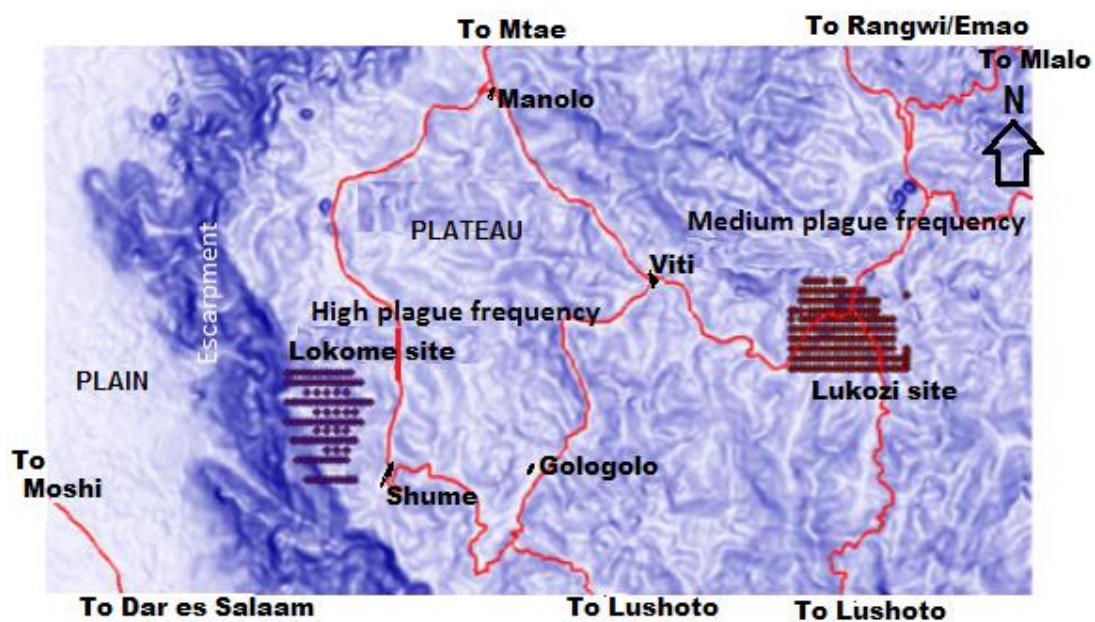
suitability of an area for rodent species (Hoover *et al.*, 1977). It has been reported too that climate determines the burrows' architecture and portal orientation such that portals are oriented towards the sunlight and sun rays' direction, and away from incoming winds (Romanach, 2005; Taraborelli *et al.*, 2009; Naderi *et al.*, 2011). Other researchers indicated that soil moisture and food availability to rodents encourage burrows' repair and burrowing activities and use (Romanach, 2005). Therefore, exploring these factors may improve understanding of predicting where rodent burrow abundance are, the information that offer means of estimating the rodent population for monitoring and surveillance before reach outbreak levels, and hence manage them.

Studies that explored the influence of soil physical properties and soils' microclimate on rodent burrows' density and their characteristics are few. Recent studies in Western Usambara Mountains partially confirmed the above hypothesis (Brabers, 2012). It is envisaged that exploration of rodent burrows' relationship with soil physical properties and soil microclimate could enlighten on why there are differences of historical plague frequency between the neighbouring villages, the fact that previous studies could not. For example some researches indicated there is a gradient of plague occurrence forming two categorical landscapes which are the high and medium plague frequency corresponding to Lokome and Lukozi landscapes (Laudisoit, 2009; Neerinckx *et al.*, 2010; Hubeau, 2010; Annaert, 2010; Ralaizafisolovony *et al.*, 2014). The objective of the current study was to find out the influence of soil physical properties and soil microclimate on burrows' abundance in Western Usambara Mountains, Tanzania.

## 5.2 MATERIALS AND METHODS

### 5.2.1 Description of the study area

The study was carried out in Western Usambara Mountains, northeastern Tanzania between September 2009 and June 2013. The area is located within Universal Transverse Mercator (UTM) Zone 37, UTM 9 474 965 N through 9 502 586 N and 444 532E through 472 276E covering an area of about 151,000 hectares (Fig. 5.1). Two sample areas (Lokome and Lukozi) were selected based on two criteria. The first one is historical plague reported incidence levels (high, medium and low). The high plague frequency landscape had plague cases that range from 4.2 – 10.5 per 1000 inhabitants; medium ranges from 1.9 – 4.2 plague case per 1000 inhabitants while the low plague frequency ranges from 0.2 – 1.9 plague cases per 1000 inhabitants.

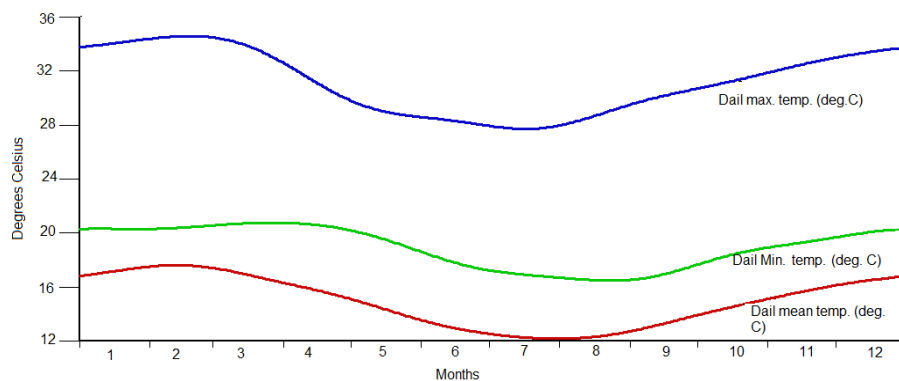


**Figure 5.1: A 3D map of part of Western Usambara Mountains showing data collection sites in Lokome and Lukozi landscapes**

The second criterion used to delineate these landscapes is differences in landform setting and farming systems, climatic variability and landform. The high plague frequency

landscape is located at an elevation of 1800 - 2100 metres above mean sea level (m a.m.s.l.), whereas the medium and low plague frequency landscapes are located at 1770 - 1890 m a.m.s.l. and below 1500 m a.m.s.l., respectively. This study was restricted in two areas, the high and medium plague frequency landscapes. Fig. 5.1 shows the location of the two studied sites and layout of observation grids.

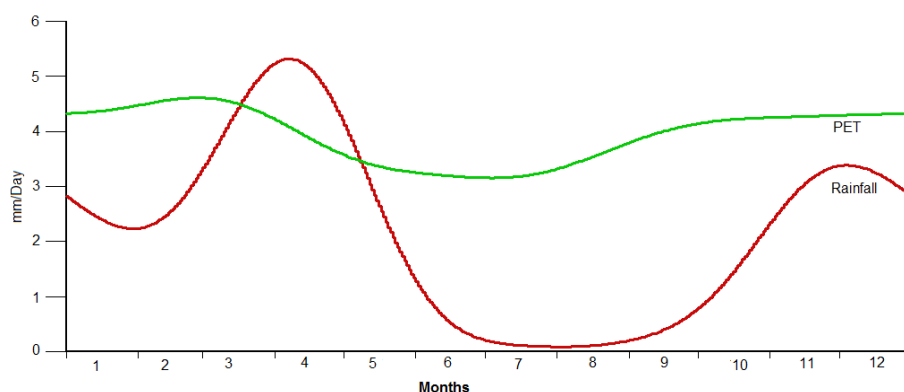
The climate of Western Usambara Mountains is characterised as “warm temperate with dry winter and warm summer”. The two areas are located in the rain shadow of Magamba ridge. Temperatures are variable where annual average ranges between 15°C and 17°C for the high and medium plague frequency areas respectively (Fig. 5.2); and a relative humidity average recorded stands at 70%. The areas receive almost similar amounts of rainfall in two seasons with slight variation from 500 to 800 mm and 600 to 900 mm per annum for the high and medium plague frequency, respectively.



**Figure 5.2: Temperature variation in Western Usambara Mountains, Tanzania**

The rainfall pattern is weakly bimodal where short rains start in October to December, but with moisture deficit, and long rains start in March through end of May (Fig. 5.3). The rainfall onset and distribution are unreliable. Rainfall onset and distribution influence

human activities and even water resources and food availability to small mammals, and hence their habitation.



