Ecological Biogeography of West Usambara Mountains: A Study on the Influence of Abiotic Factors to Spatial Distribution of Plant and Animal Species

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Additional information is available at the end of the chapter

Abstract

West Usambara Mountains, Tanzania are famous for rich biodiversity and endemic species of plants and animals. Although there have been extensive studies on plant and animals species, little attention has been given on abiotic factors influencing their spatial distribution. Given rampant degradation of vegetation and associated consequence on biodiversity, knowledge on abiotic factors influencing distribution of species along the landscape become pertinent for conservation. A study was carried out to explore abiotic factors impacting plant and animals species distribution. Soil, landform and land use/cover were studied using grids of 20 m × 20 m using FAO Guidelines for Soil Profile and Habitat Descriptions. Soils were described, sampled for laboratory analysis. Spatial distribution of plant species were determined in the grids, and along the transects, every time estimating the percent cover and describing the habitat. Distribution of animal species was studied using both small mammals and rodent burrows as proxies. Trapping was done using different traps sizes, checking daily for animal caught, counting and re-trapping. Rodent burrows were estimated in same grids by examining a width of 0.5 m from end to end of grid and total number of burrows recorded. Determination of species distribution was done using GLM regression. Results show that species are influenced by elevation, which was common to both plants and animals. Topsoil soil depth was positive to plant species whereas hillshade, surface stones, cultivation and atmospheric temperature were negatively influencing plant species. Rock outcrops, surface stones and cultivation were positively influencing small mammals distribution. It is concluded that factors influencing distribution of small mammals are elevation, surface stones, rock outcrop and cultivation. Factors influencing plant species are elevation soil depth whereas cultivation, hillshade, surface stone and rock out crops negatively impact distribution. For conservation, it is recommended that the best steps are to stop human activities leading to depletion of plant species and accelerating soil erosion and allow for self-regeneration. Control of soil erosion strongly recommended as way of plant species re-establishment.

1. Introduction

Usambara Mountains are famous Mountains ranges located at the Northeastern part of Tanzania. These are Block Mountains forming a series of 12 separate mountains described as the Eastern Arc Mountains (EAM). The EAMS stretches from Kenya the Taita hills through Udzungwa Mountains in southern highlands of Tanzania [1]. Most of the EAMs 11 separates mountains are found in Tanzania namely: North Pare, South Pare, West Usambara, East Usambara, Nguu, Nguru, Uluguru, Malundwe, Ukaguru, Rubeho, and Udzungwa [2]. The name 'Eastern Arc Mountains' (EAM) was coined as a suitable way of defining unique forests areas that comprises many rarely found plants' and animals' species [3].

Literature shows existence of intensive and extensive studies since 1800s that targeted flora and fauna throughout the individual mountains of the Eastern Arc. There are discoveries made on biological diversity for small mammals [4–7], larger mammals such as primates [8], carnivores [9], invertebrates [10], reptiles and amphibians [11], and birds [12–14]. The literature also indicates rich diversity of plants like angiosperms [15, 16]. So, far research works indicated the existence of over 100 species of birds, mammals, amphibians and reptiles, and also over 500 plants, and vast numbers of butterflies and millipedes [17].

These long-time research efforts that were made on the biodiversity treasures of the EAMs have led to the global recognition of EAMs as a very important global biological rich heritage [18], therefore, the EAMs have been designated as the 25th world's biodiversity hotspots [19, 20] and one of the World Wild Fund's Global 200 priority ecoregions [2]. Furthermore, the EAMs are not only important as the global biodiversity hotspots, but in Tanzania, the Eastern Arc forests are the source of 90% of water flowing for the hydroelectric power of the country. The forests are also the source of water for major cities including Dar es Salaam, Morogoro and Tanga all of which with human population of over 10 million people. The EAMs watersheds in Tanzania are also flowing waters through some of the National Parks including Udzungwa, Mikumi, Mkomazi, Saadani and Selous Game Reserve. In general, the EAMs are crucial for both as an ecological haven and also as socio-economic treasure of the country.

The Usambara Mountains are formed by two separate land massifs, the 'east' and 'west' Usambara' Mountains, that are separated by a 4 km wide Lwengera River Valley. These Mountains share the uniqueness of the EAM characterised by the myriads of endemic flora and fauna: a rich biodiversity, and perhaps the most studied in the EAMs [19, 21, 22]. The biologists and ecologists studied well and established factors that governed high proportion of endemism and biodiversity in the Usambara Mountains and the entire EAMs

series, linking biodiversity with long periods of tropical forest cover attributed to reliable rainfall onsets and patterns [21, 23]. However, the studies on abiotic factors influencing biotic forest dwellers were limited in the EAMs. The abiotic factors including climate, geology, soils, and landform characteristics are strong determinants of plants and animal distribution [24, 25].

The organism presence is expressed in the theory of the 'ecological niche of a species', defined by Hutchinson [26] to be 'a sum of all the environmental factors acting on the organism, in a region of n-dimensional hyperspace' of which each factor acting on the organism is one dimension within which a species can theoretically maintain a viable population. The multiple dimensions [26] include factors such as physical, chemical and biological parameters which set-up a niche with a range of prevailing conditions (landform, soils, temperature, rainfall) and resources (food, water, breeding sites, safe refuge) within which a species can persist. Knowing factors making the ecological niche are important because conservationists get to know the effects environment has on species and vice versa the effects species has on the environment. Previous studies [18–20] mainly covered species in their niche with little coverage how the environmental (abiotic) factors impact survival of the species. Lack of knowledge consequences is that endemic species of plants and animal in West Usambara Mountains and EAMs maybe threatened as abiotic factors are degrading to irreversible levels due to human interventions.

The aim of this study is to contribute the understanding of the influences the abiotic factors have on the biodiversity of West Usambara Mountains. It is expected that this will shed light to various actors on what ought be done to conserve the devastated rich biodiversity in west Usambara Mountains due changing abiotic factors including human activities such forest deforestation.

2. Methodology

2.1. Description of the study area

The West Usambara Mountains are 31 km wide and narrowed to the east 19 km wide and approximately 90 km long. The study area is a rectangle comprising part of adjoining plain, escarpment and part of plateau. The area is selected because it has diverse and unique characteristics that may help to understand how abiotic factors are influencing spatial distribution of plant and animals' species from hot dry plains across the escarpment to the cool plateau (**Figure 1**).

