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Research article

EFFECTS OF ENVIRONMENTAL VARIABLES ON THE PATTERNS OF PLANT COMMUNITY DISTRIBUTION IN THE AFRO- ALPINE VEGETATION OF SIMIEN MOUNTAINS NATIONAL PARK, ETHIOPIA

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ABSTRACT

Effect of environmental factors on the patterns of plant community formation and species distribution in the afro-alpine vegetation was conducted at Simien Mountains National Park, Northwest Ethiopia. Data were collected from stratified mountains by using systematic sampling in each stratum from October to November 2015. Vegetation and soil were sampled from 30 plots with the size of 20m X 20m and five 1m X 1m subplots, one at each corner and one at the center. Specimens were collected and identified at field and also confirmed at National Herbarium, Addis Ababa University. The analysis of soil samples were done at the Amhara Design and Supervision Work Enterprise soil test laboratory. Cluster and canonical correspondence analysis (R program version 3.1.3) were employed to identify plant community types and effects of environmental variables that shaped the patterns of community formation. Three plant community types were recognized in the study area. In the study area, altitude was the most important environmental variable followed by pH that influenced plant community formation and species distribution. Elevation was positively correlated with pH in the higher elevation and negatively correlated in the lower areas.

Keywords: Canonical correspondence analysis, environmental factors, vegetation relationship, ordination, plant community, soil analysis.

INTRODUCTION

Ethiopia is rich in vegetation diversification due to high range of altitudinal variation ranging from 110 m below sea level at Dalol to 4543m above sea level at Simien Mountains National Park. The country is one of the centers of origins and biodiversity species. It possesses six thousand to seven thousand vascular plants (Bekele, 2007; USAID, 2008). Various authors have attempted to study the Ethiopian vegetation resources employing different systems (Fichtl and Adi, 1994; Bekele, 2007; USAID 2008; Kelbessa and Demissew, 2014). They have made considerable contributions towards understanding vegetation of the country and also proposed some of the conservation strategies. Despite these studies, due to the complex nature of Ethiopian vegetation resulted from diverse topographic variations and large altitudinal range, enumeration of plant species and study of vegetation in the country is not yet completed.

As it is described by Woldu (2012), the central goal of ecology is to explain the distribution of species in terms of environmental variables presumed to the operative constraints on the species. In different areas different researchers got different results in relation to environmental factors and plant community formation and species distribution (Awas *et al*., 2001; Guoquing *et al*., 2008; Mehrjardi *et al*., 2009; Zare *et al*., 2011; Gholinejad *et al*., 2012; Kebede *et al.*, 2013).

Plant communities are mainly influenced by both biotic and abiotic factors (Chapin *et al*., 2002). To this effect, understanding of topographic and soil variables are important issue for environmentalists, ecologists, policy makers for conservation of nature. In Ethiopia, Simien Mountains National Park (SMNP) is one of the first established sites and also rich in biodiversity resources and center for the researchers more than four decades. Most of the studies completed in this area were related to fauna compared to flora. However, environmental factors especially soil related factors in relation to patterns of plant community formation and species distribution in the afro alpine vegetation is not yet done. Thus, the present study was conducted with the general objective of evaluating the effect of environmental variables such as altitude, slope, aspect, pH, texture, organic matter, soil conductivity, total nitrogen, cation exchange capacity, available phosphorus and available potassium on spatial patterns of plant community formation and species distribution.

MATERIALS AND METHODS

Description of the study area

The Simien Mountains National Park (SMNP) is located in Northwest Ethiopia (Figure 1), 850 km from Addis Ababa. The park was established in 1966 following the recommendation by the United Nation Educational, Scientific and Cultural Organization (UNESCO) mission sent to Ethiopia in 1965 (Amhara National Regional State, 2009).