**Figure 5.3: Annual precipitation distribution in Western Usambara Mountains, Tanzania**

Crops grown are common in both areas, but intensities, land sizes and varieties differ. Also, the position cultivated on the landform varies between the areas, and so are the yields per hectare. The dominant food crops grown include maize (*Zea mays*), cassava (*Manihot esculenta*), sweet potato (*Ipomoea batatas*), banana (*Musa species.*), round potato (*Solanum tuberosum*), and various beans (*Phaseolus species*). Cash crops include assorted vegetables like cabbage (*Brassica oleracea*), tomato (*Solanum lycopersicum*) and carrot (*Daucus carota*) and various fruits such as pears, plums and apples. Crop cultivation is carried out mostly on slopes and on relatively narrow U-shaped valley bottoms where traditional irrigation is practised (Lyamchai *et al.*, 1998; Meliyo *et al.*, 2004).

### 5.2.2 Determination of soil physical properties

In the field, soils were studied along pre-determined grid centres by auger to a depth 120 cm or to an obstructing layer, mini-pit to a depth of 100 cm and by representative soil profile pits which were dug to a depth of 200 cm. Soils were described using the FAO

guidelines for soil profile description (FAO, 2006). Determination was done on landform characteristics such as elevation (m a.m.s.l.), slope gradient (%) and also estimated rockiness and surface stoniness as percent coverage. Also, soil depth was determined by tape measure (cm) following the genetic horizons of soil profile, while soil dry consistence was measured by the feel method at specified depth of 0-30 cm, 30-60 cm and > 60 cm for dry soil consistence dry1, dry2 and dry3, respectively, using qualitative terms (soft, slightly hard, hard and very hard) as indicated in FAO guidelines (FAO, 2006). Soil samples were analysed for texture by hydrometer method (Gee and Bauder, 1986). The sampling plots were at a crossing of quadrats of 100 m by 200 m along and across the slope. There were a total of 117 and 200 quadrats for high and medium plague frequency corresponding to Lokome and Lukozi landscapes, respectively, (Fig. 5.1). Different lengths of quadrats were opted because the landforms were more variable along the slope than across.

### **5.2.3 Determination of soil microclimate**

Microclimate is any climatic condition in a relatively small area, within a few metres or less above and below the earth's surface and within canopies of vegetation (Hogan, 2010). It is influenced by temperature, relative humidity, wind and evaporation. In this study soil temperature and soil relative humidity were considered. The soil surface and subsoil temperatures and relative humidity (%) of subsoil at 10 and 30 cm depths were measured near the small mammal's burrow at the grid's centre. The depth of 30 cm was opted for because most rodent burrows in the Western Usambara Mountains are that deep (Brabers, 2012). Three instruments were used to assess soil temperature, each at a time (Fig. 5.4). These were Fluke 66 (infrared) thermometer, Eijkelkamp K-thermo-couple and

i-Buttons. The Fluke 66 infrared thermometer is a simple device that was used to directly read surface soil temperature by switching on the thermometer to radiate infrared signals on the soil surface which were translated into digital readings of soil temperature in degrees Celsius. Measurements were taken at random around auger holes. Shady places and live vegetation cover were avoided.



**Figure 5.4: Equipment used to collect data for soil temperature and soil relative humidity**

Another thermometer was an Eijkelkamp K-thermo-couple which was used to measure the subsoil temperature at 10 cm in degrees centigrade. The soil temperature readings were in each case taken at similar places where the surface temperature was taken and a total of five measurements were taken around the burrow.

The soil temperature and relative humidity (%) were also measured using i-Buttons. Due to their smaller size and that they could be misplaced in the soil, iButtons were tied with a piece of mosquito net, being a material that would not influence temperature and relative humidity readings. The i-Buttons were then inserted in two soil depths which

were 10 and 30 cm using a tied mosquito net in a drilled auger hole. The auger holes were filled up with soil from the same auger hole and soft soil mass from the surrounding area without rough particles or plant materials. The i-Buttons were set for three consecutive days, because this was assumed to be enough duration to capture existing soil temperature (in °C) variation in that season and it allowed easy transfer of i-Buttons to other data collection sites; they were dug up and data were transferred to the computer via data logger.

#### **5.2.4 Determination rodent burrows' abundance**

Grids of 100 m down the slope and 200 m across the slope were used to identify and study rodent burrows. In order to capture all rodent burrows in the grid with minimal errors and avoid bias, smaller grids of 20 m x 20 m were designated within the larger grids. Data collected included the number of rodent burrows, the use or non-use, and burrow portal orientation towards main slope descent.

#### **5.2.5 Data analysis**

Comparative data analysis for the two sites was done using descriptive statistics where statistical parameters: mean, median, mode and standard deviations were compared. Scatter plots and correlation were used to explore the data for multicollinearity and normality before One-Way ANOVA and regression analyses were performed. The One-way ANOVA (McCullagh and Nelder, 2007) was used to assess if the differences of means of landforms, soil physical properties and soil microclimate attributes between

high and medium plague frequency landscapes were statistically significant. Means separation was done by Tukey's test at 95% confidence interval.

Regression analysis was carried out using Generalized Linear Models (GLM) family binomial and multinomial, to identify strong attributes that explain rodent burrows' abundance and difference between the high and medium plague frequency landscapes. The GLM technique was adopted because it is suitable for regression modelling of distribution when the variance is not constant, and/or when the errors are not normally distributed (Crawley, 2007) and when the dependent variable is binary (i.e. Yes, No, or 0, 1) (McCullagh and Nelder, 2007) which applies to the data. The GLM procedure was implemented through a graphical user interface (GUI) library (Rattle) (Williams, 2009) that was operated in R-software, version R i386 3.0.0. Data sets used were small mammal burrows' abundance (presence/absence), burrow orientation and burrow use (0, 1) which were dependent (y) variables while the independent variables were soil depth (cm), textural particles (sand%, silt% and clay%), soil surface and subsoil temperature, dry soil consistence and soil relative humidity at two depth 10 and 30 cm. Categorical variables (burrow orientation and dry consistence) were assigned dummy codes. In fitting the GLM, distribution family was "Bernoulli" and link "Logit" for binary dependent variables and multinomial for multiple dependent variables were used (McCullagh and Nelder, 2007). Validation was done by data portioning whereby 70% was used for training and 30% for model development. Multicollinearity was addressed by entering weakly correlated variables serially in the model. Variables were put in the model or removed by checking variance inflation factors and checking the magnitude of error.

Developed models were selected by picking the model with a smaller Akaike Information Criterion (AIC) (Akaike, 1974).

### **5.3 RESULTS AND DISCUSSION**

#### **5.3.1 Differences in landform characteristics and rodent burrows' abundance in the two plague affected landscapes**

It was established that in the high plague frequency landscape where 117 grids were examined there were 389 rodent burrows out of which 10 had 109 fleas and 12 ticks, whereas in the medium plague frequency landscape, where 200 grids were studied, there were 100 rodent burrows and no fleas in any of the burrows. Table 5.1 presents results of landform characteristics and surface attributes and rodent burrows' abundance in the two plague affected areas of Western Usambara Mountains.

#### **5.3.2 Differences in landform attributes, soil physical properties and soil microclimate between high and medium plague frequency landscapes**

ANOVA results show that there were statistically significant ( $P < 0.001$ ) differences in elevation (metres amsl), slope gradient (%), surface rocks and stones, soil texture, herbaceous plant cover, topsoil depth (cm) and the number of rodent burrows between the high and medium plague frequency landscapes. Also, there were significant ( $P < 0.001$ ) differences between surface soil temperature (infrared), soil thermo-couple (10 cm depth) and relative humidity at 30 cm soil depth.

