Plant community and ecological analysis of the woodland vegetation in Metema area, Amhara National Regional State, Northwestern Ethiopia

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Abstract

The study was conducted in 2008 in the broad-leaved deciduous woodland of Metema in northwestern part of Amhara regional state, Ethiopia to determine plant community types and species distribution patterns and their relationship with different environmental variables. A selective approach with a systematic sampling design was used. A total of 74 quadrates, each with the size of 25 m x 25 m at an interval of 150 m to 200 m were laid along the established transect lines, following the homogeneity of the vegetation. For herbaceous and soil data collection, five subquadrats each with the size of 1 m x 1 m were established at four corners and center of every quadrate. Results showed that three community types were identified using TWINSPAN analysis and all the three community types showed good diversity in Shannon-Weiner index, the highest record by community type II. The highest similarity coefficient of 0.49 (49%) in species richness was recorded between community type II and III. Results also indicated that these community types were completely different from community types so far discovered in other dryland parts of the country. The canocial correspondence ordination diagram revealed that the distribution pattern of community type I was highly explained by moisture, while that of community type III and II by electrical conductivity and altitude and moisture, respectively. Altitude was the most statistically significant environmental variable followed by moisture and electrical conductivity in determining the total variation in species composition and distribution patterns while pH and cation exchange capacity had non significant effect. In conclusion, it is recommended that any intervention should take into account the three community types and their environmental settings to make the intervention more feasible.

Key words: Diversity, dryland, environmental variables, ordination, Metema woodland, plant community.

Introduction

Four broad vegetation types can be distinguished for the arid and semiarid regions of Ethiopia (Friis, 1992). These are broad-leaved deciduous woodland, small-leaved deciduous woodland, lowland dry forest and lowland semi-desert and desert vegetation. Increasing human pressure in recent years in the dryland is initiating the rapid advance of desertification. Furthermore, the effects of global climate change which prevails in the dryland regions has further intensified problems in dry regions making them more arid, vulnerable and difficult for habitation (Akimaliev, 2005).

Metema area is one of such dryland parts of Ethiopia located in the Northwestern part of Amhara Regional State. Like other dryland parts of the country, land degradation is rife in Metema area because of over exploitation of the woodlands and farming of the fragile lands. Transgression of agriculture towards the natural woodland, burning and overgrazing resulted in the clearing of woodlands. This in turn accelerated soil erosion and destroyed the soil and floristic diversity of the area (Sisay Asfaw, 2006). To address these problems, some research activities have been undertaken by several researchers (Sisay Asfaw, 2006). Nevertheless, most of these studies were focused only on woody species with a special emphasis on the production, population structure and soil seed bank and alternative land use options for frankincense producing species. Baseline information is lacking on the general plant diversity, plant community and other ecological perspectives which profoundly could contribute to the formulation of development and management plan for plant species growing in the area. Therefore, this research activity was intended to address this research gap. The objective of the study was, therefore, to assess plant communities and ecology of the woodland vegetation in Metema area.

Materials and methods

The study area

The study was conducted in 2008 in the Metema district in North Gondar Zone of the Amhara National Regional State of Ethiopia. It is located at 36°17' E and 12° 39' N with an altitudinal range of 550 to 1608 meter above sea level (m a.s.l). According to the National Meteorological Agency of Ethiopia (2009), the annual rainfall of Metema ranges from 514.4 to 1128 mm with a mean annual rainfall of 924.2 mm. The mean monthly minimum and maximum temperature of Metema district are 19.31^{O}C and 35.65 ^{O}C, respectively. The mean annual temperature is 32.98 ^{O}C.

Data collection

Sampling design

A systematic sampling method was employed for the study. Quadrates of 25 m x 25 m (625 m^2) were placed next to each other at the interval of 150 m to 200 m, following the homogeneity of the vegetation. Trees and shrubs were assessed in the main quadrate while seedling and sapling in two subquadrats of 2 m x 5 m laid at the beginning and the end of the baseline on opposite sides of the main quadrate. For the herbaceous species and soil sampling, a total of five sub quadrates with the area of 1 m X 1 m were laid within each main quadrate in a way that four subquadrats at the corner and one at the center (Figure 1).