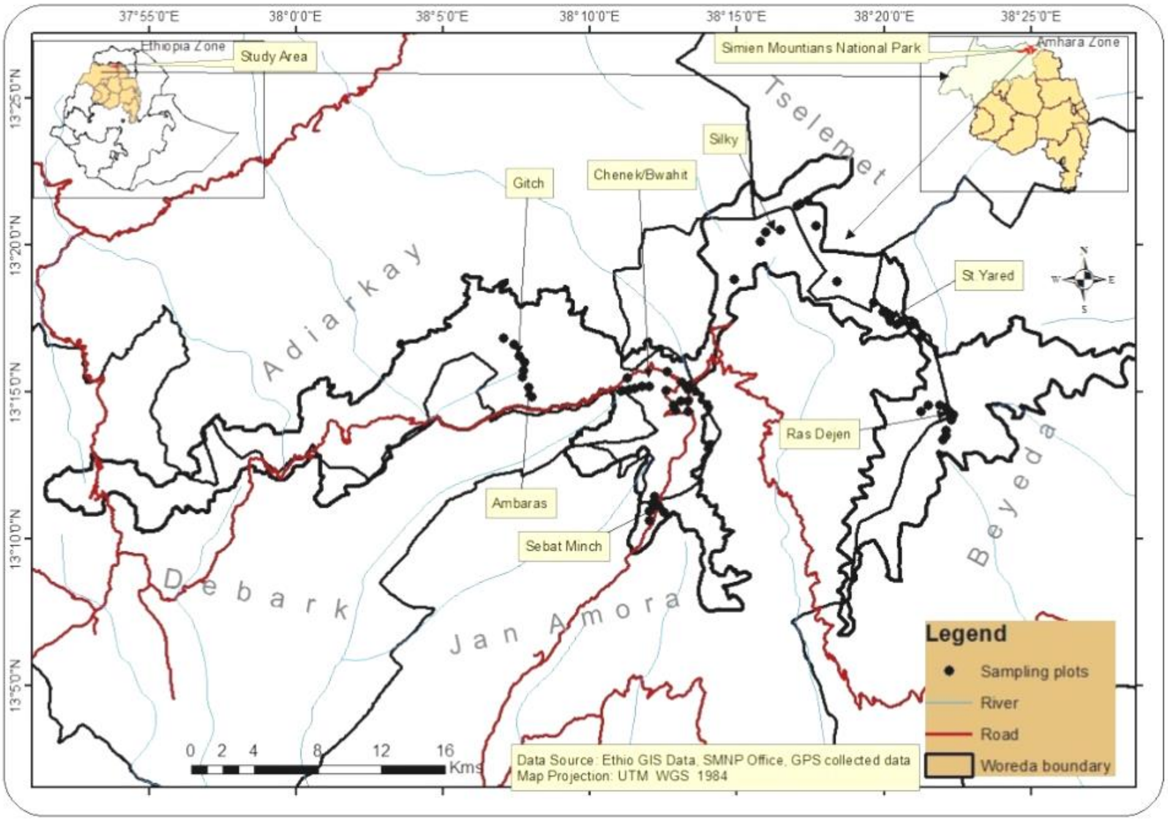


Figure 1: Study Area Map with Sampling Sites.

The present SMNP extends from 37°51'26.36"E to 38°29'27.59"E longitude and from 13°06'44.09 " N to 13°23'07.85" N latitude. The total area of the site is about 412 km^2. The current altitudinal variation was from 1900 m to 4543 m above sea level (Amhara National Regional State, 2006). High ranges of altitudinal variation temperature and soil variations are high in this area. The climate is characterized by a wet and dry season, with about 75% of annual rainfall (1350-1600 mm) between June and September. Temperatures are relatively constant throughout the year; however there is huge diurnal variation ranging from a minimum of -2°C to -4 °C at night to a maximum of 11°C to 18°C during the day (Amhara National Regional State, 2009).

Soil types of the Simien Mountains National Park vary greatly, humic andosols being the dominant in this area. The altitude range at 2500-3500 meter above sea level shallow andosols and lithosols are commonly found. Soil types that occur below 3000 meter above sea level are haplic phaeozems associated with cambisols and lithosols (Hurni, 1986). The park was extremely degraded during the Italian invasion and frequent attack from Eritrea (Puff and Nemomissa, 2005) latter, it became world site endangered in 1996 (Amhara National Regional State, 2009). The main reasons to be endangered were decline of wildlife population due to poaching and restricted habitats.