The study lies between latitude 4°30′ and 4°45′S and longitude 38°00′ and 38°45′E. It is located in a cold and warm dry zones of West Usambara Mountains. The plateau section receives annual precipitation of 1200 mm and less than 1000 mm for cold and warm plateau, respectively. The study area extends from the plain across a steeper escarpment both located in a
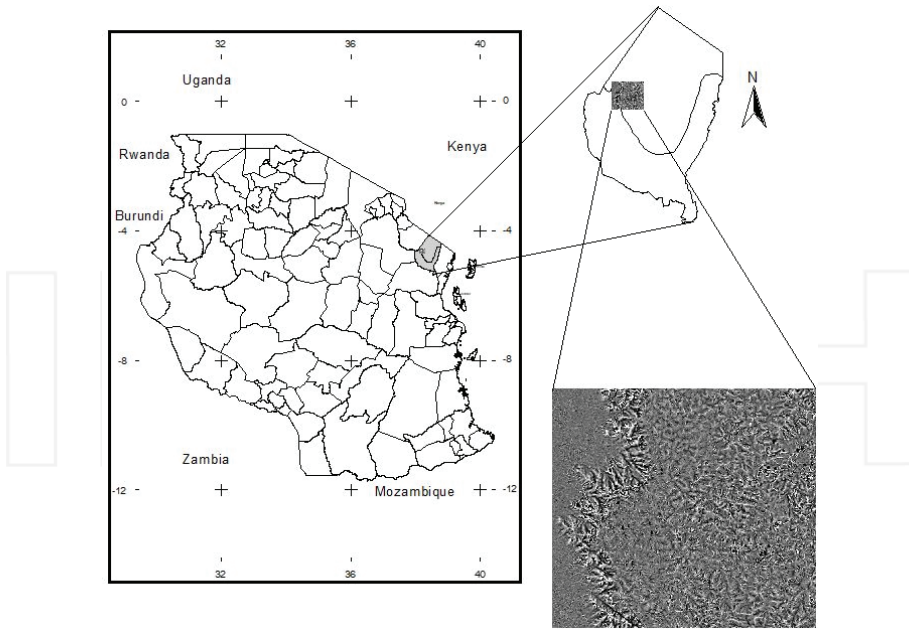
Figure 1. Location of biogeography study area, in West Usambara Mountains, Tanzania.

rain shadow side of the Usambara Mountains (plateau). The plain and escarpment receives annual precipitations of 400 and 800 mm, respectively. The average annual temperatures for plateau cold and warm zones are 14°C and 27°C, respectively, whereas the relative humidity is 70%. Temperatures in the plain range from 25 to 34°C per annum. The plateau grows diverse tropical crops and temperate fruits, while the plain has limited farming activities except for sisal (*Agave sisalana*).

2.2. Geology of West Usambara Mountains

West Usambara Mountains were formed by block faulting and repeated uplifting of Precambrian basement rocks between 180 and 290 million years ago [27, 28]. The geologic composition and variability in West Usambara Mountains depicts differences in terms of geology with regards to geomorphic position. The **plain** is mainly composed of duricrust calcareous yellow grey sand, whereas the geological rocks in the **escarpment** are gneisses mixed with undifferentiated granulites and distinctive bands of hornblende and pyroxenes. The geology in the **plateau** is mainly gneisses with leucocratic quartzo-feldspathic granulites and khondalites. There are few areas composed of recent alluvial materials like depressions and valley bottoms which are composed of mixed alluvial-fluvial materials [29].

2.3. Determination of landform and soil characteristics

Visual observation of satellite images, stereoscopic aerial photographs and orthophoto maps (numbers 9480410, 9480400, 9470410, and 9470400) was done. Also, visual analysis of

topographic and geologic maps was done. The interpretation base-map was digitised to produce the georeferenced base-map used to guide field. Transect were made for augering for mapping soils and landforms by the methods by Dent and Young [30]. At each observation site, data on landform and soil morphological characteristics were examined and recorded. Landform units similar in parent material, relief, topography and soil morphological characteristics were considered to be similar and were accorded as mapping unit. Vegetation habitats and associated characteristics were determined and mapped. Identification of vegetation was according to the FAO Guidelines [31] in grids of 20 m × 20 m. Each observation site was geo-referenced by Global Positioning System (GPS). Representative soil profiles were dug in major soils, where description was done, and then soil samples were collected from natural horizons for laboratory analysis.

Also, landform analysis was done using ASTER Digital Elevation Model (DEM) which was carried out using ArcGIS 9.3 to derive continuous surfaces for elevation (m a.s.l.) (slope gradient (degrees), slope aspect (radians), slope length (m), and slope types (straight, convexity and concavity) and different types of land surface curvatures.

2.4. Exploring species distribution with abiotic characteristics

Habitat or vegetation description was done in grids of 20 m × 20 m by estimate vegetation cover percentage. Spatial distribution of animal was done using two approaches. One was by trapping small mammals at sites where augering and/or soil (profile sites) were made using grids of 20 m × 20 m. The data were collected twice between December 2009 and March 2013. Traps of different types and sizes were employed to capture diverse mammal species such Sherman live traps, local made wire cages (for bigger sized small mammals like squirrel, genetta) and the pitfall traps, which are 10-l plastic buckets. The total numbers of traps used were 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 [32]. Traps were inspected every morning to remove trapped animals and replace the bait. Peanut butter mixed with maize bran, roasted maize grains and sardines were used as bait. The trapped small mammals were counted and recorded.

The second approach was use of a proxy, which was the rodent burrow. Total rodent burrows were estimated on the landscape. Rodents' burrows were scanned within grids of 20 m × 20 m at width of 0.5 m from one end of grid, return until finished. A number of burrows was recorded and the nearest to the centre was opened to see if the animal were in or how recent the use has been. Atmospheric temperature were measured using the infrared thermometer topsoil temperature were done using thermal couple thermometer. The topsoil relative humidity was estimated using iButtons buried 20 cm for 24–26 hours recording both relative humidity (%) and temperature (degree Celsius).

2.5. Laboratory determination of soil properties and soil classification

Selected soil physical properties were determined in the field such as soil depth (cm). Chemical and soil texture were determined in the laboratory using methods by Page and Keeney [33]

and Klute [34] respectively. Micronutrients (iron, manganese, copper zinc) were determined using Diethylenetriaminepenta-acetic acid (DTPA) according to Moberg [35]. The field and laboratory data were used to classified soils to level-2 of the FAO World Reference Base [36]. Although chemical soil properties were not used in modelling, it was used for soil classification. For modelling only topsoil depth and texture were used as input data.

