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# Using Multi Techniques Analysis in Biogeoclimatic Ecosystem Classification and Mapping of Mambilla Plateau in Taraba State Nigeria

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## Abstract

**This work used multi techniques analysis comprises GIS models, geostatistics, clustering analysis as against the traditional single layer thematic approach to characterize Mambilla Plateau, a cold highland in Taraba state of Nigeriainto biogeoclimatic ecosystem zones needed for natural resources management. The principal criteria used in classifying and mapping the ecosystems are: climate and bioclimate data, physiography (slope, relief and aspect), vegetation/landcover data. In classifying and mapping the physiography of Mambilla Plateau, the topographic layer was produced from 90 m NASA/SRTM digital elevation model. Principal component analysis, agglomerative hierarchical cluster analysis (AHC) and geostatistical techniques (Kriging) were applied to develop bioclimatic layer. A combination of vegetation field survey conducted on selected sites, un/supervised classification and the application of NDVI values was used to produce landcover map and delineation of the Plateau into vegetation units. These layers of physiographic, bioclimatic and vegetation were spatially combined using fuzzy (sum) overlay in Arc GIS 10.2 to produce 5 major and 1 subunit biogeoclimatic ecosystem zones on the Mambilla Plateau and the adjoining landscape namely: humid lowland forest/humid shrubby forest, montane forest, escarpment stream valley forest, grass cypress cool mountain and, grass eucalyptus cold high mountain. It is expected that this approach to biogeoclimatic ecosystem mapping shall form the bedrock for**

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**vegetal/forest resources management not only in the region but find application especially in most of the highland of the world.**

## Keywords

**Biogeoclimatic Ecosystem, GIS Models, Vegetal Resources Management, Classification, Mapping**

## 1. Introduction

Biogeoclimatic ecosystem classification (BEC) system is a hierarchical and multi layers classification scheme that combines three classifications: climatic, vegetation and sites (soils) to subdivide the land as was in the case of British Columbia into 14 zones, 97 subzones and 152 variants. It is not just the classification of vegetation but an integrated approach where characterization is done with due consideration to the interplay among climate, soil and topography and plant communities in an area. It represents the lowest level mapping individuals and is derived from the site series classification within BEC [1]. Ecosystem classification is basically in two broad categories. There is a spatial extent [2] that ranges from broad division eco region at scale 1:3,000,000 which could provide a starting point for determining mapping zone [3] to biogeoclimatic unit which is mapped at scale 1: 50,000

Global Earth Observation System of Systems (GEOSS) is an intergovernmental protocol that promotes the use of earth observations to address societal issues like climate change, hazards, water availability and ecosystem degradation [4]. It has adopted a standardized method of ecosystem mapping using multilayer approach and has been successfully used in terrestrial ecosystem mapping of United States, South America and Africa [4] [5]. The GEOSS approach includes mapping of the biophysical environmental attributes such as landforms, lithology, and bioclimate at a finest thematic and spatial resolution. These data set from the biophysical mapping now combine the predictor (explanatory) layers from which the location of a described vegetation is predicted using geostatistical models.

The concept of multi techniques and multi layers approach to biogeoclimatic ecosystem classification and mapping is relatively under explored in Nigeria and most especially in a typically rugged environment such as Mambilla Plateau, although a few good literatures exist on regional biogeographic description of Mambilla Plateau such as land degradation on Mambilla Plateau [6], changes in Montane forests of Mambilla [7] [8], vegetation analysis of Ngel Nyaki forests [9] and the Land and people of the Mambilla Plateau [3] [6]. Most of these works use thematic or topical approach in their analysis and description of the Plateau which shows little or less interrelationships among various ecological variables that characterize the Plateau in form of ecosystem maps. This work is expected to open research frontier on natural resources management especially as it affects the biogeoclimatic ecosystem classification of a region using multi-techniques and integrated approach to ecosystem classification and mapping, as against the traditional topical/thematic or unit based classification such as agro climatological zones, vegetation and soil zones with little or no interconnectivity among the variables.

This work is aimed at characterization of Mambilla Plateau into biogeoclimatic ecosystem unit as bedrock for assessment and management of vegetal and other natural resources of the region in particular and the nation in general.

The specific objectives are stated below:

1) To develop a biogeoclimatic ecosystem classification (BEC) of the Mambilla Plateau.

2) To use the BEC map to establish and describe relationship between plant/vegetation life and biophysical factors for effective natural resources management.

## 2. Material and Methods

**Study area**

The Mambilla Plateau is located between latitude 6.8212˚N and 7.3523˚N and longitude 10.7723˚E and 11.5345˚E and covering about 3765 $km^2$ and the adjoining lowland of 1,250 $km^2$ which all constituted Sardauna Local Government [6] [10].

It is a highland region in Taraba state in North East geopolitical zone of Nigeria. Mambilla Plateau is the northern continuation of the Bamenda highland in the republic of Cameroun. Administratively it is known as Sardauna Local Government, with her headquarters at Gembu. It is bounded in the north east by Gashaka local Government in the north west by Kurmi Local Government and south through international boundary by the Republic of Cameroun, West Africa [11]. Major settlements in the study areas are Maisamari Nguroje, Kakara, Ngel Nyaki, Mayo Ndaga and Dorofi which are accessible through the main roads that run longitudinally across the Plateau (**Figure 1**).

The climate of the Plateau is unique and remarkably semi temperate [10]. Generally the Plateau is the coldest region in Nigeria and perhaps one of the coldest in West Africa [11]. The role of altitude is very evident in temperatures distribution on the Plateau, places like Dorofi and Nguroje with altitude of 1666 m and 1618 m respectively have a minimum temperatures of 11˚C and 12˚C in December and January which are usually the coldest months whereas Gembu (1580 m) and Kan Iyaka (1216 m) recorded minimum temperatures of 13˚C and 14˚C at