Vegetation Sampling and Specimen Identification

Vegetation was sampled systematically from seven stratified mountains during flowering time (mid Oct.-mid Nov, 2015) for ease of identification and to get herbs that disappear during dry season. Taking samples was started being at the top of each stratified mountains in eight directions (North, Northeast, East, Southeast, South, Southwest, West and Northwest) at every 200 m elevation. Vegetation and terrain variables (slope, aspect and elevation) data were collected using 400 m^2 (20m x 20m) study plots. All plant species encountered in each sample plot were recorded using vernacular names and using codes. To sample cover abundance of herbaceous species, five 1 m^2 (1 m x 1m) subplots were laid one at each corner and one at center of each main plot. Slope, aspect and elevation were measured using Silva Clinometer, Rectal compass and Garmin 60 GPS respectively. Aspect was coded as follows, N=0, NE=1, E=2, SE=3, S=4, SW=3.3, W=2.5, NW=1.3 and Ridge top=4.

A total of 30 plots were laid and percent cover of all species was estimated and latter converted to 1-9 modified Braun-Blanquet scale which is widely accepted scale because of better accuracy. Specimen identification was made at field level. Those plants which were not identified in the field were recorded by their vernacular names, collected, dried and pressed for latter identification using Honeybee Flora (Fichtl and Adi, 1994), Flora of Ethiopia and Eritrea (Hedberg and Edwards, 1989; Hedberg and Edwards, 1995; Edwards *et al*., 1997; Edwards *et al*., 2000; Hedberg *et al*., 2003; Tadesse, 2004; Hedberg *et al*., 2006) and Plants of Simen (Puff and Nemomissa, 2005). Some specimens were identified by comparing with the authentic specimens in the National Herbarium, Addis Ababa University.

Soil Sampling and analysis

Vegetation and soil data were collected from October-November, 2015 at every 200 m elevation. Soil samples were taken from five 1m X 1m sub plots distributed at each corners and center of 20m X 20m main plot at the depth of 0-30 cm; then homogenized together to have composite soil sample for the main plot. A total of 30 soil samples were collected each weighed about 1kg. With the required care, samples were dried, passed through 2 mm mesh and analyzed in Amhara Design and Supervision Work Enterprise (ADSWE) soil testing laboratory. The method of soil laboratory work was based on EARO (2000). Texture (Sand, Silt and Clay) of the soil was done by Bouycous Hydrometer method; Total Nitrogen (TN) was determined by Kjeldhal method; Cat ion Exchange Capacity (CEC) was determined on the basis of $NH_4CH_3CO_2$ (Ammonium acetate) method; P^H was determined by petentio method using PH meter at 1:2.5 soil: distilled water suspension; Available Phosphorus (Avail P) was determined by Olsen method, Available Potassium (Avail K) was determined on the basis of Sodium acetate method; Organic Matter (OM) was determined by Walkley and Black titration method and Soil (Electrical) Conductivity (EC) was determined by 1:5 soil: water suspension (EARO, 2000).

Data analysis

Plant community types were determined by hierarchical agglomerative cluster analysis using R statistical software version 3.1.3. For the analysis and characterization of the communities, percent cover abundance data of 30 plots and 86 species were used. Similarity ratio was used to determine the resemblance function and the Ward's method to minimize the total within group mean square (Van Tongeren 1995). The community types identified where further refined in a synoptic table and species occurrences are summarized as a synoptic-cover abundance values (Van der Maarel *et al.*, 1987). Dominant species of each community type were identified based on their synoptic values. Finally, the community types were named based on two dominant species.

Ordination Analysis

After testing the significance of environmental variables using function Adonis test, canonical correspondence analysis (CCA) was computed to determine relationship between environmental variables and patterns of plant communities. R free statistical software (version 3.1.3.) was used for both Adonis test and CCA. CCA was found to be more appropriate to find out the influence of environmental variables on the vegetation community formation and species distribution. This is because CCA has correlation and regression parts (Borcard *et al*., 2011; Kent, 2012). According to Legendre *et al.* (2005), test of significance is less powerful than test of canonical ordination.