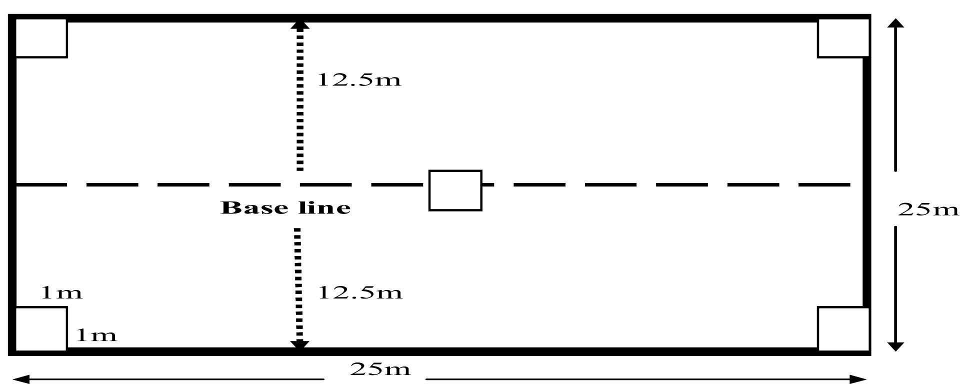

Figure 7. Sampling design for the plant community and ecological study of the woodland vegetation.

Vegetation data collection

All the plant species in all quadrates were recorded but the cover abundance of all the vascular plants in each quadrate were estimated using the visual judgment. Trees and shrubs, taller than 2 m and more than 2 cm in diameter were measured for height and diameter at breast height (DBH). Regeneration assessment was made through counting of each species in the two subquadrats of 2 m x 5 m. In all quadrates, additional trees and shrubs outside the quadrate boundaries within 10-15 m and field layer species were collected and noted as present. The collected plant specimens with their vernacular names were taken to the National Herbarium of Addis Ababa University for identification. Then, specimens were dried and identified using authenticated specimens and referring to the published volumes of Flora of Ethiopia and Eritrea.

Environmental data collection

Environmental variables including altitude, geo-reference points (Northing and Easting) were recorded and soil samples were collected from each quadrate. Location and altitude of each quadrate were measured using Geographical Positioning System (GPS). Soil samples from each five subquadrate were sampled at a soil depth of 0-15 cm. The soil samples from the five subquadrats were pooled (up to the weight of 0.7-1kg) for each main quadrate and analyzed for soil pH, electrical conductivity, cation exchange capacity (CEC) and moisture.

Vegetation data analysis

Floristic composition

Species composition: Species richness is a biologically appropriate measure of alpha diversity and is usually expressed as number of species per sample unit (Whittaker, 1972). The number of species (species richness) was determined by summing up the number of species identified directly in the field and in the National Herbarium.

Plant diversity and equitability analysis

Shannon-Weiner diversity index was used to infer about the total Metema floristic diversity and evenness. For analysis, the cover-abundance value of each encountered species was used.

Multivariate analysis

Classification analysis

The vegetation data matrix was analyzed and classified using the computer program TWINSPAN (Two-way INdicator SPecies Analysis) for Windows version 2.3 (Hill and

Šmilauer, 2005). TWINSPAN is a computer program designed primarily for ecologists and vegetation scientists who have collected data on the occurrence of a set of species in a set of samples. The samples may be stands, quadrates, or whatever is needed to the study. The program first constructs a classification of the samples, and then uses this classification to obtain a classification of the species according to their ecological preferences. The two classifications are then used together to obtain an ordered two-way table that expresses the species' synecological relations as concisely and clearly as possible (Hill and Šmilauer, 2005).