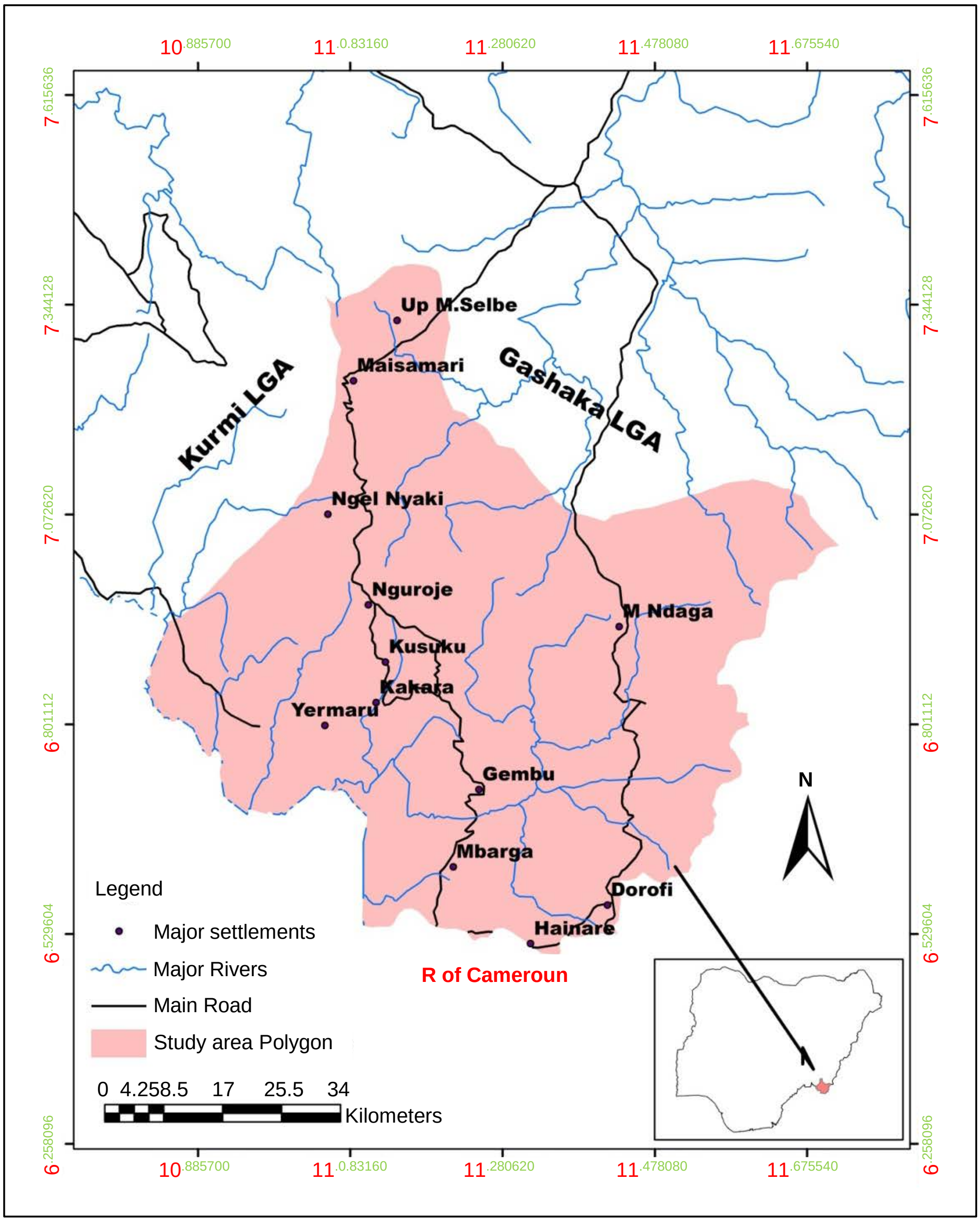


**Figure 1.** The mambilla plateau (Nigeria inset).

the same period [10] [12]. Mean annual temperature ranges from 18˚C (Dorofi and Nguroje) in the higher elevations (**Figure 2**), to 25˚C in relatively lower elevation of north east. The Plateau has summer rains which begins in early March and extending to October [10]. It has a mean annual rainfall of about 1600 mm, and it rains in almost every month except in December and January when rainfall is scanty. The altitude greatly affects rainfall distribution with area around Nguroje Maisamari and Kakara in the North receiving up to 1750 - 1800 mm total annual rainfall while the adjoining lower elevation receives about 1550 mm annual total rainfall.

Quantitative and geospatial data used in this work ranges from digital elevation model, climatic and bioclimatic data to vegetation data (**Table 1**). Analytical techniques used in the study include GIS analysis, (overlay, NDVI, image classification among others). For classification, Principal Component analysis (PCA) and Agglomerative Hirerchical Cluster Analysis (AHCA) were applied and combined with ordinary kriging, a geostatistical techniques for spatial interpolation. [12] to create bioclimatic map.

To divide the Mambilla Plateau into physiographic regions, a 90 m Digital Elevation Model (DEM) Nigeria masked data from NASA/Shuttle Radar Topographic Mission-SRTM was acquired with Mambilla Plateau data subsets and imported into GIS environment. The elevation data was processed by using the reclass menu in spatial analyst tool in Arc GIS 10.2 version to reclassify the Plateau into classes at an interval of 250 m. Slope and contour classes were further processed from SRTM Digital Elevation Model and were combined with the relief classes using map algebra in Arc GIS to produce 7 distinct physiographic (landform) regions (**Figure 2**).

To create Bioclimatic layer, the study area was divided into a grid cell of 10 km by 10 km from which 30 randomly sampled points and their coordinates were taken with at least one point per grid cell. the following bioclimatic variables were extracted from WorldClim database in DIVA GIS using climate point tool: BIO1 = mean annual temperature, BIO2 = Mean Diurnal Range (max temp-min temp) (monthly average), BIO5 = Max Temperature of Warmest Period, BIO6 = Minimum Temperature of Coldest, BIO7 = Temperature Annual Range BIO10 = Mean Temperature of Warmest Quarter, BIO11 = Mean Temperature of Coldest Quarter, BIO12 = Annual Precipitation BIO13 = Precipitation of Wettest PeriodBIO14 = Precipitation of Driest Period

The application of principal component analysis (PCA) was used to reduce the number of these chosen bioclimatic variables in the analysis and derive the principal factors that account for the variation on the Plateau. Factor loading was constructed and used to describe correlation between factors and the original variables acquired for the analysis [13] from which factor scores matrix were derived. Factors with coefficient of ± 0.5 to ± 0.9 were considered good enough and were selected for factor mapping [7]. The hierarchical cluster analysis was performed on factor scores of the principal factors in the 30 sampled points for classification and grouping. The 30 factor scores from principal factor 1 and 2 across the study area were subject to spatial interpolation by using ordinary Kriging method in ArcGIS 10.2 to produce bioclimatic layer/map (**Figure 4** and **Figure 5**).

To produce vegetation layer, first the Normalised Difference Vegetation Index (NDVI) was performed on the study area images (**Figure 6**) NDVI measures quantitatively the vegetation vigour of a given pixel which ranges from −1 to +1. Secondly the study area was stratified according to Bioclimatic zones and broad landcover units. Vegetation survey was conducted on the six selected settlements namely Maisamari, Nguroje Mayo Ndaga, Dorofi, Gembu and Upper Mayo Selbe with each site fallen under at least one Bioclimatic zone and landcover unit. From each of the selected sites, 50 plots were systematically randomly laid at 100 m interval in circular direction thus a total of 300 plots were laid to cover the entire study area. The validation or classification accuracy was done by comparing the classified images (using Maximum Likelihood Classifier) with 300 ground truth points (vegetation survey). The number of ground truth points that were actually classified as correct were obtained and divided by the total number of classified both correct and incorrect.