RESULTS AND DISCUSSIONS

Afro- alpine plant community types

Three community types were generated from 30 plots and 86 plant species cluster analysis. Similarity ratio was used to summarize the result as a dendrogram (Figure 2). Communities were named after two dominant species with higher mean cover abundance (Table 1).

***Agrostis sclerophylla – Agrostis quinquesta* plant community type**

The lowest species rich found in this community type was about 39 species and second in number of plots (Table 2). This community type was moderate in relation to the other two found in the altitudinal range of 3990-4438 meter above sea level. This community type was distributed in moderate slopes and alpine meadows. Some of the dominant plant species in this community were *Trifolium cryptopodium, Helichrysum citrispinum, Alchemilla microbetula, Dianthoseris schimperi, Satureja simensis, Cerastium octandrum, Andropogon lima* and *Satureja abyssinicca*, *Anthericasp* and *Salvia merjamie* was rare in this community. This plant community type and community type 3 were separated by community type 2 in the middle. The formulation of Cluster ID helped to know the distribution of plots in each community type (Table 2).

Table 1. Synoptic cover abundance value, bold with dominants greater than the value of 1.

	Cluster 1	Cluster 2	Cluster 3
Agrostis sclerophylla	**6.40**	0.22	0.00
Agrostis quinquesta	**3.27**	**2.33**	**1.36**
Trifolium cryptopodium	**2.67**	**1.97**	**2.45**
Helichrysum citrispinum	**2.27**	**2.67**	**1.27**
Alchemilla microbetula	**1.53**	**3.36**	**1.82**
Dianthoseris schimperi	**1.13**	**2.19**	0.27
Satureja simensis	**1.13**	0.36	**2.91**
Cerastium octandrum	**1.00**	**1.42**	0.64
Andropogon lima	**1.00**	0.44	**2.64**
Satureja abyssinica	**1.00**	0.36	0.00
Sagina afroalpina	0.87	0.67	0.09
Festuca macrophylla	0.73	**5.97**	**5.64**
Helichrysum splendidum	0.67	0.33	0.55
Ranunculus oreophytes	0.60	0.17	0.00
Agrostis diffusa	0.47	0.53	0.45
Lobelia rhynchopetalum	0.40	**1.86**	**3.27**
Cotula abyssinica	0.40	0.31	0.18
Festuca abyssinica	0.33	0.33	0.00
Hypericum revolutum	0.33	0.00	**1.00**
Thymus schimperi	0.27	0.17	**2.36**
Trifolium acaule	0.20	**1.67**	**3.36**
Senecio nanus	0.20	0.56	0.00
Swertia lugardae	0.20	0.31	0.18
Alchemilla pedata	0.13	0.56	**1.73**
Crassula schimperi	0.13	0.00	0.00
Saxifraga sp.	0.13	0.00	0.00
Bartsia longiflora	0.07	0.42	0.09
Salvia merjamie	0.07	0.33	0.09
Swertia abyssinicca	0.07	0.33	0.09
Erica arborea	0.07	0.19	**6.45**

Table 2. Distribution of plots in the plant communities and average elevation.

Communities	Average elevation	Plots in each community	No of plots
1	4214	1-12,15-17	15
2	4138	13,14,18,19,24-45,47-53,55,56 and 62	36
3	3655.5	20-23,46,54,57-61	11

***Festuca macrophylla– Alchemilla microbetula* plant community type**

This community type contains the highest number of plots 36 (58.06%) and was found in the altitudinal range of 3724 – 4552 meter above sea level. The elevation difference was very high relatively from the others, which was about 828m and hence the number of species was very high in this community (57), has extra seven species from the next community type. The community overlapped with the first plant community type in elevation and hence shared some species with the first and a few with the third plant community types. This shows that the plant community change was continuum as described by Smith and Young (1987) in this work. The most representative plant species in this community type were *Helichrysum citrispinum* which was dominant shrub in the study area, and *Dianthoseris schimpri, Cerastium octandrum, Agrostis quinquesta, Trifolium cryptopodium, Lobelia rhynchopetalum* and *Trifolium accaule* which were herbs found in a considerable number that make this plant community type. *Polygala abyssinica* and *Erodium moschatum* were few of the rare species found in this community. This community type did not show clear transitional shift from type one since the elevation range was shared.