2.6. Statistical analysis

The data was organised for multiple regression analysis. There were two dependent variables (plant cover (%) and total rodent burrows. The independent variable examined were 25, which were landform types, slope gradient (degrees), slope length (m), slope form (concave, convex, straight, compound), elevation (m a.s.l.), drainage, erosion type, rock outcrops and surface stones (number), slope aspect, hillshade (radians), slope curvature types (radians), soil depth (cm), soil texture (textural class), atmospheric temperature (degrees Celsius), topsoil (10 and 30 cm) temperature and topsoil (10 and 30 cm depth) relative humidity (%) were model input data. There was a total of 487 data entries collected. Categorical data such as textural class were given dummy number.

Abiotic factors explaining spatial distribution of plants and animals species were established by inputting 25 factors in a Generalised Linear Model, distribution family 'Gaussian' which is a multinomial for multiple dependent variables [37] applying a formula:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \varepsilon_i \tag{1}$$

Where: Y_i = respondent (dependent) variables (plant cover, trapped animals/rodent burrows as a proxy); β_0 = Intercept; $\beta_1 X_{1i} + \ldots \beta_3 X_{3i}$ = predictors or independent variables; ε_i = error term.

Using R software the GUI rattle [38]. Model validation was addressed by portioning the data. The 70% of the data was allocated for training while 30% was used to develop the model. Different runs were made first using all predictors then reduced or added examining the model goodness of fit by looking the null and residual deviance and Akaike information criteria (AIC), whereby a model with a smallest AIC and a narrower gap between null and residual deviance was opted as model explaining the factors influencing species distribution along the landscape. Multicollinearity, was tackled by keying or deleting weakly correlated variables serially in the model.

## 3. Results and discussion

3.1. Variability of landforms

The geologic characteristics and folding and faulting of the area have had significant impact on drainage line and river systems all along the plateau and escarpment. The faulting had

stronger influence on the scarp formation where there are fault lines that led to vertical scarps, and/or hanging rocks. The dense drainage and rivers network which is identical to dissection of the plateau which mainly has been influenced by hydrological water flows suggesting that the dominant land forming process in the area has been denudation by moving water (erosion) in different forms such as mass wasting (landslides, mass movement), gully, rill and sheet. The different landform components and slope forms links well with landslide and in particular waste movement. The recent and past geomorphic processes influence not only the vegetation establishment but also the habitats and the diverse animals that occupy them. This assumption is similar to the description by Cottle [24] who pointed the relationship between the geology and biodiversity of both animal and plant species.

Figure 2 describes three different geomorphic units: the plain, escarpment and plateau. The units are congruent with the geology, and plateau is the largest and strongly dissected forming a complex landscape dominated by a network of ridges at different altitude levels or terraced ridging. The plateau is characterised into three distinctive terraced plateau levels differentiated by altitude, viz.: Plateau terrace level I (PTI) a landscape situated at the altitude over 2067 m a.s.l. (i.e. characterised by irregular, conical narrow cliffs or rock outcrop narrow (<10 m) summits with limited vegetation mostly due to shallow soil (<30 cm or rockiness). Plateau terrace level II (PTII) is composed of isolated ridges with altitude range of 1862–2067 m a.s.l., (i.e. characterised by narrow ridge summits with scarps, cliff or rock outcrops and or shallow soil depth) and hence limited vegetation. Plateau terrace level III (PTIII), situated at altitude range of 1657–1862 m a.s.l. (i.e. forming a continuum of low ridges
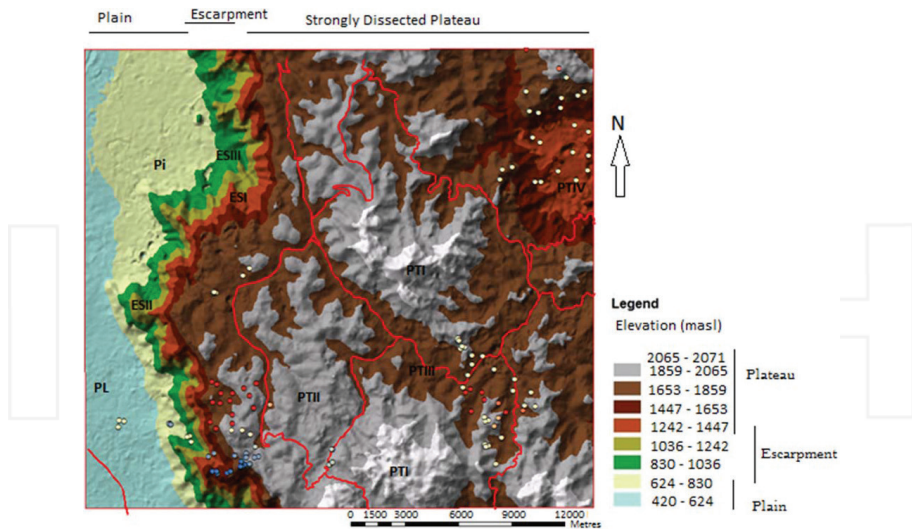
Figure 2. Landscape variation in the LEPUS project study area, West Usambara Mountains, Tanzania.

characterised by comparably broad crests with few localised rock outcrops at summits and/or upper slopes) and well covered with diverse dense vegetation where human did not clear for cultivation. There is a strong correction between plant species distribution, landform characteristics and soil characteristics particularly soil depth and quantity of gravel and/or stoniness or rockiness.

The soils in the plateau are diverse but are congruent with the landforms position on which they occur. The soils found on upper slopes and on their ridges' crests of PTI and PTII are dominantly **Regosols,** and **Lithic Leptosols.** The mid and lower slopes of PTI ridge crests are complexes of **Cutanic Acrisols** and **Cutanic Alisols**. The PTII plateau soils are **Ferralic Cambisols** on the upper slopes and **Cutanic Acrisols** and **Ferralic Cambisols** on the mid slopes [39]. The soils on ridge crests, upper and mid slopes of plateau PTIII are dominantly complexes of **Cutanic Alisols** and **Haplic Regosols**. The dominant soils in the lower slopes of PTIII are **Luvic Ferralic Phaeozems** while the dominant soils of the very narrow valley bottoms of plateau are **Mollic Fluvisols, Gleyic Fluvisols** and **Antrosols** [40].