**Table 5.1: Rodent burrows' abundance per grid, slope gradient, surface rocks/stones and herbaceous cover in the high and medium plague frequency landscapes**

<b>Statistics</b>	High	Medium	High	Medium	High	Medium	High	Medium	High	Medium	High	Medium
	Slope gradient (%)		Surface rocks		Surface stones		Herb cover		topsoil depth (cm)		Rodent burrow numbers	
Count (n)	(117)	(194)	(117)	(200)	(117)	(200)	(117)	(200)	(116)	(200)	(117)	(201)
Mean	40.0	21.9	16.3	0.13	14.3	0.1	9.5	2.6	18.9	23.2	3.4	0.5
Median	29.0	23.0	0	0	0	0	1.0	0.0	15.0	20.0	1.0	0.0
SD	48	12.0	27.2	1.2	24.1	0.5	18	12	10.0	11.4	4.7	1.6
Minimum	2.0	0.5	0	0	0	0	0	0	3.0	2.0	0.0	0.0
Maximum	500	61	90	15	90	5	80	90	50	70	25	13

Results further show significant ( $P < 0.001$ ) differences between the two landscapes for vegetation cover where there was more cover in the high plague frequency landscape because of existing forest plantations and nature reserve, and most areas of the adjoining escarpment had long time fallows. On the other hand in the medium plague frequency landscape which is below 1800 metres amsl, vegetation cover was comparatively low, although there were woodlots and few trees planted along farm boundaries and around homesteads (Table 5.1). In addition the high plague frequency landscape also experiences the wind currents blowing from the lower plains hence regulating temperatures at the altitude above 1900 metres amsl. The fact that there were more burrows in the high plague frequency landscape than in the medium plague frequency landscape (Table 5.1) may imply that soil temperatures and relative humidity were more favourable for rodents' habitation (Hoover *et al.*, 1977; Mantilla-Contreras *et al.*, 2011) in the high than in the medium plague frequency landscapes. This partly explains as to why there are plague frequency differences between the two landscapes (Davis *et al.*, 2006). Further it has been shown that elevation and human disturbances which were different in the two landscapes may also strongly influence spatial rodent distribution and hence their burrows. This agrees with a report which associated rodent population with human disturbance (Maryanto *et al.*, 2009). Also, research carried out along the slopes of Mount Kilimanjaro indicated that elevation and vegetation may similarly be influencing spatial distribution and diversity of rodents (Mulungu *et al.*, 2008).

Therefore, higher number of rodent burrows in the high than in the medium plague frequency landscapes could be attributed to the differences in heterogeneity between the two landscapes, as more variability was pronounced in the high than in the medium

plague frequency landscapes (Table 5.1). The steep slopes, rocks, stones and herbaceous cover appeared to influence greatly rodent habitation hence more burrows. The above characteristics appeared also to influence differently soil temperature and relative humidity between the high and the medium plague frequency landscapes of Western Usambara Mountains. The steep slopes, rocks, stones and herbaceous cover were pronounced in the high plague frequency landscape and provide hiding places for rodents, hence make good habitats.

Therefore, the high plague frequency landscapes had greater rodent burrows' abundance, which correspond with reported human plague frequency (Laudisoit, 2009; Neerinckx *et al.*, 2010; Hubeau, 2010; Annaert, 2010; Ralaizafisoloarivony *et al.*, 2014). These results agree well with report that rodents prefer establishing their habitation in favourable environment where risk of predators is low and where water and food resources are available (Reichman and Smith, 1990; Busch *et al.*, 2000). In addition some authors indicated that rodent burrows are selectively placed along steep slopes in upland and never in lowland (Kaufman *et al.*, 2005). Rodents may as well make burrows out of evolutionary behavioural complexities developed by genetics (Weber *et al.*, 2013). This implies that there may be differences that are based on local environment surrounding rodent populations. The two landscapes have different endowments, the high plague frequency landscape being more favoured than the medium plague frequency landscape. The findings also agree with research that indicated that rodent burrows are selectively placed along steep slopes in upland and never in lowland (Kaufman *et al.*, 2005).

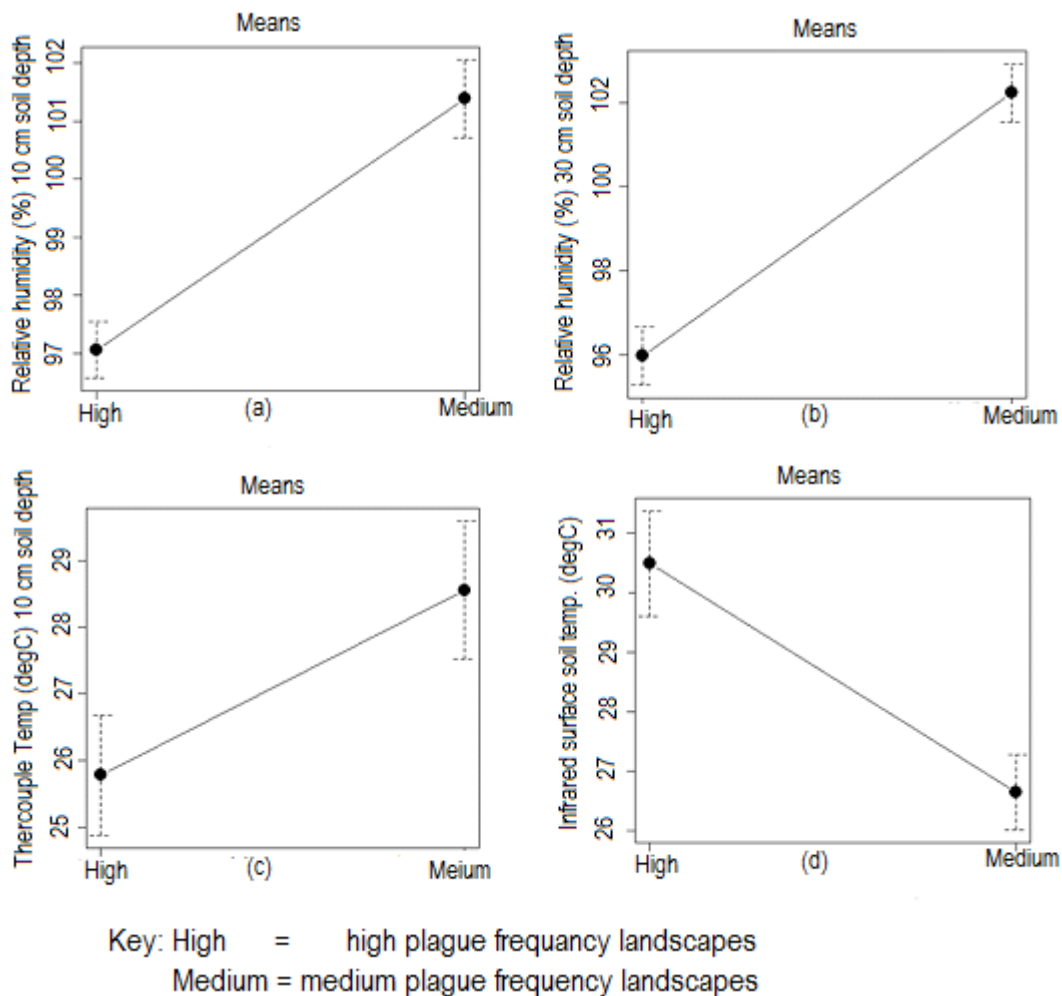
Although results on slope aspect with respect to the two landscapes were not statistically significant ( $P < 0.05$ ), results show that in the high plague frequency landscape, slopes facing south-west (SW), North (N) and north-west (NW) had 94 (24.6 %), 67 (17.4%) and 53 (13.7%) rodent burrows, respectively while in the medium plague frequency landscape, slope facing Southeast (SE), Northeast (NE) and West (W) had 30 (32.6%), 26 (28.3%), and 15 (16.3%) rodent burrows, respectively. This means rodent burrows in the high plague frequency landscapes were mostly pointing westwards (38%) whereas in the medium plague frequency they were mostly pointing eastwards (61%). The above result signifies the importance of burrow portal orientation. Other researchers have shown that small mammals orient burrows' portals to slope aspects facing solar incoming radiation to light and warm inside (Romanach, 2005; Taraborelli *et al.*, 2009; Naderi *et al.*, 2011) or just certain direction which create favourable burrow condition (Kaufman *et al.*, 2005).

The orientation of the rodent burrows' portals although meant to warm rodent burrows by orienting away from the wind in cold season and towards the wind in hotter season (Taraborelli *et al.*, 2009) it also helps the vectors (fleas to survive because they are ectothermic hence sensitive to temperature fluxes and usually develop from larvae to adult off the host i.e. the burrows' temperature becomes the only way of survival (Cavanaugh and Marshall, 1972). This means that the different soil temperatures in the two landscapes favour the vector differently. In places where temperature and relative humidity are high like the case of the medium plague frequency landscape, the environment favours fungal growth which destroys the flea larvae. It has been documented that fleas (the plague vectors) can only survive where temperatures and relative humidity are optimal for survival (Cavanaugh and Marshall, 1972; Ben Ari *et al.*, 2011), and this partly depends on

how the burrow portal is oriented towards sunlight and or wind (Taraborelli *et al.*, 2009). This might be among explanations as to why there are differences of plague outbreak in the two studied landscapes in Western Usambara Mountains. There is a difference in burrows' abundance between the two landscapes, whereby the one with fewer burrows (medium plague frequency landscape) had no fleas; while the one with high rodent burrows' abundance (high plague frequency landscape) had fleas in 15% of the counted burrows. This corresponds well with the historical plague outbreaks in the area (Davis *et al.*, 2006).