***Erica arborea–Festuca macrophylla* plant community type**

This type of plant community was found in the altitudinal range of 3508 – 3803 meter above sea level. The elevation range was narrowest of all the others and favored to Northwest directions. This plant community type was distributed in the lowest altitudinal pattern of the afro-alpine vegetation and comprised of the least number of plots (17.75%), (Table 2). This plant community type showed clear transition from plant community type two. The upper strata of this plant community types was covered by the tree species of *Erica arborea* and by few individuals of *Hypericum revolutum*. The most dominant plant species that composed in this community was *Trifolium accaule, Lobelia rhynchopetalum, Thymus schimperi, Alchemilla pedata, Andropogon lima, Satureja simensis, Alchemilla abyssinica, Hypericum revolutum, Agrostis quinquesta, Trifolium cryptopodium, Helichrysum citrispinum, Alchemilla microbetula* and *Thymus serulatus, Plantago lanceolatum* and *Hedbergia abyssinica* were some of uncommon species in this plant community.

Vegetation and Environmental Factors Relationship

Permutation test was used to obtain the p-value of the correlation coefficients. Permutation test of all environmental variables (Table 3) showed that there was a significant association of environmental variables to the afro-alpine vegetation community formation and species distribution ($F_{12, 17}$ =1.2254, and p=0.002). As a result, the test indicated that environmentally similar location was similar in species composition.

Table 3. Measure of association between environmental variables and vegetation.

	Df	Chi-Square	F	Pr (>F)
Model	12	2.2654	1.2254	0.002 **
Residual	17	2.6191		

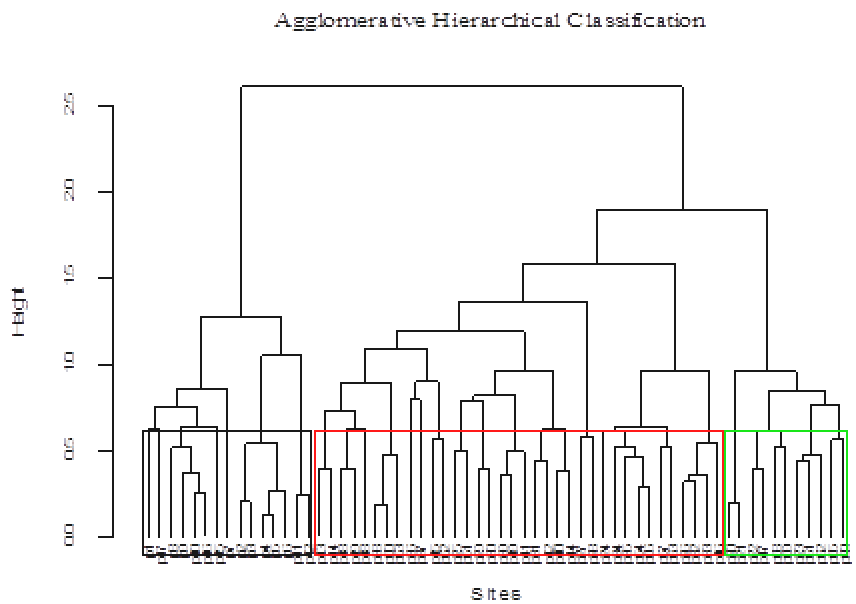


Figure 2. Dendrogram for afro-alpine plant community from Hierarchical Cluster analysis (each community was bordered in respective order of 1, 2 and 3 from left to right).

Analysis of variance from function Adonis test (Table 4) revealed the details of the most significant environmental variables. Five environmental variables, altitude, pH, sand, slope and total nitrogen, were significant among which altitude is the most significant.