To analyze with this program, the percentage canopy cover-abundance value of all vascular plant species that had been rated based on 1-9 scale of Braun-Blanquet was further converted into Canoco condensed format using WCanoImp Help File (Šmilauer, 2002b) which is a subprogram in Canoco for Windows version 4.5 (Ter Braak and Šmilauer, 2002). With condensed data entry, a large number of zero entries that make the data entry and checking prone to error were reduced. It is only those species present in a quadrate or sample that are entered, each as a couplet with a number for each species followed by its abundance score (Kent and Coker, 1992; Hill and Šmilauer, 2005).

After identifying the community types from the Ordered two-way tables of WinTWINS output, the distinguished community types were further refined in a synoptic table where each column represents a community type. These synoptic values were made by the product of the species' frequency and average cover-abundance values following Tamrat Bekele (1993). Finally, the types were named after three of dominant and/ or characteristic species.

Similarity, diversity and equitability

Diversity and Equitability: To compare the diversity and equitability between the derived community types, Shannon-Weiner diversity and evenness indices were used by using the cover-abundance value of each species encountered. Furthermore, the diversity curves were made to compare species richness and species diversity pattern between the derived community types following Gotelli and Colwell (2001). These diversity curves analysis were done using the analysis package in PAST version 1.62 (Hammer *et al*., 2001).

Similarity index: The Sorensen similarity coefficient was used to compare similarity between the community types in their species richness. According to Kent and Coker (1992), the index is widely used because it gives more weight to the species that are common to the samples rather than to those that only occur in either sample. Accordingly, Sorensen coefficient of similarity (Ss) was calculated using the formula:

$$S_s = \frac{2a}{2a + b + c}$$

Where, Ss = Sorensen similarity coefficient, a = number of species common to both samples, b = number of species in sample, and c = number of species in sample 2.

Ordination analysis

Canocial Correspondence Analysis (CCA) was employed to do ordination. CCA is a technique which reveals the linear combinations of environmental variables explaining most of the variation in the species scores along the ordination axes. CCA is sometimes considered as a direct gradient analysis because it is based on the variation in the environmental data included. However, at the same time it is an indirect method because the variation in the species occurrences is used (Kent and Coker, 1992; Tamrat Bekele, 1993). The biplot, species/environment CCA was performed with the procedures in the computer program package of CANOCO version for 4.5 (Ter Braak, 2002). All the species cover-abundance values and environmental data were used in this analysis. The species data that has been rated based on 1-9 scale of Braun-Blanquet (as modified by Van der Maarel, 1979) was converted into condensed format before analysis using WCanoImp Help File (Šmilauer, 2002b), which is the subprogram in the CANOCO for Windows version 4.5 (Ter Braak and Šmilauer, 2002). The resulted ordination diagram was further analyzed to see the distribution pattern of the derived community types using CanoDraw for windows version 4.0 (Šmilauer, 2002a), which is also the subprogram in the CANOCO for Windows version 4.5.

The statistical significance of the canocial axis in explaining species/environment data was made for the first axis and all canocial axes using the Monte-Carlo permutation tests. Permutations test "under reduced model" was used following Lepš and Šmilauer (1999 and 2003) as used by Gemedo Dalle (2004). In line with this, the statistical significance of the environmental variables in explaining the total variation in species distribution was carried out using Monte-Carlo permutation test, using a forward selection of CANOCO. Statistical analysis was also carried out to find significance correlation between environmental variables by calculating a matrix of Pearson's correlation coefficient. MINITAB statistical software version 14.13 (Anon., 2004) was used to analyze the correlation analysis.

Results

Plant community assessment

The classification analysis of the 74 quadrates using TWINSPAN method resulted in three different community types (Table 1) and these community types were further refined in the synoptic table (Table 2). Based on the dominant and/or characteristic species in the community type the three community types were denoted as:

I. *Combretum collinum-Acacia sieberiana-Balanites aegyptiaca* type

This community type was distributed between 744 m and 830 m a.s.l. altitudinal range and consisted of 10 quadrates with 49 species. In this community, *Combretum collinum* was the dominant species in the tree layer and *Acacia sieberiana*, *Balanites aegyptiaca* and *Tamarindus indica* were the characteristic species in the tree layer. *Strychnos innocua*, *Dichrostachys cinerea* and *Ziziphus abyssinica* were dominant in the shrub or tree layer while *Acacia polyacantha* was the characteristic species in this layer. *Indigofera longibarbata* was dominant species in the field layer. *Hypoestes forskaolii* and *Hygrophilia schulli* were also the dominant species in the field layer.