**Table 1.** Summary of geospatial data used.

| S/No. | Data Type | Year of Acquisitions | Resolution/Scale | Source | Application |
|---|---|---|---|---|---|
| 1 | Landsat ETM + Images | 2009-2013 | 30 m | GLCF/USGS | Landcover Mapping/NDVI |
| 2 | Digital Elevation Model (DEM) | 2000 | 90 m | SRTM/NASA | Physiographic Mapping |
| 3 | Climatic Data | 1900-2000<br>2000-2013 | 0.86 $km^2$ | WorldClim/UBRDA | Bioclimatic Classification |
| 4 | Soil Data | 2007 | 250 m | UNEP | Physiographic Mapping |
| 5 | Vegetation data | 2013 | 25 m × 4 m | Field Work | Vegetation Classification/Mapping |

Thirdly the thirty sampled field plots in vegetation survey were stratified into floristically similar groups based on the plant species, forms and cover abundance using Agglomerative Hierarchical Clustering (AHC). Classification and naming was based on dominant species. Delineation of the mapping unit's boundaries was performed using the earlier physiographic layer-elevation, contour and slope, and were spatially combined with NDVI layers and Bioclimate layers using summation of fuzzy overlay tool in Arc GIS 10.2 version.

## 3. Results and Discussion

### 3.1. The Physiographic Layer

The reclassification of Mambilla Plateau produces seven elevation classes: 250 - 500 m, 500 - 750 m, 750 - 1000 m, 1250 - 1500 m, 1250 - 1500 m, 1500 - 1750 m and >1750 m, with the highest exceeding > 1750 m found along Nguroje and Kakara axis in the north central part of the Plateau and the lowest being between 250 m - 500 m in the south western and north eastern fringes. Elevation when combined with slope resulted to seven distinct physiographic (landform) regions namely: Irregular lowlands (an average of 300 m), ridge, hills, escarpments, dissected escarpments/stream valley, mountains and high mountains (>1700 m) (**Figure 2**). The stratification of landscape by their topography or physiographic characteristic has generally provided an effective means of improving the efficiency by which spatial modeling can be accomplished not only that altitude influence the

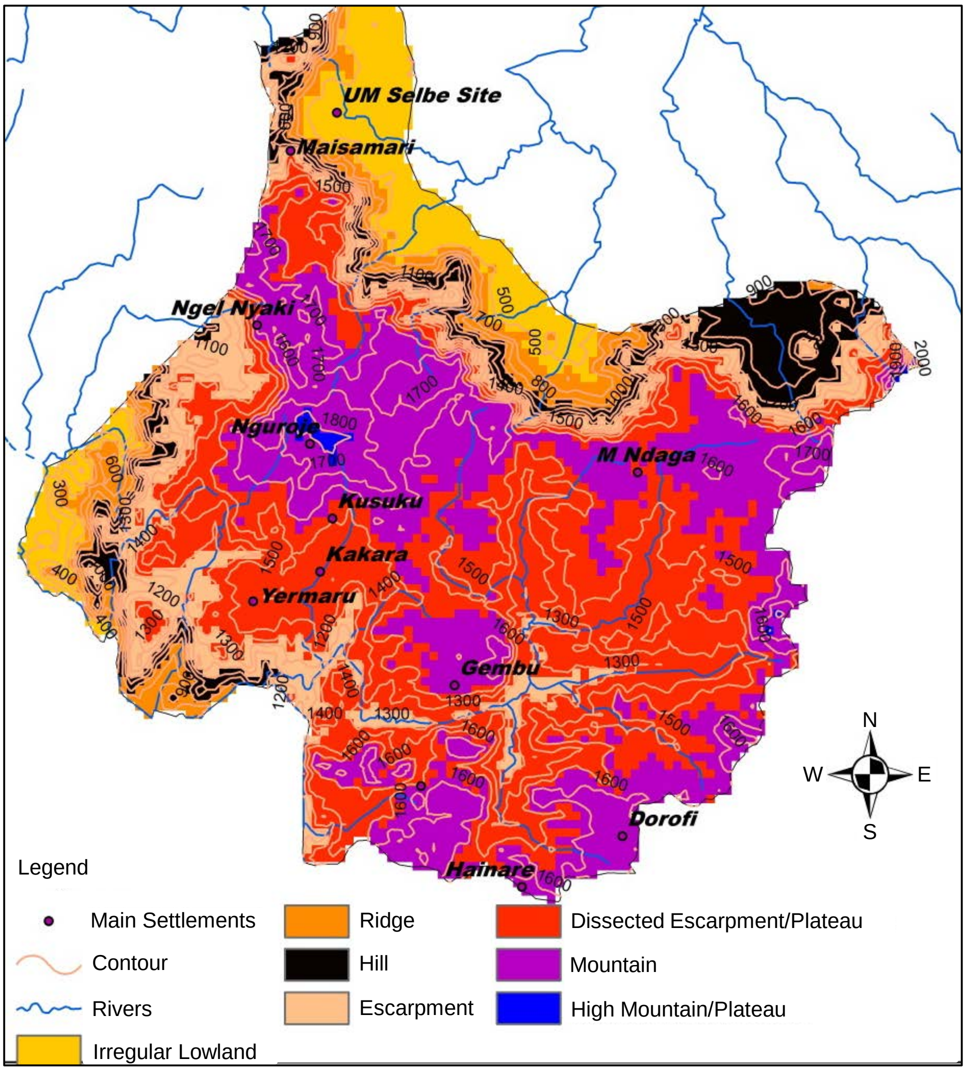


**Figure 2.** Physiographic regions of Mambilla plateau.

components of ecosystem in terms of temperature distributions and vegetation pattern [2] but also it helps in dividing the landscape into manageable units [3].

## 3.2. The Bioclimatic Layer: Classification and Mapping

The application of Principal Component analysis (PCA) reduced the original 9 Bioclimatic variables and Lon, Lat, Altitude to 2 principal factors in which factors 1and 2 with Eigen values of >1 accounted for over 85% of the total variance in the study area (**Table 2**) The factor loading matrix showed correlation between the 12 original variables and condensed factor [13]. **Table 3** showed the loading of the Lon, Lat, Altitude and 9 bioclimatic variables on each of the F1 and F2.

With coefficient of 0.976, 0.977, 0.938, 0.982 and 0.925 factor1 has high loading with variables Bio1, mean annual temperature, Bio5 maximum temperature of warmest months, Bio10 mean temperature of warmest quarter, and Bio11 mean temperature of coldest quarter, and with high negative coefficient 0f 0.966 with altitude (**Table 3**) This factor is then referred to as **Temperature factor (F1)** which explains over 66% of total variance (**Table 2**). The high loading of factor1 on Bio 14 which is the precipitation of driest period still has connection with temperature.

**Table 2.** Eigen value of the bioclimatic variables of Mambilla plateau.

| FACTOR | EIGEN VALUE | % VARIANCE | % CUM VARIANCE |
|---|---|---|---|
| **1** | 8.012 | 66.77 | 66.77 |
| **2** | 2.209 | 18.40 | 85.17 |
| **3** | 0.883 | 7.35 | 92.53 |
| **4** | 0.424 | 3.53 | 96.06 |
| **5** | 0.177 | 1.47 | 97.54 |
| **6** | 0.130 | 1.08 | 98.62 |
| **7** | 0.074 | 0.62 | 99.24 |
| **8** | 0.045 | 0.37 | 99.62 |
| **9** | 0.034 | 0.28 | 99.90 |
| **10** | 0.009 | 0.07 | 99.98 |
| **11** | 0.002 | 0.01 | 99.99 |
| **12** | 0.000 | 0.00 | 100.00 |

Source: XLSTAT statistical package.