The entire plateau is composed of aggregated micro and macro watershed with high potential for soil loss through erosion. The erosion hazard is attributed to the steep slopes; weak soil structure and poor agronomic practices whereby farmers cultivate at very steep slopes of over 45° without conservation measures. The soils of the area had overall poor fertility. One of the macronutrient phosphorus is very low below 4 mgP/kg soil which may affect uptake of others. Also, Ca, Mg and K are low in most soils. Micronutrients Fe and Mn are in very large quantities whereas Cu and Zn are within recommended critical levels. These soils are good for establishment of most vegetation and habitats. However, for food crops, which most small mammals are depending upon as food, the poor soil fertility which is leading to poor crops and in dry years no crops will soon bring in natural selection especially to animal species whereby those which will not be able to scramble for small amount of food will perish and those which will adapt to smaller amount and new food will survival. From residents of the area, there are already several species of gazelle and wild pigs, which are no longer, found in the Usambara because of poor habitats and possibly availability of food. Furthermore, it is important to note that due to the influence of elevation on temperature the plateau is colder than the low plains. There are even variations between valley bottoms, higher ridges and Mountains in the Plateau, and congruent to soil variation, there are vegetation distribution and hence forest dwellers. The explanation agree well with reported by Cottle [24] and research work by Valencia et al. [25] and Baltzer et al. [41] that soil type have a strong influence on spatial distribution of plant species.

Escarpment geomorphic unit indicates three levels of uplift, indicating tectonic cycles and it's characterised by steep slopes, canyons, cliffs and rocks with slope gradients of over 72°. There are colluvial foothills, and slope complexes with varied slopes from 3 to 60°. In certain locations, steep slopes over 60° with deep, shallow and rock soils were observed. Escarpment rises from the plain at 600 m a.s.l., to over 2000 m a.s.l. (**Figure 2**). Lower escarpment is characterised by colluvial/alluvial foot slopes, scattered foot ridges and talus slopes. Dominant soils in escarpment are complexes of **Mollic Leptosols**, **Lithic Leptosols, Cutanic Luvisols** and

Haplic Cambisols while the associated vegetation species are shrubs and large trees where soils are deep. In canyons, *Ficus* spp., have been observed and dense shrubs occupied by different animal species including primate, wild pigs and diverse small mammals [6].

The plain is the lowest geomorphic unit in the study area (**Figure 2**) divided into the upper rolling, rolling and gently undulating plain, characterised by hot temperatures, low rainfall and deep soils developed from Neogene/Miocene deposits. The dominant soils are complexes of **Fluvic Cambisols** and **Mollic Fluvisols** on the lower plain and complexes of **Mollic Leptosols**, **Cutanic Luvisols** on the upper rolling plain and **Haplic Umbrisols** on colluvio-alluvial fans [39]. Dominant abiotic factors prevailing in the plain are low rainfall and higher temperatures, which are supporting the sparse vegetation mainly woody shrubs and thickets. The diversity of animals is higher because the plain is an animal corridor from nearby Mkomazi National Park. There is also an extensive influence of humans including over grazing. Generally, climatic and soil factors are major determinant of spatial distribution of animal and plant species, which is similar to reports by Valencia et al. [25] and Baltzer et al. [41] the influence of soil types and landform characteristics on the distribution of trees.

3.2. Factor influencing diversity and species distribution in West Usambara Mountains

3.2.1. Effects of slope gradient

Slope gradient a measures of steepness of the landform surface [42], is presented in **Figure 3** in degrees, and it varied with geomorphic units. **Figure 3** shows variability from the plain, escarpment to the dissected plateau. It varies from <1° in the plain to over 64° at the escarpment.
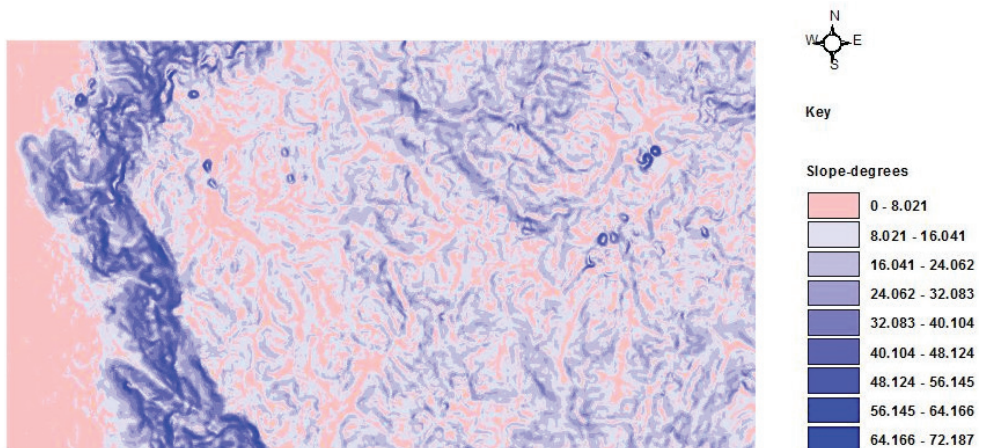
Figure 3. Slope gradient (degrees) variation along the landscape of West Usambara Mountains, Tanzania.

Very steep slopes are found in the escarpment and young landscape in the plateau. Gentle slopes are in valley bottoms and in the low plain. Due to the steep slope gradient, it is convincing that slope gradients and their types (**Figure 4**) are the strongest topographic attributes contributing significantly to landform forming processes by influencing speed, pathways of surface and subsurface water movement in the area. This conforms to report by Moore et al. [43] and Hutchinson [44] who indicated slope gradient to be among major factors of ecohydrology that influence overland flows. Similar results [45–47] indicate that slope influences water movement and landform forming processes including landslide in different parts of the globe. For instance, Zhou et al. [48] reported that most of the landslides that occurred in Hong Kong in 1993 took place on slope angles between 25 and 30°. Similarly, Mulders and Alexander [49] reported that areas with slope gradient of 35° and above have high likelihood of shallow landslides, whereas Fernandesa et al. [50] reported that in Brazil landslides are very common in slope angles between 37.1 and 55°.