II. *Boswellia papyrifera-Lannea fruticosa-Pterocarpus lucens* type

This community type was distributed between 728 m and 792 m a.s.l. altitudinal range and consisted of 50 quadrates with 74 species. In this community, *Boswellia papyrifera*, *Lannea* *fruticosa* and *Pterocarpus lucens* were the dominant species in the tree layer. Other species dominating the tree layer include *Cobretum adenogonium*, *Combretum molle* and *Grewia bicolor*. *Terminalia laxiflora*, *Albizia lophantha* and *Diospyros abyssinica* were the characteristic species in the tree layer, while *Ximenia Americana* was in the dominant species in the shrub or tree layer. In this type, *Monechma cilliatum* was the dominant species in the field layer. *Solanum anguivi*, *Allophylus rubiflorus* and *Ipomoea tenuirostris* were also the dominant species in the field layer.

III. *Sterculea setigera*-*Anogeissus leiocarrpa*-*Dalbergia melanoxylon* type

This community type was distributed between 766m and 932m a.s.l. altitudinal range and consisted of 14 quadrates with 44 species. *Sterculea setigera*, *Lannea fruticosa* and *Dalbergia melanoxylon* were the dominant species in the tree layer in the community. *Boswellia pirottae* was also the dominant species in the tree layer, while *Pennisetum pedicellatum* was the dominant species in the field layer including other species like *Panicum monticola*, *Bidens pilosa*, *Hibiscus cannabinus* and *Zinnia peruveana.*

Similarity, diversity and evenness of community types

Generally, the results of the Shannon-Weiner index indicated that all the three community types showed good diversity (Table 3). There were also fair evenness and small dominance in all types. However, based on the diversity curves (Figure 2) and Sorensen similarity coefficient analysis all community types were different. Patterns of the three communities were different owing to their difference in numbers of quadrates, species richness and diversity distribution. In terms of species richness the highest similarity coefficient was 0.49 (49%) observed between community type II and III. The dissimilarities between type I and II, and between type I and III were 0.60 (60%), and 0.65(65%), respectively.

Table 1. TWINSPAN output of Metema vegetation. I, II, and III represent community types.

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                   I                    II                                III
              5 56667776 65645555 111333456 2222334123444444553633326624722 7  1 1  21 111
              7163822149 09111235924913988475679054084023567042767815629034 32433565018867

   34 Dich Cine  3----33--- 33-------------33---gy---------------------------- --------------  000000
   28 Zizi Abys  33-3------ ---------------------3---------------------------- --------------  000001
   37 Bird Micr  -1-------- ----------------1--------------------------------- --------------  000001
   57 Vign Amba  ----3----- -------------------------3------------------------ --------------  000001
   16 Acac Sieb  ------3333 -------------------------------------------------- --------------  000010
   17 Tama Indi  --3------- -------------------------------------------------- --------------  000010
   23 Bala Aegy  ----3-33--
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Table 2. Synoptic phytosociological table for the community types.