**Table 3.** Factor loading on bioclimatic variables in the study area.

| Variables | F1 | F2 |
|---|---|---|
| Lon | −0.363 | 0.485 |
| Lat | 0.576 | **0.596** |
| Bio1 | **0.976** | −0.143 |
| Bio2 | −0.227 | **0.916** |
| Bio5 | **0.977** | −0.096 |
| Bio6 | **0.938** | −0.312 |
| Bio10 | **0.982** | −0.130 |
| Bio11 | **0.925** | −0.236 |
| Bio12 | −0.854 | −0.356 |
| Bio13 | −0.609 | **−0.638** |
| Bio14 | **−0.925** | −0.214 |
| Alt | **−0.966** | −0.024 |

F1 Temperature factor; F2 Locational factor.

Factor 2 has high loading on Bio2 which is mean diurnal range (max temp–min temp) and moderately with latitude and therefore named as **Locational factor (F2)**. Latitudinal location also affects varying day length which could cause diurnal range.

The projection of the variables and their Eigen values revealed that factor 1 and factor 2 accounted for over 85% of the total variance in the study area and is therefore good for factor mapping.

The factors scores for the 30 sampled points on the Plateau were used in mapping. The factor scores shows spatial pattern of factors in space [13] and has been severally used to construct factors map. The Agglomerative Hierarchical Cluster (AHC) analysis on factor scores matrix produced six classes and identified as: 1= very cold and wet, 2 = cold and wet, 3 = cool and wet, 4 = warm and wet, 5 = cool and moist and 6 = hot and humid (**Figure 3**).

### 3.3. Bioclimatic Mapping

Mapping is the delineation of classes into spatial units. The earlier classification of the study area into six classes provides the basis for bioclimatic mapping. The interpolation of factor scores of two principal factors of (F1 and F2) in each of the 30 sampled points displayed geographical bioclimatic variability reflecting these classes on the Plateau [14] [15]. The spatial variation in temperature factor (F1) and locational factor (F2) in the study area were shown in **Figure 4** and **Figure 5**, **Table 4**.