Figure 5 (a-d) presents results of mean plots of relative humidity (RH%), surface soil temperature (infrared) and the K-thermo-couple temperature at different depths. The results show differences between the high and medium plague frequency landscapes. The differences are statistically significant ( $P < 0.01$ ) for relative humidity (RH) (%) in the 10 and 30 cm depths. In both two depths, the RH values are higher in the medium plague frequency landscape than in the high plague frequency landscape (Fig. 5 a and b). Results also show that K-thermo-coupe temperature is significantly ( $P < 0.01$ ) higher in the medium than in the high plague frequency landscape (Fig. 5c). In the case of infrared surface temperature, higher values are observed in the high plague frequency landscape than in the medium plague frequency landscape.

Generally, the high infrared surface soil temperature could be attributed to the dense presence of rocks and stones which were significantly ( $P < 0.01$ ) higher in the high than the medium plague frequency landscape. These rocks and stones heatup during the day time consequently elevating surface temperature.



**Figure 5.5: Soil temperature and relative humidity in the high and medium plague frequency landscapes, Western Usambara Mountains, Tanzania**

The high K-thermo-couple temperature and relative humidity (%) could be attributed to the landform setting, land use and topsoil depth. Results show that there were statistically significant ( $P < 0.01$ ) differences between the two plague affected landscapes for elevation and slope gradient, and these may have influenced the amount of solar energy the different landscapes receive. Again, the medium plague frequency landscape has been deforested and seasonally cleared extensively for cultivation thereby allowing sunshine to illuminate over the surface directly and the solar energy absorbed and stored in the soil,

making the soils warmer in the medium plague frequency landscape. However, in the high plague frequency landscape where there is more vegetation cover (plantation forestry, natural forest) and steep slopes, these reduce the amount of solar radiation the area receives as they cover the surface at small angle which reduces its effectiveness and hence reduced solar energy trapped, hence reduced soil temperature. The high relative humidity levels in the medium plague frequency landscape could be attributed to topsoil depth which was significantly ( $P < 0.01$ ) deeper and with less stones and rocks than the topsoil depth in the high plague frequency landscape. It could also be attributed to the nature of slopes of the landscape which allow rainfall infiltration which provokes more rock and soil parent material weathering than in the steep and short slopes in the high plague frequency landscapes.

Table 5.2 presents the results of dry consistence between two landscapes. The results show that the topsoils were harder (consistence dry 1 and dry 2) in the high plague frequency landscape as compared to soft and lightly hard consistence observed in the medium plague frequency landscape. The dry consistence difference between the landscapes was not significant, but the high plague frequency landscape was generally more compacted. Research findings elsewhere have shown that soil hardness negatively influence burrowing as rodents avoid using much energy to dig in hard places (Lovegrove, 1988). However, if there is no softer place, and no alternative hiding caves, rodents make burrows even in hard places but the network and complexities may be different (Reichman and Smith, 1990; Busch *et al.*, 2000).

**Table 5.2: Differences in dry soil consistence in the studied plague affected landscapes**

Statistics	High plague frequency			Medium plague frequency		
	Consistence	Consistence	Consistence	Consistence	Consistence	Consistence
	Dry 1	Dry 2	Dry 3	Dry 1	Dry 2	Dry 3
Mean	1.3	1.4	1.2	1.1	1.3	1.2
Median	1	1	1	1	1	1
STD	0.59	0.62	0.93	0.38	0.60	0.69
Skewness	1.61	0.84	0.46	1.31	1.25	0.53
Minimum	1	1	1	1	1	1
Maximum	3	3	4	2	3	3
n	117	117	117	200	200	200

Key: Consistence dry: 1=soft; 2=slightly hard, 3=hard, 4=very hard

### 5.3.3 Generalized Linear Model (GLM) regression analysis

#### 5.3.3.1 Influence of soil physical properties and soil microclimate on rodent

##### burrows' abundance in the high plague frequent landscapes

Table 5.3 shows the influence of soil physical properties, temperature and relative humidity attributes on burrows' abundance. Topsoil depth (Depth1, 0-30 cm), which is a natural Ap/Ah horizon (FAO, 2009), was a statistically significant ( $P < 0.05$ ) soil physical property for prediction of burrows' abundance, with a relative influence of 39.5%. This implies that thick  $\leq 30$  cm Ap (topsoils Ap depth in cm) encourages rodent burrowing. The average thickness of topsoil (Table 1) in which the rodent burrows were located in this study are in line with a report that rodent burrows are limited to topsoils, at depths of 10 – 45 cm (Goyal and Ghosh, 1993), but this may vary with soil types whereby in sandy soils burrows can go as deep as 190 cm (Gano and States, 1982); and seasons and type of rodents (Kumar and Pasahan, 1993; Goyal and Ghosh, 1993).

**Table 5.3: Soil physical properties and soil microclimate factors explaining burrows' abundance in the high plague frequency landscapes**

Variable	Constant/ Estimate	Std. Error	z value	Pr(> z )
(Intercept)	-0.34	13.159	-0.026	0.979
Depth1 (0 - 30 cm)	0.119	0.0829	1.442	0.015*
Depth2 (30 - 60 cm)	0.010	0.0522	0.185	0.854
Depth3 (> 60 cm)	-0.005	0.0302	-0.16	0.873
Consistence Dry1 (0 - 30 cm)	1.395	1.3679	1.02	0.308
Consistence Dry2(30 - 60 cm)	-0.436	1.2023	-0.363	0.717
Consistence Dry3 (>60 cm)	0.391	0.8062	0.485	0.628
Infrared Temperature (Celsius)	-0.049	0.0685	-0.724	0.469
Thermal Couple (10cm)	0.068	0.0451	1.522	0.128
Relative humidity (%)_10cm	-0.108	0.1166	-0.931	0.352
Relative humidity (%)_30cm	0.070	0.1262	0.554	0.579

Significant levels: 0 '\*\*\*\*' 0.001 '\*\*\*' 0.01 '\*\*' 0.05 '\*' 0.1 '.' 1

These results also agree well with other researchers who indicated that rodents prefer topsoils for burrowing because they are well drained (Rhodes and Richmond, 1985; Naderi *et al.*, 2011), loose and easy to make burrows without using much energy as compared to cohesive and compact subsoils (Rhodes and Richmond, 1985; Cameron *et al.*, 1988; Laundre and Reynolds, 1993; Luna and Antinuchi, 2006; Skliba *et al.*, 2011).

### 5.3.3.2 Influence of soil physical and soil microclimate to rodent burrow portals' orientation in high plague frequency landscapes

Table 5.4 presents results indicating that there was no statistically significant influence of soil physical properties and soil microclimatic attributes on rodent burrow portal orientation. This would mean that the considered attributes were not good predictor variables with regard to rodent burrow portals' orientation.

**Table 5.4: Soil physical properties and soil microclimate factors explaining burrow portals' orientation in the high plague frequency area**

Variable	Estimate	Std Error	t-value	Pr(> t )
(Intercept)	3.393	1.126	3.012	0.00352**
Depth1 (0 - 30 cm)	-0.019	0.016	-1.229	0.22295
Depth2 (30 - 60 cm)	0.009	0.012	0.692	0.49101
Silt (%) (Ap)	-0.017	0.014	-1.213	0.22899
Clay (%) (Ap)	-0.017	0.020	-0.815	0.41783
Consistence Dry1 (0 - 30 cm)	0.514	0.289	1.778	0.07941
Consistence Dry2 (30 - 60 cm)	-0.418	0.292	-1.43	0.1568
Consistence Dry3 (> 60 cm)	-0.012	0.184	-0.065	0.94797
Infrared Temperature Celsius	-0.023	0.018	-1.281	0.20402

Significant levels: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 '' 1

### 5.3.2.3 Influence of soil physical properties and soil microclimate attributes on burrows' use in the high plague frequency landscape

Table 5.5 presents results showing that topsoil depth, Ap/Ah horizon (topsoils Ap depth in cm) and sub-soil temperature were statistically significant ( $p < 0.05$ ) in influencing rodent burrow use with relative influence of 28.8 and 32.8%. This would mean that both soil depth and subsoil-temperature encourage burrow use. This could be attributed to the topsoils' textures which are mainly sandy clay loams, well drained, slightly harder; so do not collapse easily, hence preferable by burrowing and use.

