Soil and Topographic Impacts on Vegetation Dynamics in Remnant Forest Patches of Este District, South Gondar Zone, Ethiopia

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Abstract

Plants interact with soil, geophysical, and disturbances within their habitats. This research aims to investigate the impact of soil, geophysical, and disturbances on plant species diversity attributes (diversity, richness, and evenness) in five forest patches of Este District, South Gondar Zone, northwestern Ethiopia. Vegetation and environmental data were collected from 71 square sampling plots (400 m^2 area), laid at parallel transects in the forest patches. We collected data on plant species attributes, soil (acidity (pH), cation exchange (EC), exchangeable sodium percentage (ESP), organic matter, organic carbon, available potassium, available phosphorus, total nitrogen, bulk density), geographic (altitude, slope, and aspect), and disturbance level of the habitats. The correlation in plant species diversity attributes and environmental parameters was performed using various functions in R statistical programming. The correlation analysis indicated that the plant diversity attributes were associated with EC and ESP negatively and pH positively; with altitude and disturbance (both negatively and positively depending on the range of the gradients). It is concluded that plant attributes interact with environmental conditions in a range of strengths of interactions. This study was based on small samples in a single district. Therefore, it would be helpful if future researchers could cover larger geographical areas with different land-use types and collect larger soil samples for evaluation of the impacts of most primary and secondary soil nutrients on the plant attributes. This would allow a more comprehensive analysis that would be beneficial for forest management and conservation strategies in a study region.

Introduction

Plants as living things resulted from the interaction of their habitats' soil-geophysical and genetic characteristics (Hinsinger 2013). Soil supports and provides nutrients as well as water for plants (Onwuka and Mang 2018). Researchers compared the roles of soil characteristics to climate and found that soil has a more significant effect on plants than climate (Maire et al. 2015). Vegetation restoration needs soil with properties appropriate to the species (Wang et al. 2016). Soil characteristics limit plants' distribution across the different types of ecosystems (Fujii et al. 2018). Interaction between humans and plants also affects plant survival and diversity (Schaal 2018). Humans conserve, protect or damage plants for varied purposes, such as agriculture, energy, and urbanization (Nyhus 2016).

Soil characteristics, such as soil acidity (pH), electrical conductivity (EC), soil texture (ST) (sand, silt, and clay), total nitrogen (TN), available phosphorus (Av. P), available potassium (Av. K), cation exchange capacity (CEC), organic carbon (OC) and bulk density (BD) are among the main soil characteristics in determining the habitat preferences of plants (Hinsinger 2013). An ecosystem's health could be measured using these soil parameters by comparing the analysis results with standard values for similar geophysical sites (Kelly et al. 2009; Russell 2013).

The impact of pH on plant species richness varies from region to region depending on the level of precipitation (Palpurina et al. 2017). However, other sources indicate a negative and positive influence of pH to plant species richness (Zarfos et al. 2019) and (Gough et al. 2000), respectively. Species diversity decreases as pH increases (Zarfos et al. 2019) while diversity increases as pH goes from zero to seven (Gough et al. 2000). Similarly, the findings of the impact of electrical conductivity (EC), soil texture (ST) (sand, silt, and clay), total nitrogen (TN), available phosphorus (Av. P), available potassium (Av. K), cation exchange capacity (CEC), organic carbon (OC) and bulk density (BD) on the plant diversity also varies from region to region. These soil characteristics, such as OC, OM, N, Av. P (Long et al. 2018), EC, and ST (Zuo et al. 2014) could enhance plant species attributes.

Similarly, topographic variables, such as elevation, slope, and aspect also affect plant species' distribution (Zeng et al. 2017). The impact of elevation on the plant species diversity, richness, and evenness is not clear-cut (Lovett 1999). Some authors explain that as elevation increases, such plant attributes increase too (Zhanga and Dongb 2010). However, others have found just the opposite in that an increase in elevation leads to a decrease in plant diversity (Kflay et al. 2019). The third group of authors states there is a positive association between the elevation and plant distribution until a certain extent of altitude and then a negative association as the elevation continues to rise (Bertuzzo et al. 2016). The impact of slope and aspect on the plant distribution is also not clearly understood (Bertuzzo et al. 2016; Singh 2018).

Disturbances, such as grazing, fire, agricultural expansion, etc., also impact plant species composition and diversity (Shrestha et al. 2013; Willig and Presley 2018). Disturbances may have a positive influence on the vegetation attributes to a certain extent of disturbances (Shrestha et al. 2013). However, disturbances most often influence vegetation negatively (Willig and Presley 2018). While the relationship between vegetation attributes and disturbance is often negative (Wise 2017), in sometimes and locations, an intermediate level of intermediate disturbance can increase plant diversity (Shrestha et al. 2013).