Community Types	I	II	III
Size	10	50	14
Combretum collinum	**4.00**	1.58	0.36
Acacia seberiana	**2.10**	0.00	0.00
Balanites aegyptiaca	**1.70**	0.00	0.00
Strychnos innocua	1.70	0.60	0.36
Dichrostachys cinerea	1.60	0.44	0.00
Ziziphus abyssinica	1.50	0.10	0.00
Acacia polyacantha	1.20	0.00	0.00
Indigofera longibarbata	0.80	0.50	0.71
Tamarindus indica	0.60	0.00	0.00
Albizia melanoxylon	0.50	0.00	0.36
Hypoestes forskaolii	0.40	0.20	0.14
Hygrophilia schulli	0.30	0.28	0.14
Boswellia papyrifera	0.70	**4.16**	2.79
Lannea fruticosa	3.10	**4.14**	1.50
Pterocarpus lucens	1.60	**3.90**	0.71
Cobretum adenogonium	0.80	1.34	0.36
Terminalia laxiflora	0.00	1.08	0.00
Albizia lophantha	0.00	0.86	0.00
Ximenia americana	0.50	0.84	0.00
Monechma cilliatum	0.50	0.64	0.36
Combretum molle	0.40	0.62	0.00
Convolvulus Kilimandschari	0.00	0.46	0.00
Solanum anguivi	0.00	0.24	0.00
Allophylus rubiflorus	0.00	0.22	0.00
Grewia bicolor	0.20	0.22	0.21
Diospyros abyssinica	0.00	0.20	0.00
Ipomoea tenuirostris	0.00	0.16	0.00
Sterculea setigera	2.40	2.20	**6.07**
Anogeissus leiocarrpa	4.80	2.18	**5.29**
Dalbergia melanoxylon	0.00	0.10	**2.14**
Boswellia pirottae	0.70	0.24	1.36
Pennisetum pedicellatum	0.90	1.22	1.36
Panicum monticola	0.40	0.10	0.50
Bidens pilosa	0.00	0.22	0.43
Hibiscus cannabinus	0.00	0.22	0.29
Zinnia peruveana	0.00	0.24	0.29

Values are the product of average cover-abundance value and frequency in the type. Only species with at least one value ≥0.15 were included. Values in bold refer to the occurrences as characteristic species which were used as the naming of each type. The sequence of types follows roughly the arrangement in the ordination diagram in Figure 6).

Table 3. Diversity and evenness of three community types.

Diversity Indices	I	II	III
Shannon	3.43	3.55	3.08
Shannon Evenness	0.63	0.48	0.51
Dominance	0.05	0.05	0.08
Species Richness	49	74	44

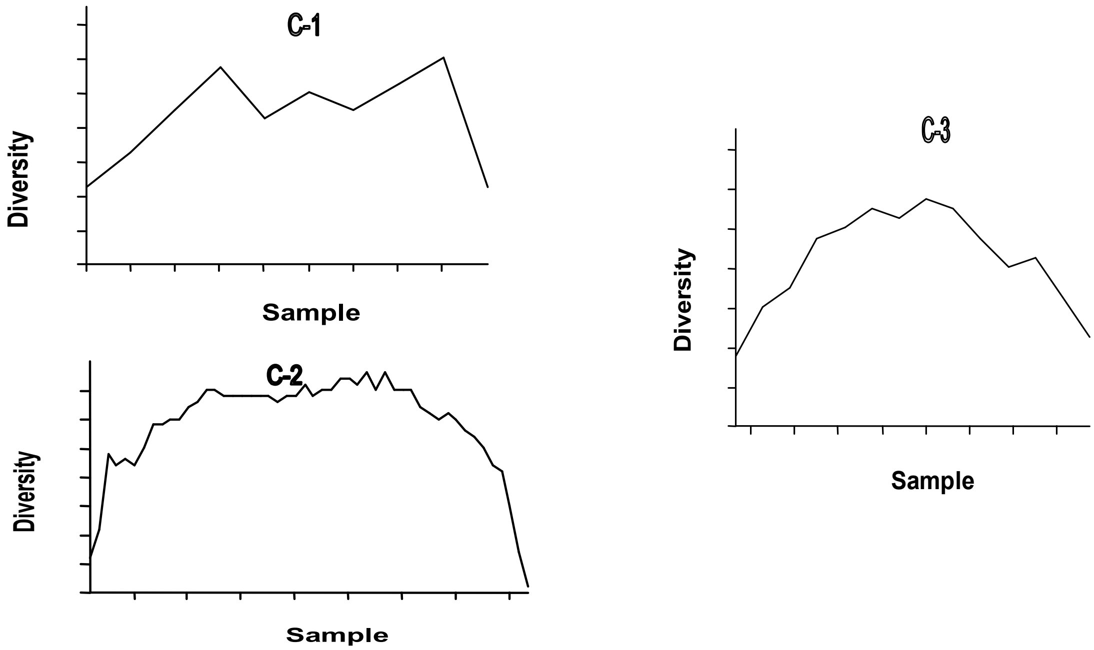

Figure 2. Diversity curves of three community types (C-1 = Community I, C-2 = Community II and C-3 = Community III).