**Table 5.5: Soil physical properties and soil microclimate factors explaining burrows' use in the high plague frequency landscapes**

Soil properties	Df	Deviance	Residual Df	Residual Deviance	Pr(>Chi)
Constant			45	63.77	
Depth1 (0 – 30 cm)	1	3.9567	44	59.813	0.04669 *
Depth3 (> 60 cm)	1	3.7019	43	56.111	0.05435.
Consistence Dry1 (0 - 30 cm)	1	1.5825	42	54.528	0.20841
Thermal Couple_10cm	1	4.509	41	50.019	0.03372 *

Significant levels 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

The results agree with previous research which indicated that rodents make and prefer burrows for security, nursing the young ones, for storage of food and for cushioning from weather fluxes (Reichman and Smith, 1900; Busch *et al.*, 200). Soil types impact the depth at which burrows are set. Literature shows that in sandy soils rodent burrows are very deep whereas in clayey soils they are shallow and complex and difficult to make (Gano and States, 1982; Gase and Jasch, 2005). It has been reported that rodents makes burrows where the energy use is minimal (Luna and Antinuchi, 2005). In the studied landscapes, the burrows' depths were mainly within 30 - 45 cm soil surface.

### 5.3.3.4 Influence of soil physical properties and soil microclimate attributes on burrows in the medium plague frequency area

Table 5.6 presents results on coefficients' estimates, direction of influence and standard error of predictors. Results show statistical significance ( $P < .05$ ) for the topsoil dry consistence (consistence dry1), subsoil dry consistence (ConsDry2) and subsoil relative humidity (RH (%) 30 cm) to influence burrows' abundance in the medium plague frequency landscape. While the topsoil dry consistence encourages burrowing, the subsoil relative humidity discourages burrowing. These results suggest that burrows are likely to be more abundant in relatively harder and less humid topsoils, than in soft and moist topsoils.

The negative influence of relative humidity on rodent burrows' abundance could be attributed to the requirement by rodents to disperse heat, which is compromised in the high relative humidity environment (Kay and Whitford, 1978). Research elsewhere has shown that rodents prefer to make burrows in soft, well drained soils in order to reduce thermal stress and the cost of burrow making (Romanach, 2005; Wlasberg, 2000).

**Table 5.6: Influence of soil physical properties and soil microclimate attributes on rodent burrows' abundance in the medium plague frequency landscape**

Variable	Estimate	Std error	z value	Pr(> z )
(Intercept)	353.11	29107.97	0.012	0.9903
Depth2 (30 - 60 cm)	-0.003	0.029	-0.095	0.9247
Depth3 (> 60 cm)	0.009	0.021	0.413	0.6799
Consistence dry1 (0 - 30 cm)	2.536	1.266	2.003	0.0452 *
Consistence dry2 (30 - 60 cm)	-2.821	1.344	-2.099	0.0358 *
Consistence dry3 (> 60 cm)	0.786	0.801	0.982	0.3262
Infrared Temperature (Celsius)	-0.015	0.059	-0.247	0.8047
Thermal Couple_10cm	0.0121	0.036	0.335	0.7379
Relative humidity (%)_10cm	0.024	0.035	0.683	0.4947
Relative humidity (%)_30cm	-0.121	0.061	-1.991	0.0465 *

Significant levels: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

The reason is that rodents are homeothermal (they are animals that maintain body temperature at a constant level) and need to regulate their body temperature through evaporation, which is highly reduced when relative humidity is high (Kay and Whitford, 1978; Reichman and Smith, 1990; Busch *et al.* 2000). Further, relative humidity has been illustrated as key to flea survival because the larvae are susceptible to desiccation and in excessive relative humidity attacked by fungi (Cavanaugh and Marshall, 1972). Other reports show that because most of the life cycle of flea is in the rodent burrows the distribution and pattern of fleas can be determined by the habitat differences and in particular the surrounding microclimate (Shenbrot *et al.*, 2010).

#### **5.3.3.5 Influence of soil physical properties and soil microclimate attributes on burrows' use in the medium plague area**

Table 5.7 presents results showing that dry consistence of both topsoil and subsoil (ConsDry1-2) is statistically significant ( $p < .05$ ) soil physical properties predicting burrow use. The signs for the coefficient in the dry consistence for the top and subsoils are positive and negative, respectively. This implies that extended use of burrow depends on the degree of resistance of burrow to collapse, a characteristic which is dependent on compaction or on the top-soil dry consistence where burrows are normally found. In the subsoil, dry consistence discourages burrowing into hard layers. This agrees with other studies that rodents avoid digging burrows in compacted areas to reduce energy use (Romanach, 2005; Luna and Antinuchi, 2005).

**Table 5.7: Influence of soil physical properties and soil microclimate on burrows' use in the medium plague frequency area**

<b>Variable</b>	<b>Estimate</b>	<b>Std. Error</b>	<b>t-value</b>	<b>Pr(&gt; t )</b>
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Intercept	7.725873	8.100885	0.954	0.342
Depth1 (0 - 30 cm)	-0.0023	0.003197	-0.719	0.4732
Depth2 (30 - 60 cm)	-0.00261	0.002589	-1.008	0.3155
Depth3 (> 60 cm)	-0.00014	0.002208	-0.065	0.9482
Sand % (Ap, 0 - 30 cm)	-0.06825	0.080756	-0.845	0.3996
Silt % (Ap, 0 - 30 cm)	-0.07055	0.081416	-0.866	0.3878
Clay % (Ap, 0 - 30 cm)	-0.07631	0.082167	-0.929	0.3548
Consistence Dry1 (0 - 30 cm)	0.232137	0.110805	2.095	0.0381 *
Consistence Dry2 (30 - 60 cm)	-0.23406	0.101675	-2.302	0.0229 *
Consistence Dry3 (> 60 cm)	0.099652	0.090067	1.106	0.2706
Infrared temperature (C)	0.005249	0.006148	0.854	0.3948
Thermal Couple_10cm	0.0002948	0.003778	0.078	0.9379
Relative humidity (%)_10cm	-0.00028	0.004025	-0.071	0.9438
Relative humidity (%)_30cm)	-0.00475	0.003732	-1.272	0.2057

Significant levels: 0 '\*\*\*\*' 0.001 '\*\*\*' 0.01 '\*\*' 0.05 '.' 0.1 '.' 1

Other physical soil properties and soil microclimate attributes tested did not show any influence on burrow use, although the coefficients for soil depth (0 to >60 cm), textural particles, and relative humidity seem to negatively influence rodent burrows' abundance.

### 5.3.3.6 Influence of soil physical properties and soil microclimate attributes on burrows' portals orientation in the medium plague frequency area

Table 5.8 presents results which depict that subsoil dry consistence, significantly ( $p < 0.05$ ) influences negatively burrow portals' orientation. These results suggest that subsoil dry soil consistence discourages portal orientation, implying that the rodent portal set-up may not be influenced by the variables that were considered in the model.

**Table 5.8: Influence of soil physical properties and soil microclimate on burrows' portals orientation in the medium plague frequency area**

	Estimate	Std. Error	t-value	Pr(> t )
(Intercept)	2.496455	1.494738	1.67	0.0970 .
Silt (%) (Ap, 0 - 30 cm)	-0.00824	0.008869	-0.929	0.3544
Clay (%) (Ap, 0 - 30 cm)	-0.02037	0.01473	-1.383	0.1689
Consistence dry1 (0 - 30 cm)	0.596808	0.31892	1.871	0.0633 .
Consistence dry2 (30 - 60 cm)	-0.52158	0.22136	-2.356	0.0198 *
Consistence dry3 (>60 cm)	0.08976	0.155418	0.578	0.5645
Infrared tempera. (C)	0.012672	0.017327	0.731	0.4657

Thermal Couple 10cm	0.003644	0.010816	0.337	0.7367
Relative humidity (%) 10cm	-0.00766	0.011076	-0.691	0.4904
Relative humidity (%) 30cm	-0.00844	0.010579	-0.798	0.4264

Significant levels: 0 '\*\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 '' 1

Although, the variables that were considered apparently did not show significant, the field data show that rodent burrows were oriented down the slopes or sideways in order to avoid surface run-off, or oriented in directions that avoid cold winds and/or that aid trapping of sunlight energy into the burrow. Our results are in agreement with those published earlier indicating that rodent orient burrows towards sunlight direction (Romanach, 2005, Taraboreli *et al.*, 2009; Torres *et al.*, 2003).