Therefore, the west Usambara Mountain slopes of over 35°, mainly in escarpment and in plateau terraces PTI and PTII suggest that landslides could been one of the landforming processes in the past and still active given observable landslide scars in the area. The major slope forms are convex with excessive eroding and washing power hence exposing rocks to the surface, and/or concave with deposition manifested with deeper topsoils mainly none rocky or stony.
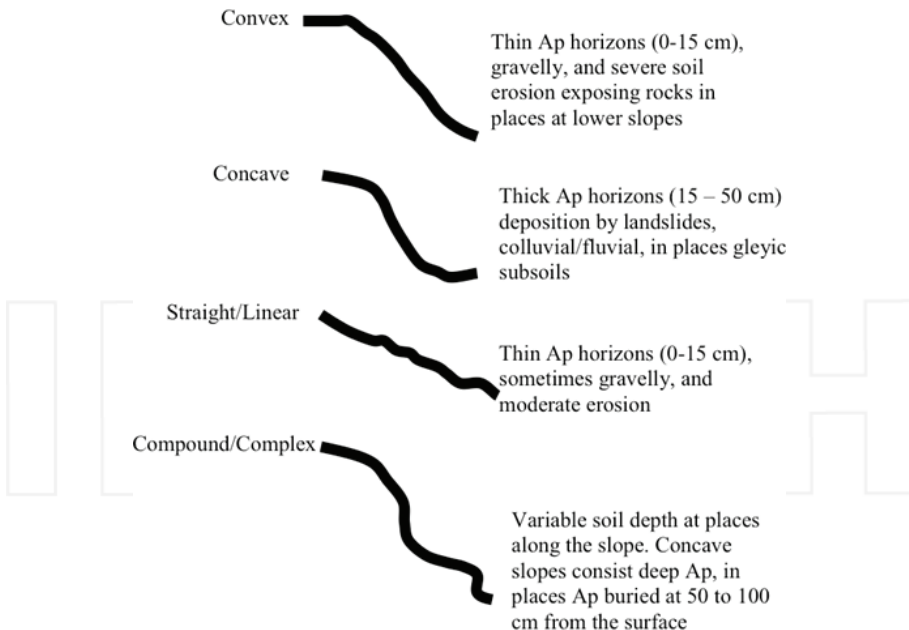
Figure 4. Dominant slope types in West Usambara Mountains, Tanzania.

3.2.2. Slope forms

Apart from slope gradient, slope forms (**Figure 4**) also vary in the area with convex slope form characterised with severe soil erosion (landslides, mass movement), hence has thin topsoils and in place stony and/or gravely surfaces and poor vegetation cover. Concave slope form are characterised as recipient sites with deep topsoils of over 50 cm in some places. Straight slope form although not apparent in the area, resembles convex in soil forming processes as they highly erodible, mainly washing by water. The complex slopes exhibit diverse properties depending on local area characteristics.

Slopes gradient and slope form have been found to strongly influence vegetation in Usambara Mountains. Dense vegetation is found in concave slopes with relatively deep soils and where moisture collects for longer times. This is in contrast to convex slopes with gravelly and shallows soils where there sparse vegetation and in many incases they harbour woody shrubs. It has been observed from this study that there are associations between vegetation establishment, and animals' species, which comply with studies by Njaka et al. [6] and Meliyo et al. [51]. This is in agreement with a work by Valencia et al. [25] who reported the influence of slope gradient and forms to trees distribution in South America.

3.2.3. Geomorphic processes

Active and dominant geomorphic processes operating and hence influencing spatial distribution of plant and animals along the landscapes is mainly water movement. Running water has effected by speed, dissolution and rock weathering which is facilitated by dissolved oxygen. Slope allows ponding or slow movement of water, which influences multiple physical chemical and biological processes.

Slope gradient dictates even the type of soil coverage in the area in terms of soil depth, textural compositions and even soil fertility status, and therefore establishment of vegetation and habitats and animal species. **Plate 1** shows geomorphogenetic processes mainly combined water and slope gradient.

Major processes are gravity mass movement, creep, rock fall, which are all accelerated by steep slopes and over saturation rainfalls. Geomorphomogenetic processes are active in the entire area, steep slope areas being highly prone to soil and debris removal whereas the low-lying areas are active sinks of seasonal varied textural materials. **Plate 1(a)–(d)** below indicates dominant morphogenetic processes shaping the landscape in the area. **Plate 1(b)** is mainly depositions of eroded materials of varied texture due to heavy rainfall.

3.3. Spatial distribution of animal and plant species along the landscape of West Usambara Mountains

Table 1 shows that plant and animal species occur across the three major geomorphic units. The diversity of species per landscape varies as has been reported by Meliyo et al. [51] and Njaka et al. [6]. The authors indicated that species specifically vegetation/habitat diversity
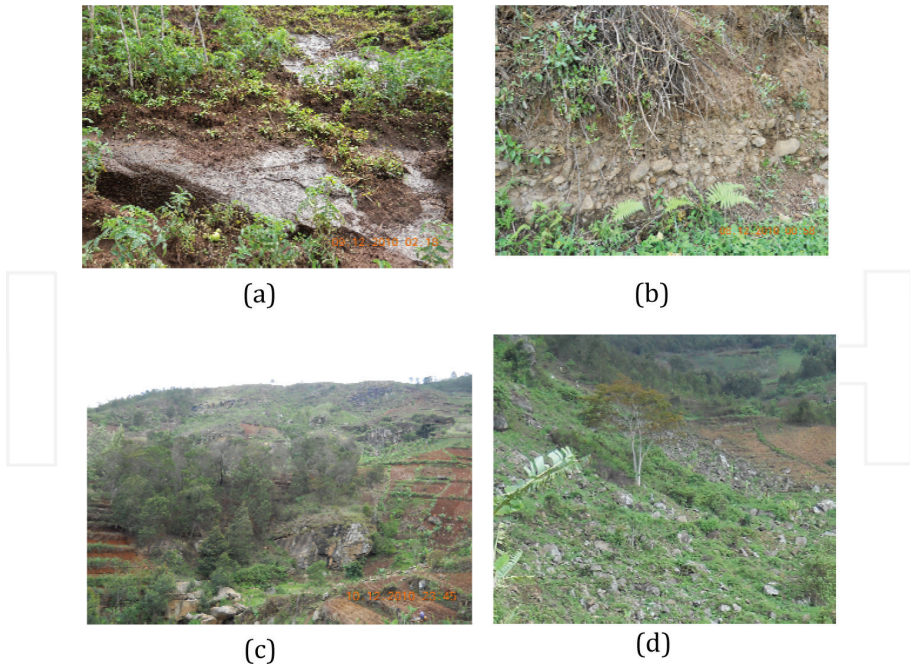
Plate 1. Morphogenetic processes shaping the landscape: (a) Mass movement where soils are eroded at wide portion of landscape down the slope after rainfall. (b) Shows deposition of varied rocks and boulders falling from upslope, (c) Shows old landslide scars prominent in the study area indicating the role played by landslide in the existing landform, and (d) Shows rock fall in the plateau, the practice very common along steep slopes over 25°, which is the case in the plateau and escarpment.

increases with increasing elevation. **Table 1** depicts that there were differences of abundance and types of vegetation cover/habitat and small mammals species found at different landscapes. Results show that there were fewer small mammals in the plain compared to the plateau. Although the number of small mammals increased with elevation (escarpment) the number in the plateau were more than the plain and the escarpment geomorphic units. Plant species or habitats in the low plain are mainly woody shrubs; thickets and even the scattered trees in some places are those salt tolerant species. This could be attributed to the fact that the plains are characterised by low sporadic rains and long period of droughts, that have led to development of sodic and saline soils, which only plants adapted to it could survive the hard shrubs and thickest.