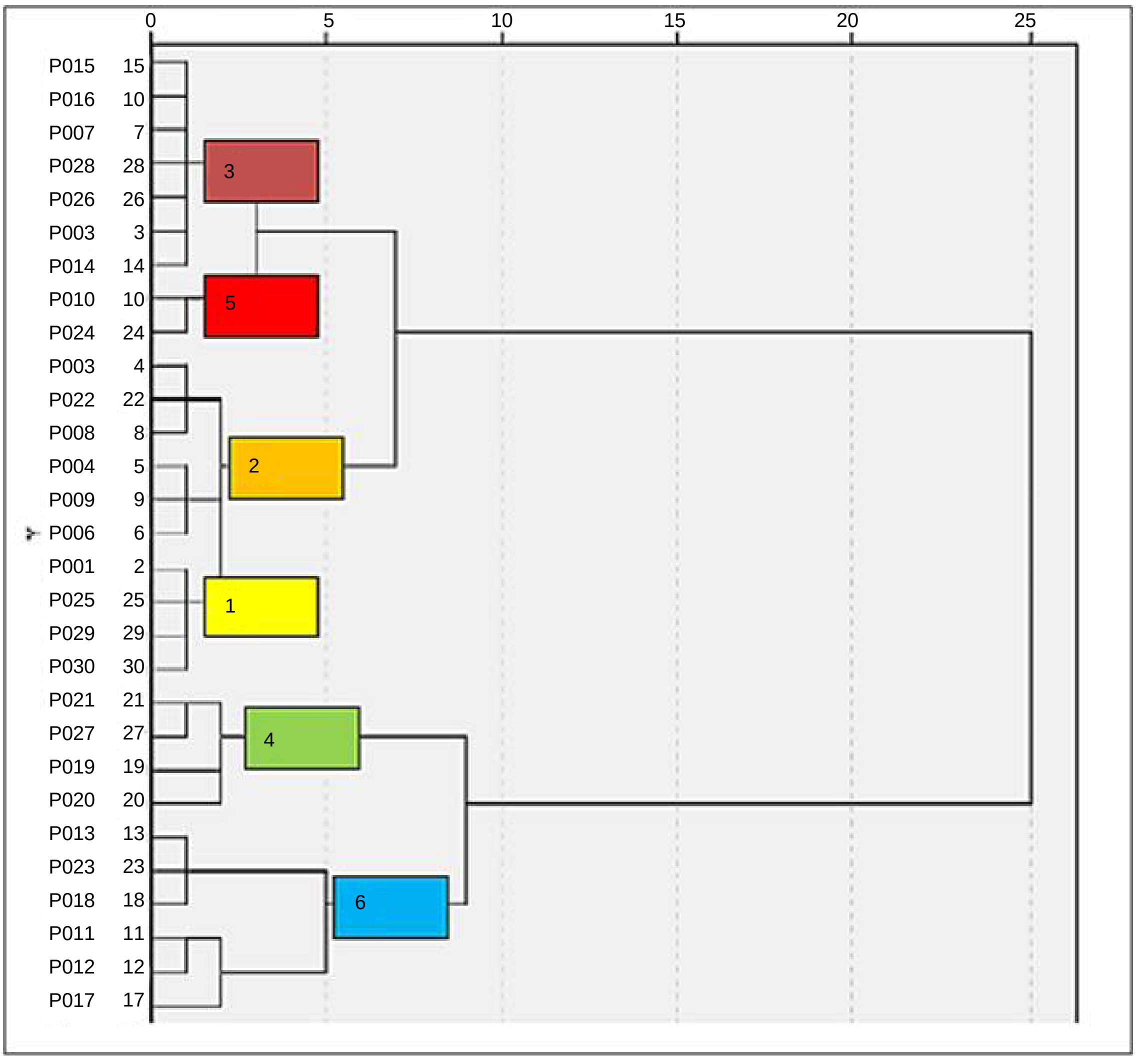


**Figure 3.** Allocation of plots into clusters (AHC) based on factor scores.

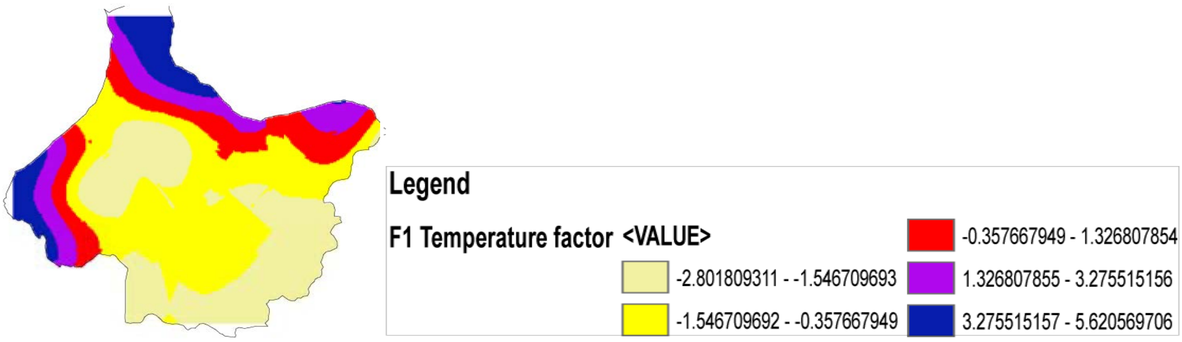


**Figure 4.** Spatial distribution of factor 1; Source: Author's Work, 2015.

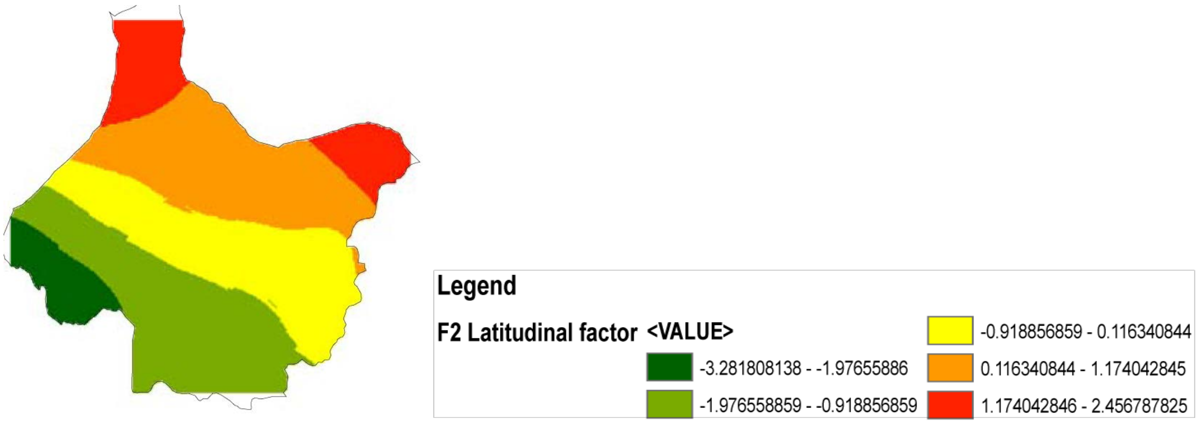


**Figure 5.** Spatial Distribution of factor 2; Source: Author's Work, 2015.

Temperature Factor (F1)

The result of F1 was very similar to annual mean temperature pattern; it shows that temperature (mean annual temperature and maximum temperatures of warmest months) plays a very crucial role in Bioclimatic pattern on the Plateau. The negative scores in F1 indicate area where the climatic factor mostly the mean annual temperature is lower than the average while the positive scores indicate area where this factor is higher.

The score of −2.8 to −1.5 was recorded in the north central around the Nguroje-Kakara axis, south and south eastern parts in Dorofi and fringes of Chappal Waddi in the Far East (**Figure 4**). The score of 3.2 was recorded in the far north and western fringe. Though precipitation is generally high in the study area including the relatively hotter region but least populated area of the north east and western corner however, it presupposes that it does not account for much variation in plant responses to climatic variables on the Plateau as depicted in its coefficient matrix loading of −0.854 which ranks eighth among the Bioclimatic variables in F1.

Locational Factor (F2)

Though F2 is denoted as latitudinal factor because of its moderate loading of about of 0.6 with latitude and 0.925 (**Table 3**) with diurnal range temperature, the positive and negative scores on F2 depicts the degree of latitudinal variation in climatic parameters on the Plateau while the negative values shows greater role of latitudinal position on the bioclimate pattern, the positive values depicts lesser role of latitude in modifying the bioclimate.

The factor scores generally shows which of the variables has more influence in each group and best describe bioclimatic spatial variation in geographic space, given the weight of the factor score this was used to name the Bioclimatic zones where negative F1 depict degree of coldness and precipitation intensity and positive F1 degree of warmness. The following bioclimatic zones are therefore identified and mapped as shown in **Figure 6**.

### 3.4. Mapping Biogeoclimatic Zones into Vegetation Units

The NDVI values across the Mambilla Plateau has highest value of 0.6 representing the closed forest area, 0.3

**Table 4.** Bioclimatic factor scores at the sampled points.

| ID No | Lon | Lat | F1 | F2 |
|---|---|---|---|---|
| P001 | 11.7190 | 6.9933 | −1.661 | −0.591 |
| P002 | 11.7781 | 7.6775 | −1.273 | 0.536 |
| P003 | 11.1208 | 6.8264 | −1.282 | −1.111 |
| P004 | 11.4175 | 6.5409 | −2.516 | −1.462 |
| P005 | 11.5322 | 6.8395 | −1.721 | −1.227 |
| P007 | 11.4572 | 6.9031 | −1.420 | 0.534 |
| P008 | 11.2447 | 6.7047 | −0.936 | −1.639 |
| P009 | 11.1364 | 6.6285 | −2.832 | −1.321 |
| P010 | 10.9833 | 7.1667 | −2.468 | 2.329 |
| P011 | 11.1536 | 7.3363 | 4.957 | 1.857 |
| P012 | 11.1822 | 7.2991 | 5.316 | 1.735 |
| P013 | 11.8772 | 7.2479 | 1.978 | 2.181 |
| P014 | 11.1507 | 7.7270 | −1.236 | 0.699 |
| P015 | 11.1965 | 7.3542 | −2.884 | 0.722 |
| P016 | 11.2194 | 7.0114 | −2.118 | 0.691 |
| P017 | 11.2453 | 7.1558 | 4.123 | 0.733 |
| P018 | 11.5289 | 7.7845 | 1.737 | 1.360 |
| P019 | 10.9188 | 6.9752 | 3.320 | −1.235 |
| P020 | 10.8412 | 6.8635 | 4.453 | −2.584 |
| P021 | 10.9616 | 6.7231 | 2.558 | −3.270 |
| P022 | 10.9712 | 6.8836 | −0.785 | −1.159 |
| P023 | 11.6292 | 7.4387 | 2.177 | 1.884 |
| P024 | 11.6952 | 74116 | −1.984 | 2.483 |
| P025 | 11.2681 | 6.8607 | −1.523 | −0.261 |
| P026 | 11.6533 | 6.8979 | −1.740 | 1.177 |
| P027 | 10.9759 | 6.7116 | 1.849 | −2.992 |
| P028 | 11.5605 | 6.8148 | −1.881 | 0.495 |
| P029 | 11.5002 | 6.6858 | −2.046 | −0.344 |
| P030 | 11.5118 | 6.6314 | −2.169 | −0.752 |

Source: PCA XLSTAT 2010.

shrubby forests with grass understory and 0.1 and −0.0 denoting grassland and bare surface respectively (**Figure 7**). The overall classification accuracy was 83.33% (**Table 5**). However, there are differences in classification accuracy among classes with 100% accuracy recorded for escarpment forest (**Table 6**).