## 5.4 CONCLUSIONS AND RECOMMENDATIONS

### 5.4.1 Conclusions

It is concluded from this study that:

- i. There are differences of studied soil physical properties and soil microclimate in the studied landscapes.
- ii. Topsoil depth has influence on rodent burrows' abundance where higher influence is apparent in the high than in the medium plague frequency landscape.
- iii. Dry soil consistence (hardness) discourages rodent burrowing but encourages burrow use.
- iv. Relative humidity discourages burrowing in the medium plague landscape and due to fungal infection associated with high relative humidity it also seems to discourage flourishing of the plague vector (flea) larvae.
- v. Differences observed in soil physical properties and soil microclimate between the studied sites correspond with the observed rodent burrows' abundance in the two landscapes, implying that soil physical properties and soil microclimate could partly

explain burrows' abundance in the area. This also partly explains the historical plague outbreak difference that exists between the two landscapes.

#### **5.4.2 Recommendations**

More research is strongly recommended on the role of soil physical and chemical properties and broad range of soil microclimate in influencing where burrows are set. This will add knowledge on the areas where rodent populations are likely going to be high, thereby facilitating forecasting, monitoring and management.

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**Appendix 5.1: Correlation of burrow characteristics, soil physical properties and soil microclimate for high and medium plague frequency landscapes**

	BDT	BDT2	Burro Use	BPO	Depth1	Depth2	Depth3	Sand	Silt	Clay	Cons Dry1	Cons Dry2	Cons Dry3	Infrar_TempC	Them Cuple_10	RH(%)_10cm
BDT2	0.634	1														
	0.000															
BurroUse	0.545	0.91	1													
	0.000	0.000														
BPO	0.608	0.966	0.897	1												
	0.000	0.000	0.000													
Depth1	-0.093	-0.127	-0.161	-0.115	1											
	0.1	0.024	0.004	0.041												
Depth2	0.022	0.029	0.026	0.033	-0.014	1										
	0.699	0.615	0.641	0.565	0.806											
Depth3	0.05	0.067	0.092	0.071	-0.054	-0.008	1									
	0.406	0.27	0.131	0.241	0.374	0.889										
Sand	-0.137	-0.109	-0.053	-0.096	0.073	0.015	-0.043	1								
	0.015	0.054	0.35	0.089	0.197	0.792	0.477									
Silt	0.114	0.136	0.079	0.11	-0.105	-0.024	0.112	-0.85	1							
	0.042	0.015	0.159	0.051	0.064	0.674	0.065	0.000								
Clay	-0.044	-0.121	-0.086	-0.087	0.097	0.016	-0.136	0.299	-0.752	1						
	0.436	0.031	0.127	0.123	0.086	0.775	0.025	0.000	0.000							
ConsDry1	0.138	0.135	0.097	0.14	0.042	0.149	-0.057	0.008	-0.085	0.14	1					
	0.014	0.016	0.086	0.012	0.46	0.008	0.351	0.889	0.132	0.013						
ConsDry2	0.002	-0.052	-0.042	-0.037	-0.06	0.117	-0.003	0.1	-0.107	0.077	0.553	1				
	0.97	0.36	0.453	0.516	0.289	0.039	0.961	0.077	0.058	0.173	0.000					
ConsDry3	-0.01	-0.027	0.006	-0.038	-0.018	-0.031	-0.048	0.096	-0.072	0.015	0.173	0.397	1			
	0.859	0.636	0.918	0.502	0.748	0.58	0.43	0.09	0.203	0.793	0.002	0.000		1		
Infrar_TempC	0.164	0.144	0.163	0.147	-0.104	0.06	-0.002	0.007	-0.058	0.079	0.13	0.165	0.125			
	0.006	0.016	0.006	0.014	0.083	0.316	0.974	0.91	0.334	0.186	0.03	0.006	0.037		1	
ThemCuple_10	-0.007	0.091	0.085	0.084	-0.066	0.033	-0.082	-0.074	0.105	-0.092	-0.064	0.037	0.098	0.274		
	0.907	0.137	0.164	0.168	0.281	0.592	0.205	0.229	0.085	0.133	0.296	0.546	0.109	0.000		
RH(%)_10cm	-0.224	-0.233	-0.265	-0.211	0.173	-0.015	-0.094	0.084	-0.079	0.048	-0.043	-0.009	-0.002	-0.207	0.086	1
	0.000	0.000	0.000	0.001	0.006	0.815	0.16	0.182	0.207	0.45	0.49	0.891	0.97	0.002	0.209	
RH(%)_30cm	-0.251	-0.298	-0.297	-0.284	0.095	-0.024	-0.067	0.04	-0.039	0.021	-0.092	-0.023	-0.1	-0.224	-0.004	0.398
	0.000	0.000	0.000	0.000	0.131	0.7	0.32	0.522	0.536	0.745	0.147	0.713	0.114	0.001	0.951	0.000

Cell Contents: BDT upper numbe is a Pearson correlation coefficient and the lower number is its P-value. (Significant  $P < 0.05$ ) BDT = burrow dsnsity total (count per 400 sq m), BDT2 = Burrow presence or absence (0,1), BPO = Burrow portal orientation

## CHAPTER SIX

### 6.0 GENERAL DISCUSSION AND CONCLUSIONS

#### 6.1 GENERAL DISCUSSION

##### 6.1.1 Landforms, soil properties, small mammals (rodents) and fleas

In Lushoto District, knowledge is lacking about the role of landforms and soil properties in relation to the occurrence of the plague disease. It is thus clear that the natural habitat of plague, and consequently the precise location of infestation sites in Lushoto are also unknown. Therefore, this research attempted to focus on the elaboration of landforms and soil properties with respect to potential hosts and vectors of plague in order to link them with the distribution of plague. This hypothesis was tested by modelling landforms and soil properties as proxy that could enlighten on the description of plague foci and possibly explain the nature of re-emergence of plague disease after several decades of quiescence (Neerinckx *et al.*, 2010; MacMillan *et al.*, 2012). This research was initiated to refine our understanding due to the fact that this type of studies relating landforms-soil properties-plague hosts and vectors abundance are limited particularly for Lushoto District (Brabers, 2012; Neerinckx, 2010). Understanding landforms and soil properties in the Lushoto plague focus could provide an insight into plague foci, with respect to rodents as plague hosts, and hence enable one to account for the differences of plague occurrence between neighbouring villages.

The results of this study clearly show that the landforms in Lushoto District are variable with strong dissection and steep slopes of different curvatures. The dissection constitutes a complex system of elongated terraced ridges and debris slides separated by narrow to

wide U-shaped drainage valleys (converging hydrological flows). The observed landforms are complex surface features with varying moisture conditions, vegetation and microclimates. These conditions have been reported to favour the occurrence of small mammals and fleas (Randhir, 2007; Jake *et al.*, 1997; Monjeau *et al.*, 1997). It is also noted that soil properties are also strongly correlated with landforms. The landform-soil properties model clearly demonstrated significant relationship between small mammals' and fleas' occurrence with landform features, namely elevation and slope aspect. Among the studied soil properties, extractable phosphorus and per cent base saturation are strong soil predictors for richness and evenness both of small mammals and flea abundance. Distribution of fleas was also, in addition, favoured by hill-shade, organic carbon and exchangeable magnesium.

In general, there are no studies that have directly related landforms and soil properties with plague hosts and/or vectors. Most studies have related elevation with small mammals' and fleas' abundance and diversity in a plague focus (Joseph *et al.*, 2012; Mulungu *et al.*, 2008; Grytnes *et al.*, 2002; Brown, 2001). In some of these case studies, landscape factors are suggested to be an important parameter for prediction of plague hosts and vectors in a plague focus but only little elaboration is given on the type of landscape factors to be considered (MacMillan *et al.*, 2012; Neerinckx, 2010; Collinge *et al.*, 2005). Others have stressed on the relationships between small mammals and fleas with habitats related to altitudinal gradient and vegetation but not landform types such as slope aspect, form and curvature, depositional, structural and erosional landforms and soil properties (Mulungu *et al.*, 2008; Witmer, 2004; Sanchez-Cordero, 2001). Therefore, this study has provided insight into small mammal and flea dynamics in relation to landforms

and soil properties in a plague focus and hence could possibly facilitate better ways of managing host vector outbreaks and plague risks.