The soils of the escarpment are mainly shallow, gravelly, stony and rocky and in some places just rocky land without soil. This implies that many plant species grow with difficulties. In few areas with deep soils, there were large trees and dense none thorny shrubs, well established compared to the drier plain. Moisture availability also could be a factor-segregating species distribution. **Table 1** further shows that some animal species are located only in one geomorphic unit and not the other. For instance, *Dwarf Mangoose*, *Genetta genetta* and Squirrels

were just found in the plains, although different elevations. This could be attributed to the characteristics of the niche, which encompasses food availability, breeding places and or climate adaptation.

Landscape	Elev (m a.s.l.)	Slope (%)	Plant species/habitats	Trapped small mammals	Type small species
UP	480	7	WST	7	Acomys
UP	480	7	WST	1	*Dwarf Mongoose*
UP	480	7	WST	1	Squirrel
RP	615	15	WST	1	*Genetta genetta*
RP	615	12	WST	3	Squirrel
RP	615	15	WST	1	Acomys
RP	615	15	WST	1	Praomys
LE	830	30	WSST	3	Aethomys
LE	830	56	WSST	1	Acomys
UE	1350	80	WSST	7	Aethomys
UE	1350	55	WSST	1	Grammomys
UE	1350	55	WSST	1	Lophuromys
UE	1350	55	WSST	1	Mastomys
UE	1350	55	WSST	1	Otomys
UE	1350	55	WSST	1	Praomys
P	1850	23	CSST	1	Aethomys
P	1850	23	CSST	3	Crocidura
P	1850	90	CSST	24	Grammomys
P	1880	90	CSST	28	Lophuromys
P	1740	90	CSST	41	Mastomys
P	1740	70	CSST	4	Mouse legeda
P	1860	90	CSST	52	Praomys
P	1860	90	CSST	2	Rattus
P	1860	70	CSST	2	Shrew

UP, undulating plain; RP, rolling Plain; LE, lower escarpment; UE, upper escarpment; P, plateau; WST, woody shrubs and thickets; WSST, woody shrubs+surface stones; CSST, cropland+shrubs+surface stones.

Table 1. Spatial distribution of plant and small mammal species in West Usambara Mountains.

Plant species in the plateau are mainly plantation forest, where *Pine* spp., *Eucalyptus* spp., and *Camphor* spp., are planted for timber, project. Before 1980 most of the mountains and hills of the study area were treeless, due to deforestation followed after independence 1961, which then cleared thousands of forests for obtain farmland. Deforestation was followed by severe soil erosion, which the Tanzania Government intervened by formulating a project Soil Erosion Control and Agroforestry Project (SECAP) [52], which promoted tree plants and agroforestry. Hence individuals established tree woodlots in places where was stricken by soil erosion and landslides. However, in the plateau there are still few, small pockets of natural forest such Magamba Nature Reserve. That kind of forests remains, are the pockets harbouring the natural rich biodiversity of plant and animal species, west Usambara Mountains.

3.4. Abiotic factors explaining spatial distribution of species along the landscape

Table 2 and **Figure 5** present results that indicates that factors influencing spatial distribution of small mammals were elevation ($p < 0.001$), surface stones ($p < 0.001$), rock outcrop and cultivation (%) ($p < 0.05$) and slightly surface curvature (profile and cross) which is negatively influencing species spread across the landscape ($p < 0.1$). The atmospheric temperature and

Coefficients	Estimate	Std. error	t-value	Pr(>|t|)
(Intercept)	−5.8547295	1.2733596	−4.598	5.49e-06***
Elevation (m a.s.l.)	0.0024506	0.0006312	3.883	0.000118***
Rock_Out_crop	0.4354978	0.1870275	2.329	0.020307*
Surface_Stone	1.3789108	0.3826639	3.603	0.000347***
Slope_Aspect	0.0011544	0.0011295	1.022	0.307281
Profile_Curv	0.3181454	0.1881989	1.690	0.091599.
Cross_Curv	−0.3193107	0.1882792	−1.696	0.090558.
Soil_Depth1	−0.0175444	0.0158829	−1.105	0.269894
Soil_Depth3	−0.0055701	0.0150322	−0.371	0.711143
Cultivated_Area	0.0268368	0.0136358	1.968	0.049641*
Atmospheric T°C	0.0191391	0.0170757	1.121	0.262929

Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.
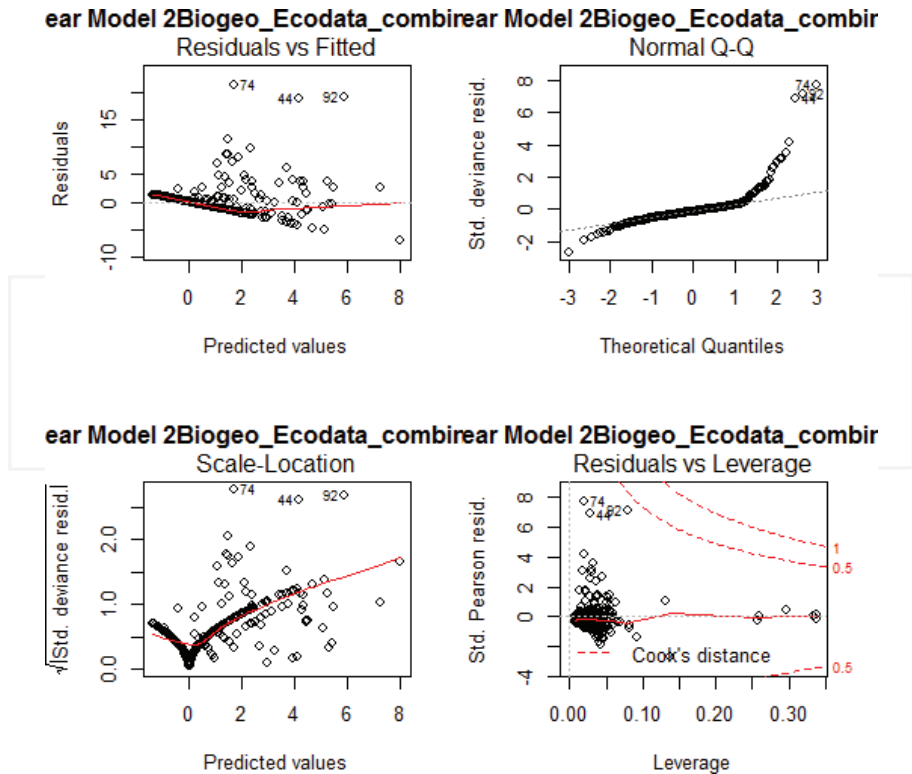Null deviance: 3956.1 on 481 degrees of freedom.
Residual deviance: 3026.9 on 471 degrees of freedom.
One observation deleted due to missingness.
AIC: 2277.5.