The NDVI (**Figure 7**) was combined with the supervised classification and vegetation survey which produced 5 broad landcover classes: dense forest, shrubby and escarpment forest cover, grassland and settlements (**Figure 8**). Forest cover (20%) were found mostly at the escarpments fringes in the north east and south west of the Plateau while grassland about 70% dominate the landscape, water bodies and settlements constitute the remaining 10%

Spatial combination of physiographic layer, bioclimatic layer and vegetaion vigour layer (NDVI) produces 5 major and I sub Biogeoclimatic zones: 1) Humid lowland forest. 2) Humid shrubs forest. 3) Montane/escarpment forest. 4) Escarpment stream valley sub montane forest. 5) Grass cypress cool highland. 6) Grass eucalyptus cold high mountain (**Figure 9**, **Figure 10**).

## 3.5. Description of Biogeoclimatic Ecosystem on Mambilla Plateau

### 3.5.1. Humid Shrubs-Forest (HSF) of Antere, Ndum Yaji

Similar and merge with the humid lowland forest is the humid shrubs forest zone. This region accounts for about 10% of the study area. It comprises of undulating lowland, low hills and irregular plains, the height ranges from 450 m to 700 m mostly of north east facing gentle slope. Notable area in this zone is Antere and Ndum Yaji in

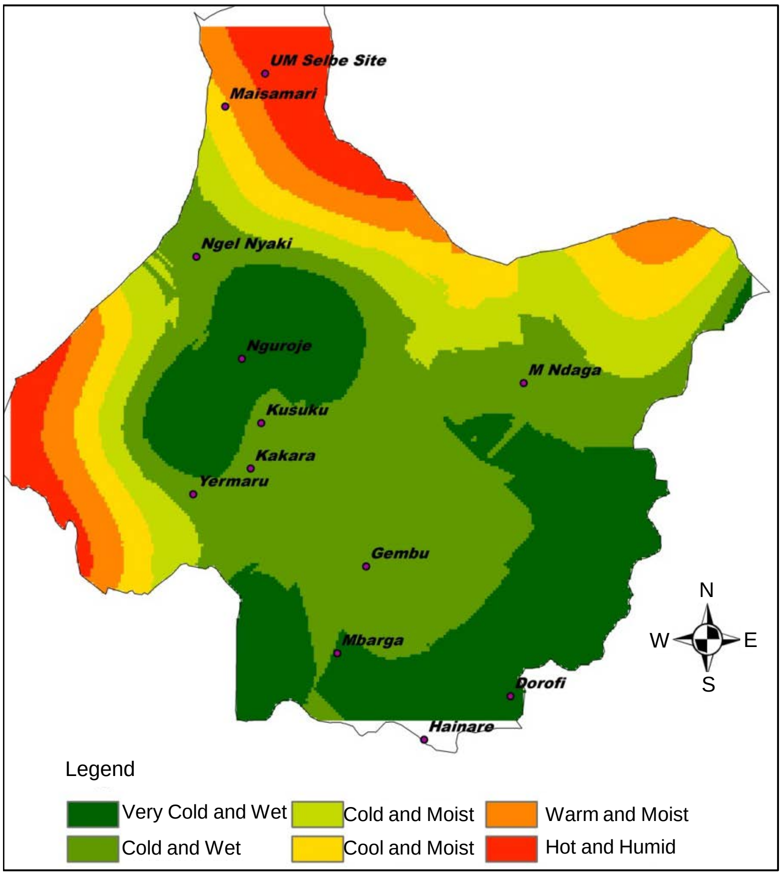


**Figure 6.** Bioclimatic zones on Mambilla plateau.

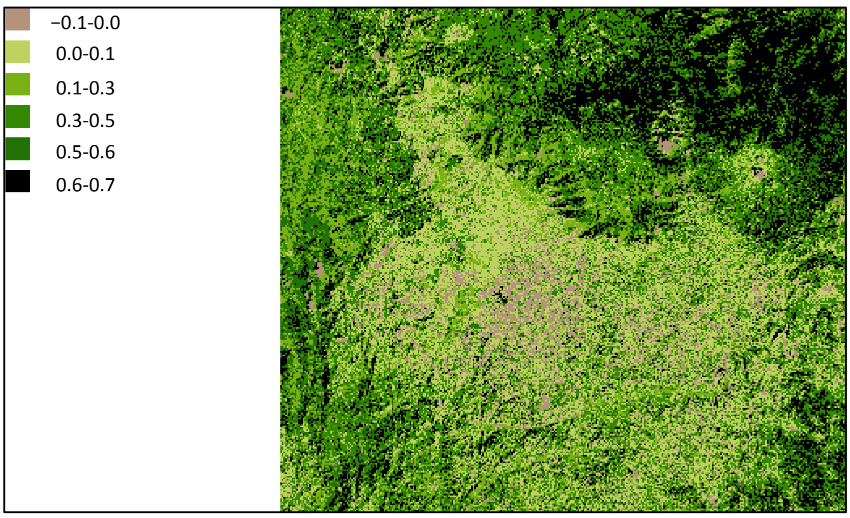


**Figure 7.** NDVI of Mambilla Plateau and adjoining lands.

the south, it is very similar to humid lowland forest as both had relatively high temperature (mean annual temperature of 24˚C) however it is wetter than the former, the total annual rainfall in this region could reach 1650 mm, the wetter and lower elevation area of this region supports forest growth, while shrub such as *Cyatheaceae manniana* is found around the low hills and irregular plains. Tall but tough grasses are beginning to appear as under story.

**Table 5.** Classification error matrix.

| | Ground Truth Points | | | | |
|---|---|---|---|---|---|
| Classified | Forest | Grassland | Shrub/forest | Escarpment Forest | Total |
| Dense Forest | 60 | 00 | 10 | 00 | 70 |
| Grassland | 00 | 120 | 20 | 10 | 150 |
| Shrub/Forest | 00 | 00 | 40 | 10 | 50 |
| Escarpment Forest | 00 | 00 | 00 | 30 | 30 |
| Total | 60 | 120 | 70 | 50 | 300 |

Over all accuracy 60 + 120 + 40 + 30 =250/300 × 100 = 83.33%.