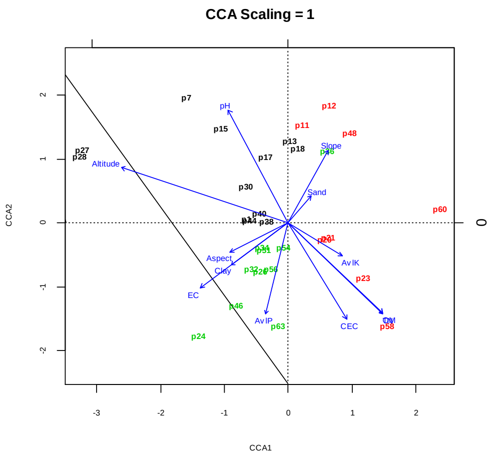
Table 4. Adonis Significance Test.

Variables	DF	Sums of Sqs	Mean Sqs	F. Model	R^2	Pr (>F)
Aspect	1	0.2632	0.26321	1.3718	0.03525	0.19
Slope	1	0.4412	0.44123	2.2997	0.05909	0.02 *
Altitude	1	0.8774	0.87741	4.5730	0.11750	0.01 **
pH	1	0.5657	0.56568	2.9483	0.07575	0.01 **
EC	1	0.2338	0.23379	1.2185	0.03131	0.31
Sand	1	0.4811	0.48107	2.5073	0.06442	0.01 **
Clay	1	0.1402	0.14019	0.7306	0.01877	0.67
CEC	1	0.1942	0.19418	1.0121	0.02600	0.46
OM	1	0.1290	0.12898	0.6722	0.01727	0.82
TN	1	0.4037	0.40371	2.1041	0. 05406	0.03 *
AvlP	1	0.1753	0.17527	0.9135	0.02347	0.58
AvlK	1	0.3009	0.30095	1.5685	0.04030	0.15.
Residuals	17	3.2618	0.19187		0.43680	
Total	29	7.4674			1.00000	

Significant codes: 0.001 '**' 0.01 '*' 0.05 '.'Where, DF=degree of freedom, Pr=probability, R^{2}= coefficient of determination.

Masresha (2014) found that nine variable was significant among 13 in the afromontane vegetation distribution of SMNP. Altitude was the most significant variable followed by CEC. These two studies indicated that altitude was most important factor that contributes for the vegetation community formation and species distribution in the afro- alpine and afromontane of SMNP. Following the tests of significant variables, ordination of sites with environmental variables (Fig. 3) was made using canonical correspondence analysis to show which variables have more effect on specific sites of the study area. Sites were expressed with species similarities in advance to prevent blurt of the figure due to cloud of species when plotted.

Different environmental variables showed variations in different sites of the study area. Though the influence of altitude was most significant everywhere (Table 4), the community formation and species distribution in Ras Dejen and Sebat Minch areas were more explained by this variable. On the other hand pH was important variable in Bwahit and Chenek area. Organic matter and total nitrogen were the most positively (when the value of one of the variables increase, so do the other) strongly correlated variables and equally the most important variables that explain the vegetation in Ambaras area and was negatively (when the value of one of the variables increase, the other decrease) correlated with pH and altitude. Slope was other explanatory variable and positively correlated with sand. Both of these variables were important in explaining the vegetation in St. Yared areas. Available potassium was the variable that had influence on the vegetation of Chenek areas next to pH. Cation exchange capacity (CEC) was negatively correlated with pH and explained the vegetation of Chenek areas. Electrical conductivity (EC) and clay was much correlated with EC being more important to explain the vegetation in silky and Gitch areas. In addition, available phosphorus and aspect had effect on the vegetation composition of these areas.



P=plot

Figure 3. Ordination of environmental variables to vegetation sites.

The highest correlations in the first and second axes are the more important in explaining the variation in species distribution in relation to the specified environmental variable. In this case, from the output, the more explanatory variable are altitude with the negatively highest correlation with the first axis (-0.85) and pH positively correlated with the second axis (0.58). The Eigen values were high in the first and second axes always with decreasing values showed that the first two axes explained 31.4% of the variation in the species distribution mainly with those variables (Table 5). Eigenvalues are measures of the importance (variance) of the axes. They can be expressed as proportions explained, or proportions of variation accounted for (Borcard *et al.*, 2011).