Table 2. Factors influencing distribution of small mammal species along the landscape of West Usambara Mountains, Tanzania.

Figure 5. Plot of deviance residuals from GLM fitted to establish factors influencing small mammal species distribution along the landscape of West Usambara Mountain, Tanzania.

many other factors that were considered did not work out to be predictors. These results are congruent with field observation presented in **Table 1**, which show that the number of small mammals trapped was high in the plateau (higher elevation) than in the escarpment and the plain.

The results are too supported by those reported by Njaka et al. [6] who indicated that small mammal abundance increased with increasing elevation. The increase of small mammals with elevation could be attributed to favourable climatic conditions such occurrence of rainfall and reduced temperature compared to the low plain characterised by hot temperature and drought. Cultivation of food crops in the higher plateau due to comparably higher rainfall and cool temperatures serves as the habitat and continuous food supply which in short while attracts species but in future lead to extinction of those which do desire human interactions. The above account is in agreement with Ward et al. [53] who indicated that distribution of species is influenced by a large number of abiotic factors like environmental stability, habitat heterogeneity and relevance [54] and ecosystem production. It is also true that surface stones

and rock outcrops offer small mammal both safe havens and breeding places. This implies that surface stones and rock outcrops create microhabitats that are hardly accessible to disturbances due to other organisms mostly humans. All predictors had positive coefficients, which show positive correlation of the independent variables to dependent ones. Surface stones and rock outcrops are microhabitats with unique characteristics, which influence spatial distribution of the small mammals particularly in the plateau [51]. The results also show that surfaces stones make microhabitat which influence abundance and hence distribution small mammals along the landscape, and the high population of small species at the plateau may be attributed to microhabitat as well as stable food supply associated to food crop cultivation. The results also agreed well with field data which show that few species were captured per trap station in the plain than the plateau, and also the plant species richness and diversity are greater in the plateau than the plain. Similar results were reported by Meliyo et al. [51] and Njaka et al. [6]. The results are also in agreement with those presented by Hastie et al. [55] who indicated that microhabitat influences local density of species and their spatial distribution, however, our results could not show that temperature and moisture to be important drivers of spatial distribution in the study area.

Table 3 and **Figure 6** present results depicting abiotic factors influencing spatial distribution of plant species along the landscape of West Usambara Mountains. The results show that elevation (metres above sea level), top soil depth and cultivation practices are major determinants of spatial distribution of plant species and they are statistically significant ($p < 0.001$) predictors, although cultivation practices are negatively influencing plant distribution i.e. vegetation clearing.

Other negatively influencing factors of statistical significance are hillshade ($p < 0.01$) and surface stones ($p < 0.05$) and atmospheric temperature in degrees Celsius ($p < 0.05$) (**Table 3** and **Figure 6**). Our results are in agreement with findings by Chen et al. [56] who studied factors affecting the distribution of pant species in Hainan Island, China, and reported many factors including elevation, soils, rainfall and human disturbances.

Similarly, our results on spatial distribution of plant species in the west Usambara Mountains are supported finding by Trigas et al. [57] who reported an increase in proportion of plant species endemism with increasing elevation of Cretan Mountain that could only be explained by elevation-driven ecological factors. Ecologically, there are many factors coming into play, including temperature, rainfall, soils, and where human disturbances occur particularly deforestation, these leading to plant species extinctions in some area in the world [56].

3.5. Human influence on distribution of small mammals and plant species in West Usambara Mountains

Table 3 and **Figure 7** present results of the influence of human being on small mammals and plant species. History shows that once the Usambara was covered by natural forests where diverse plants and myriads of small mammals were living in none-disturbed habitats. In 1980, most of the land has been cleared, and **Table 3** shows a strong statistical significance influence of cultivation on plant species. Other studies [58], compared biological diversity,

Coefficients	Estimate	Std. error	t-value	Pr(>|t|)
(Intercept)	−6.905e+01	1.838e+01	−3.757	0.000194***
Elevation (m a.s.l.)	6.761e-02	6.124e-03	11.041	<2e-16***
Slope_length	1.199e-01	1.092e-01	1.098	0.272673
Rock_Out_crop	−3.288e+00	1.694e+00	−1.941	0.052846.
Surface_Stone	−8.595e+00	3.445e+00	−2.495	0.012957*
Slope_Aspect	7.467e-03	1.105e-02	0.676	0.499410
Hillshade	−1.167e-01	3.542e-02	−3.295	0.001061**
Profile_Curv	3.692e+01	2.340e+01	1.577	0.115370
Plan_Curv	8.933e-04	1.235e-03	0.723	0.469747
Cross_Curv	2.419e+01	1.210e+01	1.999	0.046196*
General_Curv	−1.420e+01	1.037e+01	−1.369	0.171794
Longit_Curv	−3.325e+01	1.754e+01	−1.896	0.058643.
Tanget_Curv	−1.355e+01	2.430e+01	−0.557	0.577536
Soil_Depth1	7.674e-01	1.437e-01	5.341	1.46e-07***
Soil_Depth2	−5.494e-02	1.149e-01	−0.478	0.632629
Soil_Depth3	−1.241e-01	1.356e-01	−0.915	0.360555
Cultivated_area	−6.209e-01	1.239e-01	−5.014	7.64e-07***
Atmospheric T°C	−3.463e-01	1.634e-01	−2.119	0.034588*
Soil_Temper10cm	−2.299e-02	9.084e-02	−0.253	0.800349
Relat_Hum10cm	−2.412e-02	1.047e-01	−0.230	0.817888
Relat_Hum30cm	1.308e-01	1.346e-01	0.972	0.331514

Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.
Null deviance: 360945 on 481 degrees of freedom.
Residual deviance: 233953 on 460 degrees of freedom.
AIC: 4395.