**Table 6.** Individual landcovers class accuracy.

| | | |
|---|---|---|
| Dense Forest | 60/70 ×100 | 85.6% |
| Grassland | 120/150 × 100 | 80% |
| Shrub/Forest | 40/50 × 100 | 80% |
| Escarpment Forest | 30/30 × 100 | 100% |

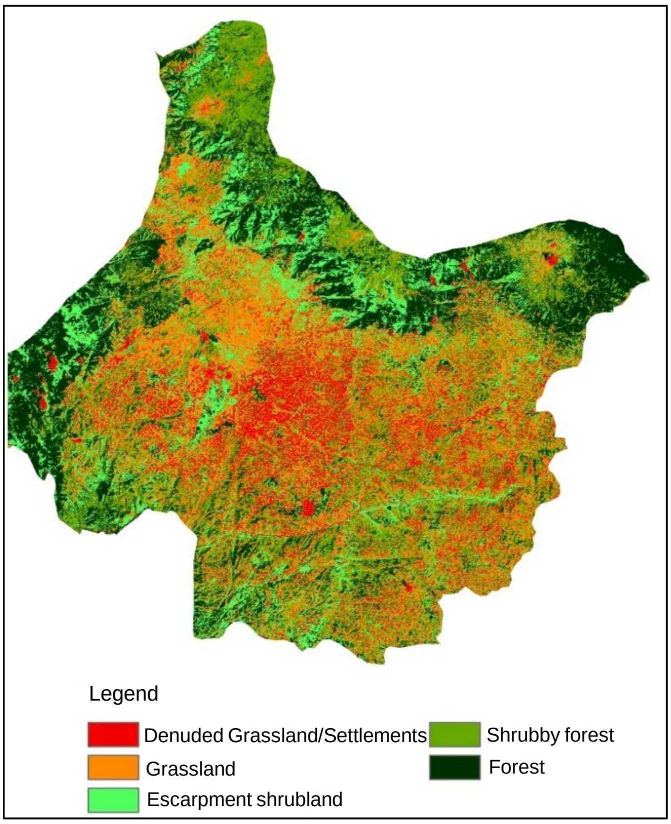


**Figure 8.** Broad landcover of Mambilla plateau.

### 3.5.2. Sub/Montane Forest (SMF) of Ngel Nyaki

This zone is characterized by ridges, hills, and escarpment; it composes of similar plant forms as in escarpment stream valley montane forest except it differs in the altitude. This region receives an annual total rainfall of 1600 mm and mean annual temperature of 24˚C. The mild temperature and moderately high rainfall in this zone make it to support dense vegetation. The average height ranges from 1000 m in Kan Iyaka in the east to over 1400 m in the western escarpment at Ngel Nyaki which contain approximately 46 km$^2$ of diverse afromontane tree