Ordination

Canocial correspondence analysis of quadrates (Figure 3) showed the following relationship between the total vegetation data and the environmental variables. Axis 2 reflected electrical conductivity (EC), pH, moisture, and cation exchange capacity (CEC), while axis 1 revealed a gradient of altitude (Alt). The canocial correspondence analysis coefficients (Table 4) revealed that EC and moisture were the most significant variables in determining the variation in species composition, followed by pH and CEC in axis 2. The eigenvalues for the first axis of the species/environment biplot was 0.195 and the second axis is 0.179, representing 30.7% and 58.9% of the total variance, respectively. In other words, the first two axes account for 89.6% of the variance in the species/environment data implying the constraint analysis of the first two axes was fairly enough in explaining floristic and environmental data. According to Monte-Carlo significance test (Table 4), altitude was the most statistically significant environmental variable in determining the general species distribution and association, followed by moisture and electrical conductivity. However, pH and CEC are non-significant in explaining the total species distribution patterns in the woodland.

Table 4. Correlations of species ordination axis with environmental variables, eigenvalues and percentage variances explained from canocial correspondence analysis of the first two axes (axis1 and axis 2).

Factors	Axis 1	Axis 2	Monte-Carlo Test (at p<0.05)		
			Eigenvalues	**F-ratio**	**P**
Altitude	0.7905	0.2145	0.183	1.801	0.002
Moisture	-0.1444	-0.6196	0.133	1.295	0.034
Electrical Conductivity	-0.4787	0.5024	0.154	1.508	0.036
pH-H_2O	-0.3421	-0.1825	0.090	0.871	0.728
Cation Exchange Capacity	-0.1361	-0.0835	0.083	0.803	0.86
Eigenvalue	0.195	0.179	**Axis 1**	1.808	0.044
Species-environment correlations	0.863	0.821	**All Axes**	1.255	0.012
% variance of species-environment relation	30.7	58.9			

As to the derived three community types distribution and association pattern with the environmental variables (Figure 4), types were emerged to the right and left of the diagram. However, due to the fact that community type I and II showed overlapping at large, ordination for only community type II and III was performed to reveal the clear separation (Figure 5). Generally, from the ordination results, it was observed that species of community type I occurred more along moisture gradient and are species that their association was highly explained by moisture. Species of community type III occurred along with electrical conductivity and are species that their association and distribution is highly explained by electrical conductivity (EC). The distribution of the species in community type II was highly explained by moisture and altitude.