Table 3. Factors influencing distribution of plant species along the landscape of West Usambara Mountains, Tanzania.

indicated that human population growth has negatively affected natural resources, and hence biodiversity (**Figure 7**). Some hotspots such as eroded lands, deforested areas, dried water sources and undesirable tree species have been identified as creation of mankind, which are inversely related with rich biological diversity. Many animals (small and large) have been killed for food or because they destroy food crops planted. The consequences have been decline over time in per capita food production and increasing food insecurity and poverty, which are accelerating degradation of biodiversity of both plant and animal [58], particularly in the western facing drier West Usambara Mountains.
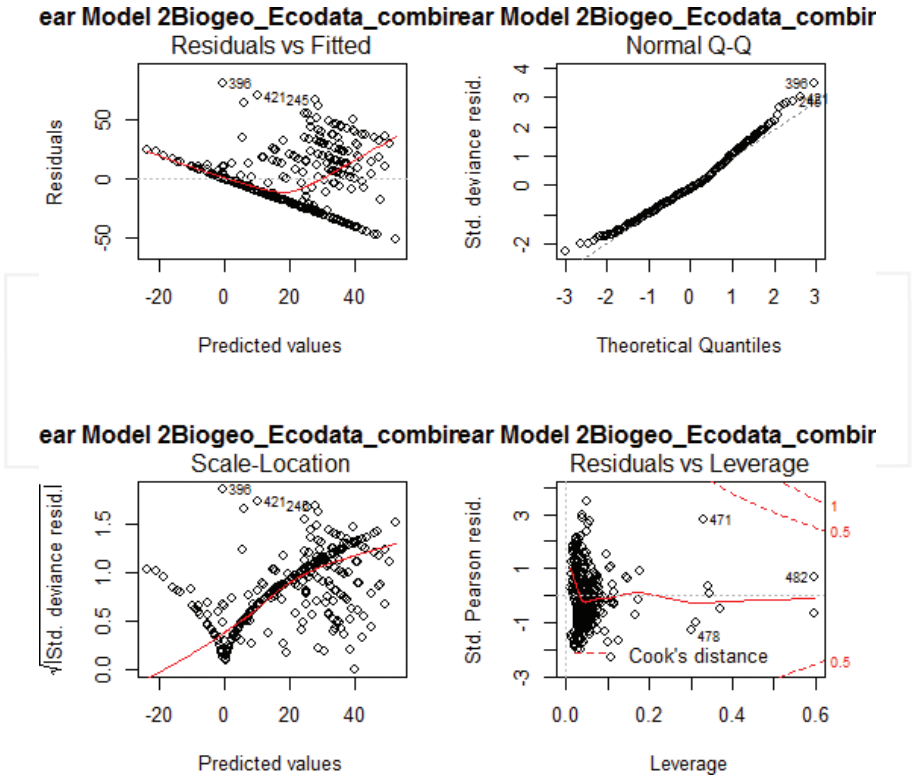
Figure 6. Plot of deviance residuals from GLM fitted to establish factors influencing plant species distribution along the landscape of West Usambara Mountain, Tanzania.
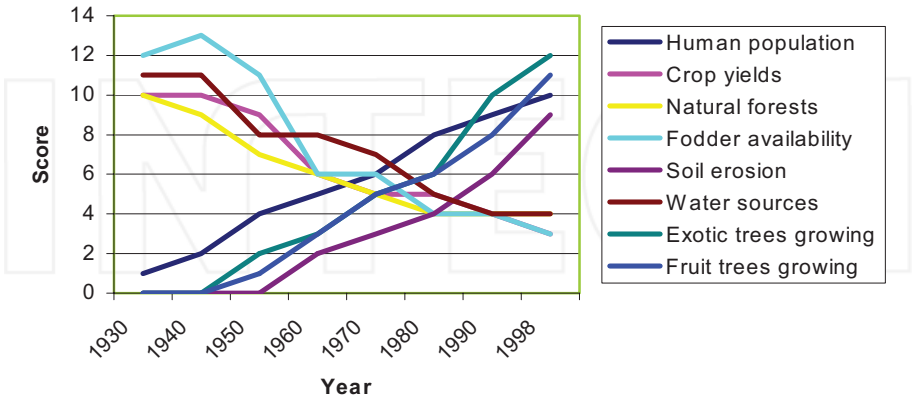

Figure 7. Historical account of human population pressure influence to the natural resources degradation West Usambara Mountains of Tanzania (Source: Meliyo et al. [58]).

4. Conclusions and recommendations

4.1. Conclusions

The study area was heterogeneous site composed of plain, escarpment and strongly dissected plateau in West Usambara Mountains, with different geology, landforms and soils types. The three geomorphic units have different plant and animal species – plain with shrubs and thickets which decline with increasing elevation while trees increase with increasing elevation from upper part of the escarpment to mountainous in the plateau. The geomorphological setting of the area has had the influence on plant and animal (small mammal) species spatial distribution. Abiotic factors explaining spatial distribution of plant species are landform characteristics including elevation, slope gradient and topsoil soil depth which have positive coefficients indicating that as factors increases so do plant species. There are factors negatively hindering spatial distribution including cultivation, which involve vegetation clearing, atmospheric temperatures and surface stones. Factors influencing spatial distribution of small mammals (animals) are elevation, surface stones, rock outcrop and cultivation. These factors signify favourable atmosphere, safe havens and food availability for small mammal to flourish. Most of the factors influencing both plant and animal species apart from cultivation, which involves deforestation or vegetation clearing are natural.

4.2. Recommendations

The factors influencing spatial distribution of plant and animal species in West Usambara Mountains have been established which are natural: elevation, atmospheric temperature, soil depth and slope gradients. The only factor, which is manmade, is cultivation which is negatively related to plant species but encourages spatial distribution of small mammals. Therefore, for conservation purposes, it is recommended that the best undertaking is stopping human activities leading to depletion of plant species and allow for self-regeneration. Facilitating control of erosion in steep slope areas is also recommended as way of plant species re-establishment. Land clearing for farming need to be control and establish a balance between human and ecologically acceptable land clearing considering that both farming and nature conservation are needed.

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