### **6.1.2 Soil micronutrients and landforms in the plague risk area**

Most of the plague studies in East Africa have stressed on the importance of edaphic factors in understanding the disease dynamics (MacMillan *et al.*, 2012; Eisen *et al.*, 2012; Neerinckx *et al.*, 2010; Kamugisha *et al.* 2007; Laudisoit *et al.*, 2007; Davis *et al.*, 2006; Kilonzo *et al.*, 1992). Some studies have attempted to examine the surface landscape connectivity (landforms and soils) to the ecology of plague (Brabers, 2012; Neerinckx, 2010; Massawe, 2010). Others suggest that soil physical and chemical properties are important factors influencing rodents, which are the hosts of plague (Brabers, 2012; Neerinckx, 2010; Massawe, 2010). Occurrences of plague hosts in some places were observed to correlate with soils which have medium or high concentrations of iron, cobalt, and titanium, and low concentrations of copper, nickel, and vanadium (Neerinckx, 2010; Rotshild, 2001; Mezentsev *et al.*, 2000). In this study an attempt was made to investigate the status of soil micronutrients with respect to landforms in the plague focus of Western Usambara Mountains, where data on soil micronutrients are lacking. In this area relationships of these nutrients with landforms (which are important factors for host and vector habitats) have not been investigated. The hypothesis was addressed in this study in order to contribute to the ongoing landscape-ecological research on plague in Western Usambara Mountains and elsewhere in East and Central Africa.

In Western Usambara Mountains, three definite landforms, which are the Plain, Escarpment and Plateau, with different history of plague frequency, were identified and considered for soil micronutrient investigations. The Plateau is characterised by

heterogeneous elongated terraced ridges of narrow crest, steeper upper slopes, mid-slopes, lower slopes and valley bottoms (van Engelen and Dijkshoorn, 2013). The slopes of this landscape range between  $<1$  and  $64$  degrees, with convexities and concavities that form the divergence and convergence of overland flow. From the results of soil micronutrients investigated from these landforms, it was clear that high values of Fe and Cu were found in the soils of lower slopes and valley bottoms of the plateau and concavities of the upper escarpment but at elevations  $>1750$  m a.m.s.l., and in soils with higher pH values ( $>5.5$ ). Neerinckx *et al.* (2010) reported similar observations from 13 villages located in Western Usambara Mountains plateau with high frequency plague reported cases. In these villages the author observed that they were located at higher elevations ( $>1750$  m a.m.s.l.) but close to valley bottoms with soil pH  $>5.5$  and higher concentrations of copper, zinc, and calcium. It is important to report here that trace elements including Fe, Zn and Cu have been reported to be essential minerals in mammals for multiple cellular biochemical functions, including fertility and immunity (Dickinson *et al.*, 2008; Nube and Voortman, 2006; Deckers and Steinnes, 2004). In this study it was established that Fe has strong correlation with both plague hosts and vector abundance. Although, it should be noted that the study was done at an exploratory scale and it will require further detailed research for understanding the complexity involved and the inter-linkages between plague hosts, vectors and the disease. However, the results provide indicators that could support plague surveillance and control when the factors of landforms and soil micronutrients are considered holistically with other environmental factors.

### **6.1.3 Landforms/surface attributes and rodent burrows**

In many studied plague foci *Yersinia pestis* maintains its cycle through transmission between adult fleas and rodent hosts (Ben Ari *et al.*, 2010; Gage and Kosoy, 2005). Earlier studies suggested that virtually all mammals can become infected (Gage and Kosoy, 2005). However most of the significant hosts are rodents which live in burrows where they can support large flea populations (Nelson and Smith, 1980). Landforms are suggested as one of the important parameters that can influence rodent burrows' distribution. In this study a hypothesis was suggested to test whether landform characteristics and surface attributes at farm scale were important factors that influence rodent burrows, which are surrogate for rodent abundance and hence for predicting plague risk areas. The test was carried out in three landscapes, namely high, medium and low plague frequency. These landscapes differ significantly in elevation, slope position, gradient, aspect and curvature as demonstrated by this study.

It was clearly noted that high plague frequency landscapes had higher elevations, slope gradient and degree of dissection as compared to medium and low plague frequency landscapes in the study area. In this study, hillshade, slope gradient, herbaceous cover, bare ground, elevation, longitudinal curvature, general curvature and plan curvature were the important landform and surface attributes suggested to influence rodent burrow abundance and distribution in the studied landscapes. More rodent burrows were observed in the high plague risk area when compared to medium and low risk areas. The better predictor variables were high elevations, slope position and vegetation cover. Other surface attributes observed to pose a significant influence include dead tree stumps from harvested plantation forest, surface stones and rock outcrops, where rodents could make

rather safer burrows from predators, especially raptors and domesticated animals. Also in these positions there was food crops intercropped with trees, which provided rodents with food on which they could live and multiply.

This work is in agreement with earlier research works where hillshade shows both the influence of topographic and intensity of sun shine in different landform types in composing rodent burrows (Goyal and Ghosh, 1993; Bogaart and Troch, 2006; Busch *et al.*, 2000). Slope gradient, was reported to influence land use patterns within the rodent's habitats in terms of accessibility and food supply (Jaksic, 1986; Abramsky *et al.*, 2000; Romanach, 2005; Nemati *et al.*, 2013). Research by Massawe (2010) demonstrated significant positive correlation between slope gradient and abundance of both plague hosts and vectors in some selected villages in the high and medium plague frequency areas of Western Usambara Mountains. Other research by Seabloom and Reichman (2000) indicated that movement of subterranean animals generally will be unaffected by the steepness of the terrain in which they live.

The difference observed from these results between the studied landscapes is twofold: the natural and manmade habitats (such as surface stone hills) and forest plantations (with dead tree stumps and dead mulch) that provide good habitats for rodents as are not found in medium plague frequency landscapes. It should also be noted that the high plague frequency landscape is also adjoining the escarpment which is characterised by very steep slopes, with limited accessibility to humans and domesticated animals like dogs, hence creating a safer habitat for rodents. It has also been established that the low plague frequency landscapes, which are situated in the depression below 1500 m a.m.s.l., had no

rodent burrows. The distinct explanation here could be elevation difference between the two landscapes, with elevation difference of about 800 m. This observation agrees well with the conclusion made by Neerinckx *et al.* (2010), who observed correlation between high plague cases and elevations above 1750 m a.m.s.l. Similar results were reported by Eisen *et al.* (2012) and MacMillan *et al.* (2012) who observed in West Nile, Uganda, that plague cases correlated with elevations above 1300 m a.m.s.l. This implies that plague foci in east Africa are located in high elevations at least above 1300 m a.m.s.l. for Uganda and 1750 m a.m.s.l. for Tanzania.

It was further observed that burrow density in the high and medium plague frequency landscapes were mainly located in the upper and lower slopes, respectively. The difference observed is associated to land use characteristics whereby in high plague frequency landscapes cultivation of crops in the plantation forests and in landforms with abundant rock outcrops encourages rodent burrowing. However, in the medium plague risk landscape the sustainable food resource is available at lower slopes and near valley bottoms. It could be summed up that surface attributes favour rodent burrowing in high plague frequency landscapes whereas in the medium plague frequency landscape slope position, length and aspect are the dominant landform characteristics favouring rodent burrows.

It is clear from this study that the factors of landform and surface attributes investigated with respect rodent burrowing could offer a better indication of rodent populations and hence good surrogates for prediction of plague risk areas (White *et al.*, 2008; Randall, 1993; Reichman and Smith, 1990). The work compliment earlier research most of which

was related to rodents' survival and soil suitability for burrowing (Mora *et al.*, 2010; Laundre and Reynolds, 1993).

#### **6.1.4 Soil physical properties, soil microclimate and rodent burrows**

Soil type has a significant influence on the spread and abundance of rodents (Brabers, 2012). Evidence shows that distribution of rodents at different spatial scales is often related to particular soil types (Price and Podolsky, 2004). Some earlier studies suggest the importance of cover density (Groertz, 1971), food resources (Noffsinger, 1976), soil texture (Fisher and Antony, 1980) and moisture (Miller, 1964) for rodent habitat selection and preference. Small mammals, including rodents, commonly use shelters for protection against predation and against unfavourable environmental conditions. Burrows are quite often used by rodents for shelter in many landscapes (Busch *et al.*, 2000; Kumar and Pasahan, 1993). A typical rodent burrow consists of a surface opening, feeding tunnels, nesting chambers and food caches (Brabers, 2012). The most common burrow functions are resting, feeding, shelter from danger and raising the young (Brabers, 2012). Soil physical properties, and burrow's micro-climate which is a function of soil type and micro-geographical features, are suggested to be vital parameters that influence distribution of rodent burrows. Microclimatic variables affecting soil properties, such as temperature and soil moisture, will change the suitability of an area for a rodent species for burrowing (Hoover *et al.*, 1977).