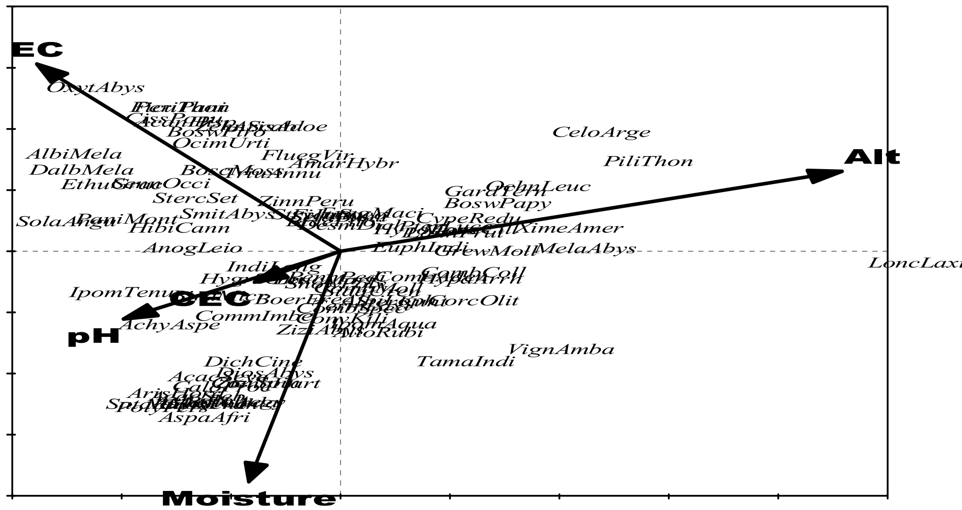

Figure 3. Species/Environment biplot ordination diagram of Metema vegetation from canocial correspondence analysis. Associated correlations, eigenvalues and percentage variances explained are giv

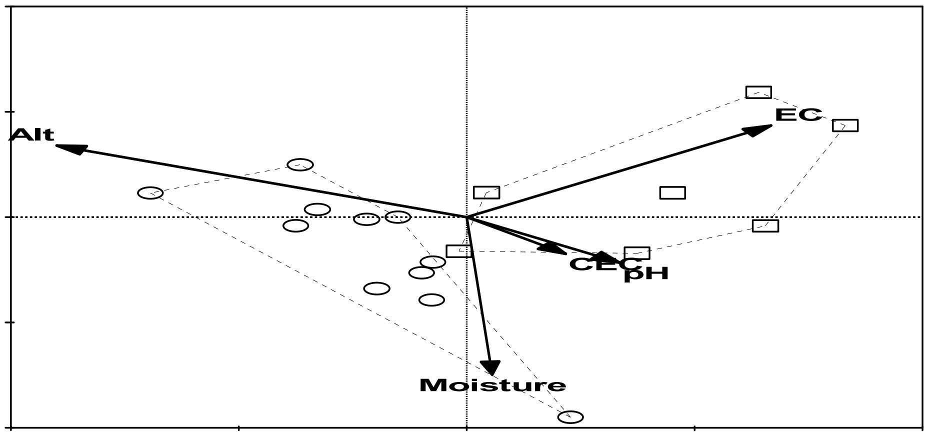

Figure 5. Canocial correspondence ordination of the two communities. Each symbol represents the weighted average of one species. Each envelop encircled around different symbols represent the two different communities: II (○) and III (□).

Correlation of environmental variables

Cation exchange capacity (CEC) had strong positive correlation with electrical conductivity (EC), pH, and moisture. But, CEC had significant and negative correlation with altitude (Table 5). EC had significant and positive correlation with pH and negative correlation with altitude. pH had significant and negative correlation with altitude and positive correlation with moisture. Moisture had significant and strong negative correlation with altitude (Table 5).

Table 5. Pearson's product moment correlation coefficients between the environmental variables.

	CEC	EC	pH	Moisture	Altitude
CEC	-				
EC	0.493***	-			
pH	0.881***	0.431***	-		
Moisture	0.664***	-0.024ns	0.772***	-	
Altitude	-0.274*	-0.361**	-0.428***	-0.319**	-

***, **, * and ns denote significant differences at p<0.001, p<0.01, p<0.05 and non significant differences, respectively.

Discussions

Community types

According to Clements (1916 and 1992) as cited by Kent and Coker (1992), plant community are seen as clearly recognizable and definable entities, which repeat themselves with great regularity over a given region of the earth's surface. This study assessed whether there were or not repetition of the three community types of the Metema woodland in other previously reported community types from other dryland parts of Ethiopia. It was found that the community types of Metema woodland were completely different from community types so far discovered in other dryland areas of the country. For instance, Gemedo Dalle *et al*. (2005) had identified eight plant communities*: Acacia drepanolobium-Pennisetum meziamum*, *Bidens hildebrandtii-Chrysopogon aucheri*, *Chrysopogon aucheri-Commiphora africana*, *Cenchrus ciliaris-Chrysopogon aucheri*, *Acacia bussei-Pennisetum meziamum*, *Commiphora erythraea-Sansevieria ehrenbergi*, *Acacia mellifera-Setaria verticillata* and *Heteropogon contortus-Hildebrandtia obcordata* in Borana lowland. Similarly, Haileab Zegeye *et al*. (2005) also identified nine community types in the Rift Valley area: *Euphorbia tirucalli–Acacia tortilis–Euphorbia abyssinica, Ficus vasta–Ficus ingens–Ficus sycomorus, Steganotaenia araliacea–Maerua triphylla–Cussonia holstii, Euphorbia tirucalli–Solanum schimperianum–Acacia tortilis, Justicia schimperiana–Pavetta gardeniifolia–Cordia monoica, Olea europaea–Juniperus procera–Dodonaea angustifolia, Senna singueana–Pavetta gardeniifolia–Grewia velutina, Aeschynomene elaphroxylon–Sesbania sesban and Pappea capensis–Rhus natalensis–Maytenus senegalensis.*