Table 5. Bi-plot scores for constraining variables in the whole community (7 CCA axes excluded).

Factor	CCA1	CCA2	CCA3	CCA4	CCA5
Aspect	-0.30	-0.15	-0.329	0.4097	-0.060
Slope	0.20	0.37	0.257	0.3357	0.323
Altitude	-0.85	0.28	0.222	0.0042	-0.122
pH	-0.31	0.58	-0.114	-0.0746	-0.493
EC	-0.45	-0.33	-0.111	-0.3797	0.356
Sand	0.12	0.14	-0.360	-0.7389	0.327
Clay	-0.29	-0.21	0.480	0.4417	-0.199
CEC	0.30	-0.49	-0.023	0.0202	0.247
OM	0.48	-0.46	0.203	-0.2318	0.523
TN	0.48	-0.46	0.205	-0.2299	0.521
AvlP	-0.12	-0.47	0.063	-0.2400	0.049
AvlK	0.27	-0.17	-0.245	-0.4822	-0.165
Eigenvalue	0.3953	0.3162	0.2830	0.2515	0.19882
Proportion Explained	0.1745	0.1396	0.1249	0.1110	0.08777
Cumulative Proportion	0.1745	0.3141	0.4390	0.5500	0.63779

Avl = available, CCA1 = canonical correspondence analysis axis one

According to Woldu (2012) and Kent (2012), the length of the variables indicates the importance of that variable with respect to the other variables in influencing the vegetation community formation and species distribution. The direction of the arrow shows the correlation among environmental variables and the influence on indicated sites of the vegetation. Elevation and pH were found to be positively correlated which was uncommon. This might be due to lesser disturbances in the higher elevation. The soil in which the samples were taken was not affected by erosion because of low disturbance and strong prevention of soil eradication by *Festuca* and other grass species as well as rock and hence not strongly acidic. But in relatively lower altitudes there was slight decrement in pH due to some sort of disturbance at least there was livestock trampling that exposed the soil for erosion as well there was farming practice some years ago because of closeness to villages. This was in line with Puff and Nemomissa (2005) that the disturbance was high nearby the villages and the severity went up in the dry season due to shortage of foraging.

Altitude was found to be very important in many studies in influencing the plant community formation and species distribution (Jin *et al.,* 2008; Khalik *et al*., 2013; Achiso, 2014; Masresha, 2014). Achiso (2014) found that altitude and pH were equally important, though negatively correlated, in community formation and species distribution. In the works of Jin *et al*. (2008) altitude was the main variable that determines the vertical distribution of vegetation whereas the horizontal distribution was affected by aspect in the Qilian Mountain, China. In the works of Woldemichael *et al.* (2010) altitude and slope were the main important factors among environmental variables that affect the plant community and species distribution in Hugumbirda-Gratkhassu National forest priority area, South Tigray, Ethiopia.

CONCLUSION

Altitude was the main factor not only to influence the patterns of community formation and vegetation distribution in the afro-alpine areas of the SMNP but also affect the correlation and regression among other environmental variables. As elevation changed the relationship of other environmental variables varied. Vegetation was affected by many environmental variables. Among the environmental variables texture (silt) was the least important that matter for vegetation and community formation in the afro-alpine of SMNP. The concept that accepted as a general truth could not work on the correlation between altitude and acidity, when altitude increases acidity also increases. In the case of SMNP the higher in altitude were not the more in acidity because of undisturbed areas in the higher elevation. So, the reality for aggravation of acidity could be disturbance than solely by elevation. Grasses especially *Festuca* species are the best plants that conserve soil erosion. They grow very close to each other as well lots of fibrous root protect the upper part of the soil from runoff. Soil conservation by woody species could work well in the gorgeous and lowlands especially where high water volume is frequent near by the rivers. This calls park managers to consider *Festuca* spp. for soil conservation in the park. Further, study on climate change through ecological modeling is a demanding task to examine the effect of climate change on the plant community formation and species distribution of the park.

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