Despite all the previous studies, there is insufficient data and studies that link soil physical properties soil microclimate and rodent burrows in the plague foci. Following these observations the current study attempted to test the hypothesis that soil physical

properties and microclimate are key predictors of rodent burrow abundance, use and orientation at farm scale in the plague foci of Western Usambara Mountains. The study was carried out in two plague risk areas representing historical plague high and medium frequencies. The areas also differ in farming systems, climate and the landforms, mostly dissection, and slope gradient. In the high plague frequency area, farming system is dominated by plantation forest, natural forest and cultivation is on sloping lands and in steep slopes of the escarpment. There are limited valley bottoms in the area, which is also characterized by short steep slopes. The medium plague frequent landscape is dominated by cultivation of sloping land and intensive cultivation of valley bottoms for vegetables. The landform is mainly dominated with rather long and comparatively less steep slopes. There is no much variation of rainfall and ambient temperatures.

Following the results obtained from the study it was clearly demonstrated that topsoil thickness, which ranged between 10 and 45 cm, favoured rodent burrow abundance in the high plague risk areas. This observation is attributed to better soil drainage condition, soil structure and soil lower bulk density (Brabers, 2012). The results are also confirmed by earlier research works that have shown concentrations of small mammal burrows in the topsoils to range from 10 to 49 cm, but to vary with soil types, soil texture (Gano and States, 1982) and the type of rodents (Romanach, 2005; Goyal and Ghosh, 1993; Kumara and Pasahan, 1993;). The situation was, however, different in the medium plague frequency landscape where the thickness of topsoil seemed to discourage rodent burrowing. This could be attributed to differences in soil physical properties including soil higher bulk density, soil structure and consistence which seem to be better developed in the plague high frequency than in the plague medium landscape. The observed

differences in soil physical properties in the two landscapes could be attributed to land use, particularly effect of long term tillage, where in the high plague frequency landscape there are more fallow periods unlike to the medium plague frequency landscape which has been under continuous cultivation for a long time.

The study has also established that the soil temperature in the high plague frequency area was a determinant factor for burrow use. The study demonstrated clearly that soil depth, consistence and temperature encourage burrow use in the high plague frequency landscape. The differences between the studied plague risk areas could be attributed to variations in land use and elevation. The importance of thermal regulation and the influence of temperature for burrowing have been reported (Kumar and Pasahan, 1993; Goyal and Ghosh, 1993). Soil depth, dry soil consistence and subsoil relative humidity (RH (%) at 30 cm soil depth) favour burrow abundance and use in the medium plague frequency area. The observed differences in relative humidity between the two plague risk areas could be attributed to topographic setting and surface characteristics, where there are steeper slopes and many surface rock outcrops associated with shallow soils in the high plague frequency area as compared to medium plague frequency area. The study could not observe any effect of soil physical properties and microclimate on burrow orientation.

## **6.2 GENERAL CONCLUSIONS AND RECOMMENDATIONS**

### **6.2.1 General conclusions**

This research has attempted to establish a landscape ecological framework in which the importance of factors of landforms, soils and soil microclimate linked to rodents, fleas and rodent burrows can be analysed as proxy for plague risk predicting behaviour. The study provides an insight on landforms, soil properties, small mammals (rodents) and

fleas, soil micronutrients and landforms in the plague risk area, landforms/surface attributes and soil physical properties, and soil microclimate with rodent burrows as surrogate for modelling plague risks in Western Usambara Mountains, Tanzania. It is a known fact that rodents play an important role in the spread of plague. Although a lot of research has already been done related to rodents' ecology, both in the area and worldwide, very little is known about the importance of landforms and surface characteristics, soil properties, soil micronutrients and soil microclimate with plague risks as related to small mammals (rodents) and fleas. That is why the emphasis of this research was to provide a quantitative and qualitative account on the influence of landscape characteristics (landforms and surface attributes), soil properties and microclimate on the distribution of rodents and fleas and rodent burrows in three plague risk landscapes representing historical plague high, medium and low frequency. The study confirmed the hypotheses tested including:

- i. Plague hosts and vector abundance are influenced by landforms and soil properties.
- ii. Status of soil micronutrients particularly Fe and landforms in the plague risk area influence plague host and vector abundance.
- iii. Rodent burrows are influenced by landforms/surface attributes and soil physical properties, and soil microclimate

In the light of the above hypotheses the following pertinent conclusions can be made.

- i. Landforms in the study area are variable with strong dissection and steep slopes of different curvatures. The dissections constitute a complex system of elongated terraced ridges and debris slides separated by narrow to wide U-shaped drainage

valleys (converging hydrological flows). The observed landforms are complex surface features with varying moisture condition, vegetation and microclimates. These conditions were observed to favour the occurrence of small mammals and fleas.

- ii. The landform-soil properties model clearly demonstrated significant relationships between small mammals and fleas' occurrence with landform features, with elevation and slope aspect being the strongest predictors. Among the studied soil properties extractable phosphorus and per cent base saturation were strong soil predictors for richness and evenness of both small mammals and flea abundance. Distribution of fleas was also influenced by hill-shade, organic carbon and exchangeable magnesium.
- iii. This study has provided insight into small mammals' and fleas' dynamics in relation to landforms and soil properties in a plague focus and hence could possibly facilitate better ways of managing host-vector outbreaks and plague risks.
- iv. High values of Fe and Cu were found in the soils of lower slopes and valley bottoms of the plateau and concavities of the upper escarpment but at elevations >1750 m a.m.s.l., and in soils with higher pH values (>5.5). Further the studied micronutrients, Fe strongly explains correlation existing between plague hosts and vectors abundance and hence related to the plague reported cases in the studied landforms. However, the interpretation of these results to the possible influence of the studied micronutrients on small mammals (rodents) and fleas and/or to humans will have to require additional studies.

- v. High plague frequency landscape has higher elevations, slope gradient and degree of dissection when compared to medium and low plague frequency landscapes in the study area. In this study hillshade, slope gradient, herbaceous cover, bare ground, elevation, longitudinal curvature, general curvature and plan curvature are the most important landform and surface attributes suggested to influence rodent burrow abundance and distribution in the studied landscapes. More rodent burrows were observed in the high plague risk area than in medium and low risk areas.
- vi. The difference observed from the relationship between landform and surface attributes with rodent burrows in the studied landscapes is attributed to natural habitats and man made habitats (such as surface stones heaps and forest plantations with dead tree stumps and dead mulch) that provide good habitats for rodents in the high plague frequency landscape but are not found in the medium plague frequency landscape.
- vii. The investigated factors of landform and surface attributes with respect rodent burrowing offer a good indication of rodent populations and hence good surrogates for prediction of plague risk areas and control.
- viii. The study clearly demonstrated that thickness of topsoil is important for rodent burrow abundance in the high plague frequency landscape while soil depth, consistence and temperature encourage burrow use. Soil depth, dry soil consistence and subsoil relative humidity (RH (%)) at 30 cm soil depth disfavour

burrow abundance and use in the medium plague frequency areas. The study could not observe any effect of soil physical properties and microclimate on burrow orientation.

### **6.2.2 General recommendations**

The study has provided detailed quantitative and qualitative description on landforms, surface properties, soil properties and soil microclimate with respect to rodents' and fleas' abundance and rodent burrows, which could facilitate better ways of managing host vector outbreaks and plague risks. However, pertinent questions still remain that will require further investigations in future plague risks research. In the light of this study the following recommendations are pertinent:

- i. There were relationships and differences between the three plague risk landscapes representing historical high, medium and low plague frequencies. This study partially explained the reported plague differences. However, integration of results from case studies in the study area with regard to landscape factors and other ecological studies using the other strong methods of analysis BRT and Ecological Niche Modelling (ENM) is strongly recommended.
- ii. The Ecohealth research approach to broaden the scope of plague research with work packages encompassing dormant reservoir of plague, including wildlife reservoir, telluric reservoir, and vector-host communities as dependent on landforms, soils and human behaviour is strongly recommended.
- iii. Comparative research between plague endemic areas such as Lushoto and Karatu/Mbulu is also recommended to explore the influences of similar ecological variables as those studied herein across different plague areas.

### **6.3 IMPLICATIONS OF THE STUDY TO POLICY**

This study established areas in the landscape where plague hosts (rodents) are likely to be found. Most of the implicated rodents were spatially found in the plateau, in the upper slope for the high plague frequency landscapes and at lower slopes in the medium plague frequency landscapes. It did also establish that within farms, western facing slopes, with herb cover, were likely to be infested by rodents. The study also established that high plague frequency landscapes had more rodent burrows than other areas, hence showing landscape to be of high priority in monitoring for control of outbreaks.

Therefore, the information obtained from this study could be applied as early warning system for surveillance, monitoring and then control of rodent populations before they reach outbreak levels in Western Usambara Mountains, Lushoto District, and in similar ecological settings with rodent problems.

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