This may suggest that the Metema woodland is an isolated system of its own because of the past and present interactions of local biotic and abiotic factors such as temperature, edaphic, rainfall, anthropogenic, faunal, topographic and geographic factors. However, community type II, *Combretum adenogonium-Anogeissus leiocarpa*, of this study showed similarity with one community out of the seven community types identified from Gambella region by Tesfaye Awas *et al*. (2001). According to this report, *Combretum adenogonium*, *Pterocarpus lucens*, *Terminalia laxiflorus* along with *Anogeissus leiocarpa* were the dominant species in the tree layer of *Combretum adenogonium-Anogeissus leiocarpa* type.

In this study similarly*, Combretum adenogonium*, *Pterocarpus lucens* and *Terminalia laxiflorus* were the dominant species in the tree layer of community type II i.e., *Boswellia papyrifera-Lannea fruticosa-Pterocarpus lucens*.

This similar finding further ratifies the earlier suggestion that the fact that Gambella and Metema are located in proximity and adjoining geographical areas might made them similar in their emerged plant associations as compared to Borana and Rift Valley areas, which are not in proximity with Metema woodland. This implied that the further we went to the closer geographical location, the more probability we would have in finding similar associations of plant communities. The complex interaction of environmental variables along spatial gradients will form a complex environmental gradient that characterizes the nature and distribution of communities along landscapes (Urban *et al*., 2000).

Environmental analysis

Plant community distribution along the geographical gradients is manifestation of physical factors such as elevation gradients, soil heterogeneity and microclimate, biotic response to the physical factors, and historical disturbances (Urban *et al*., 2000). In the current study, it was noticed that the distribution and association pattern of community type I was explained by moisture while the patterns of type II and III by both moisture and altitude, and electrical conductivity, respectively. Several researchers (Friis, 1992; Tamrat, 1993; Kumlachew and Tamrat, 2002) have reported the influence of altitudinal gradient on plant community distribution. Altitude had been recognized as an important environmental factor that affects radiation, atmospheric pressure, moisture and temperature, all of which have strong influence on the recruitment, growth and development of plants and the distribution of vegetation types. In agreement with the above authors, this study also found that altitude was the most significant environmental variable that determined the general occurrence and distribution pattern of plant community in the Metema woodland vegetation. While, moisture and EC were the second and third most significantly important environmental variables in determining the pattern of community occurrence and distribution.

Conclusions and Recommendations

The current result would make future management of the vegetation feasible, since recognition of more or less homogeneous communities and the associated environmental settings facilitate the choice of appropriate managerial interventions. The ordination analysis revealed that community type I emerged with the gradient of moisture while that of type II with altitude and moisture, and type III with electrical conductivity. Of all the environmental factors studied, altitude was the most significant variable in explaining the total vegetation variations followed by moisture and electrical conductivity. However, cation exchange capacity and pH were non-significant in doing so for the Metema woodland. This research finding was found to be similar with various studies made in the country which reported that altitude had been the most important environmental variable in determining the occurrence and distribution of plant communities. In conclusion, this study recommended that any intervention should take into account the three community types and their environmental settings to make the intervention more feasible. Finally, further research has to be initiated to fill the gaps of this research, especially investigation on the area of socio-economic and ethnobotanical perspectives.

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