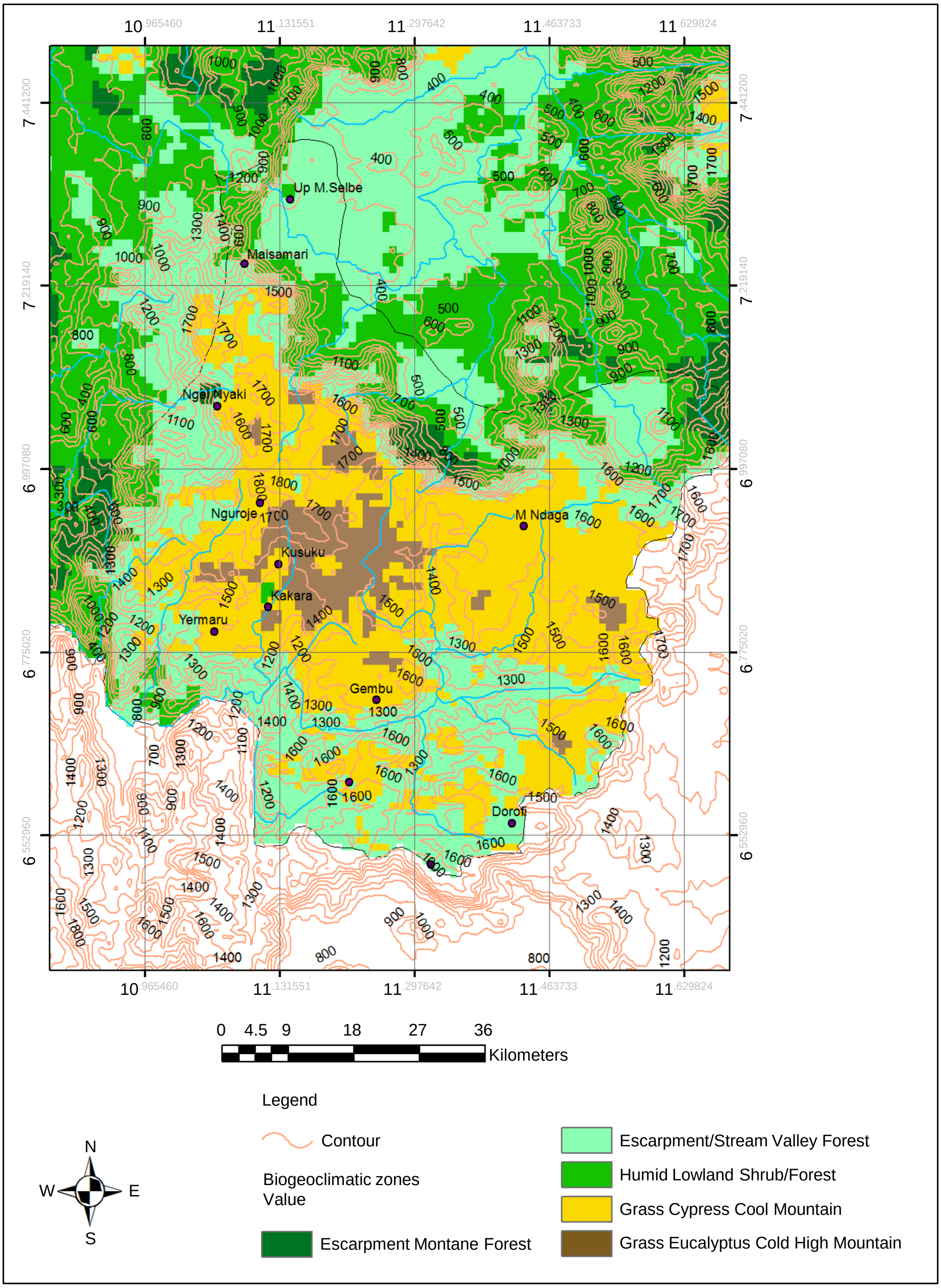


**Figure 9.** Biogeoclimatic ecosystem zones on the Mambilla plateau.

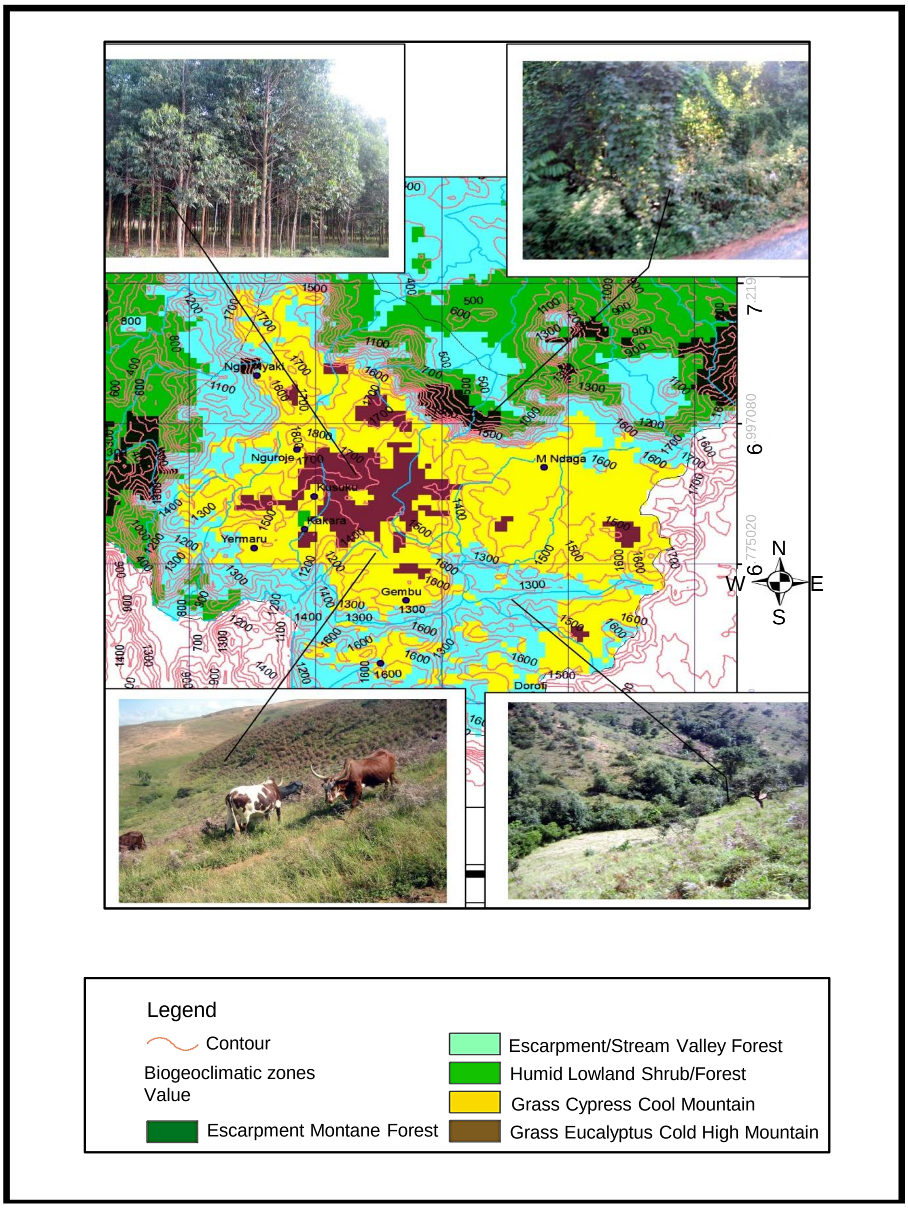


**Figure 10.** Graphic sections of plant species of Mambilla biogeoclimatic ecosystem zones. *Humid lowland forest and shrubby forest ecosystem were merged in the final map; Source: Salako G *et al*. (2015) [11].

species. Common species here include *Entandrophragma angolense*, *Poulteria altissima*, *Khaya grandifoliola and Syzygium guineense.*

#### 3.5.3. Escarpment Stream Valley Montane Forest (EVF) of Antere Donga Valley, Njawai and Hainare

This region is topographically unique and complex. It comprises of diverse landforms ranges from very steep escarpments, foothills and breaks, deep valleys and ridges. It is mostly found in the border between highland region of Nguroje-Maisamari and the escarpment in the north east and western part around Ngel Nyaki. Also in the mid southern parts, this region bisects the two highlands of low mountains region with steep slope escarpment and the deep valley which serves as river Donga channel to the Hainare in far south.

The average height ranges from 1300 m to 1500 m however in the deep rivers valley it could be as low as 500 m. With a mean annual temperature of 22˚C and total annual rainfall of 1700 m, this zone is cooler and wetter than the three previous zones. Shrubs dominate the plant forms here, however, close canopy of trees are found along rivers valley and foothills. Common tree species are *Raphia mambillensis* (*Pteridium aquilinum*,) *Halleastipulosa*, *Polyscias fulva*, *Symphonia globulifera and Vitex doniana*. *Combretum molle was abundant*, Shrubs include *Clerodendrum violaceum*, *a climbing shrub*, *Landolphia landolphioides* [7] [9].

### 3.5.4. Grass-Cypress Cool Mountain (GCM)

This is the largest region in the study area occupy about 65% (2312 $Km^2$) of the total area on the study area covering the entire central parts except the Nguroje-Kakara-Kusuku Grass cold high mountain zone (**Figure 9**). It extends from Yerimaru in the west and eastward to Mayo Ndaga, Gembu in south central half, Mbaga and Bang in the south. Maisamari is a transition between escarpment forest and Grass Cypress Cool Mountain. The average elevation ranges from 1250 m to 1600 m and it is characterized by rugged hills and mountains. Though this region is described as cool however there are some variation in temperature among locations due to influence of relief and urbanization, Mayo Ndaga with average minimum temperature of 13˚C and mean annual temperature of 24˚C is cooler than Gembu whose minimum temperature rarely falls below 14˚C and mean annual temperature of 26˚C.

Though cypress tree grow and does well in this zone it equally support eucalyptus. Grass is the dominant plant form in this ecosystem and the common species are *Blaeria spicata S. ramosa and Sprobulus.* Wild guava shrubs are found along the roads as one approach Maisamari up till Gembu. Cattle's rearing is the predominant occupation in this zone and mostly practiced by the Fulani thereby making the zone highly vulnerable to overgrazing.

### 3.5.5. Grass-Eucalyptus Cold High Mountain (GCHM)

Grass eucalyptus Biogeoclimatic ecosystem zone occupies Kusuku Nguroje Kakara axis in the North central part and in the south about 9 km from Dorofi. This is an upland volcano underlain by basaltic rock and punctuated by high hills. An average height is about 1500 m with the Nguroje hills reaches up to 1800 m. This zone is the coldest of all zones. The mean annual temperature is 19˚C and maximum annual temperature rarely exceeds 25˚C Frost is a common occurrence in the month of December and January where minimum temperature could be as low as 10˚C with an annual total rainfall of 1850 mm; rainfall is very high and well distributed throughout the year. Grass is equally the predominant plant cover, cattle's grazing is much more intense in this zone as many patches of land had been denuded of grass cover; however, eucalyptus which was introduced on the Plateau in the late 1950s has become a prominent feature of the landscape. Also there are patches of cypress and pine trees planted in the residential areas.

## 4. Conclusions and Recommendations

Although the climate and the topography of the Mambilla Plateau are generally described as temperate and rugged mountain respectively, it is erroneous to assume that the topography and the climatic parameters especially the temperature are uniform throughout the entire landscape. This supported the earlier observation on temperature and rainfall variability on the Plateau. However, the application of geospatial techniques has enabled us to integrate these multi layers parameters in order to identify six biogeoclimatic zones on the Plateau with their unique characteristics features.

Relief however plays a prominent role in defining the pattern and landscape characteristics as the biogeoclimatic zones on the Plateau highly reflect the topography.

The biogeoclimatic ecosystem zones on the Plateau where unique ecological characteristic features of each zones are presented are thereby recommended to be adopted as framework for natural resources planning and management by both the Taraba state government in particular and Federal Republic of Nigeria in general.

The presence of fringe forest in the escarpment and stream valley is an indication that the zone could be a good habitat for forest growth and therefore should be designated for conservation and management.

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