Understanding how the current soil and geophysical characteristics of an ecosystem are essential in predicting the plants' general conditions is a question for both conservation and future research (Yang et al. 2020). Learning more about how these characteristics affect plants is essential in deciding vascular plants' management strategies (Rodrigues et al. 2018). Evaluating the level of disturbance that plants can tolerate will also help define management options (Shrestha et al. 2013).

This study aims to better understand how the association between soil, geographic characteristics, and disturbance from animal grazing or human interference affects plant species richness, biodiversity, and distribution. The study was carried out in five selected forest patches in the forest patches of Este District, South Gondar Zone, Northwestern Ethiopia.

Materials And Methods

Study area

This study was conducted in forest patches of Este District, South Gondar Zone, Amhara Regional State, Ethiopia. The district is covered areas in 37˚49'28" to 38˚15'55" East, and 11˚09'05" to 11˚43'57" North, about 250 km northeast of Bahir Dar and 650 km northwest of Addis Ababa, the regional and Ethiopia's capital cities, respectively. The district covers approximately 1365 km^2 area. The elevation varies from 1200 to 4160 m. a. s. l. It is bordered to the north, south, east, and west by Farta, Hulet Ejju Enese (East Gojjam Zone), Lay Gaint, and Anda Bet districts, respectively (Fig. 1).

Figure 1. Elevational ranges of Este district

The district is classified into 45 small administrative units called ‘kebele’, of which 3 are urban and 42 are rural according to the current regime. About 211000 people, of whom 108000 and 103000 are male and female, live in the district. The majority of the people (93%) live in rural areas practicing agriculture as a source of income (Central Statistical Agency 2015). The district produces extra staple food items such as “teff”, wheat, barley, maize, potato, etc. (Meron et al. 2014). The annual means and ranges of rainfall are 107 mm and 71 to 140 mm. Similarly, the annual means and ranges of temperature are 17°C and 5 to 29°C. The rain is unimodal in its pattern. The maximum rainfall is from June to September while the least rainfall is from January to March (Fig. 2).

Figure 2. Climate diagram of Mekane Eyesus town (political center of Este District)

Sampling design and data collection

The vegetation data were collected from 71 20 x 20 m plots, which were placed systematically on parallel transects in five sample forests. Vegetation abundance, species richness, natural regeneration status, and growth habits were collected as vegetation data. Similarly, environmental data (soil, elevation, latitude, longitude, and disturbance level) were collected from the same plots. Five replicate soil samples were collected from each of the 71 plots. The five proximate plots were mixed to make composite soil samples. The soil samples were grouped into two based on their ecosystem types (Afroalpine and sub-afro-alpine (AASAA) and Dry evergreen forest (DAF)). After grouping, 17 soil samples (five from AASAA and twelve from DAF) were chemically analyzed for their pH, EC, ST (sand, silt, and clay), TN, Av. P, Av. K, CEC, OC, and BD. The pH, ST, TN, Av, K, Av. P, and CEC were determined following potentiometric, hydrometric, Kjeldahl, Olsen, factor, and ammonium acetate methods, respectively (Sahlemedhin and Taye 2000). Similarly, OC and BD were determined as proposed by Rashidi and Seilsepour (2009) and Saini (1966), respectively. The organic matter (OM), sodium adsorption ratio (SAR), and exchangeable sodium percentage (ESP) were estimated using the following formulae below (Khatoon et al. 2017), (Al-Busaidi and Cookson 2003) and (Elbashier et al. 2016), respectively.

$$OM(\%) = organiccarbon(\%)x1.72(1)$$

$$SAR = 0.464EC + 7.077(3)$$

$$\mathrm{ESP} = 0.84 \times \mathrm{SAR} + 2.17(4)$$

GPS data were collected using a Garmen-60, while disturbance was visually approximated for the plots. The sampling plot's slope and aspect were recorded following methods in England (1971) and Méndez-Toribio et al. (2016), respectively. The aspect was measured in the way of Méndez-Toribio et al. (2016) did with little modifications as 1 (N), 1.5 (NW), 2 (W), 2.5 (SW), 3 (S), 3.5 (SE), 4 (E) and 4.5 (NE) (England 1971; Thomas et al. 2012). The disturbance level of the sites was estimated visually and grouped the levels into six disturbance levels. These were no disturbance (0), slightly disturbed (1), low disturbance (2), moderately disturbed (3), highly disturbed (4), and strong disturbance (5).

Statistical analysis

The soil and geographical characteristics such as elevation and soil characteristics were correlated with species richness, diversity indices, and evenness to understand the interaction between vegetation and environmental attributes. The association between vegetation attributes and environmental variables and between sampling plots and environmental constraints was tested with RDA and CCA's ordination techniques using library vegan (Oksanen et al. 2007), respectively. The community types and characteristic association with mean, range, minimum and maximum values of environmental variables were aligned against the community types of the study area. The trend of species richness against EC, SAR, ESP, altitude, disturbance, and Shannon diversity was tested to estimate the association between species richness and environmental parameters.

Results

Impact of environment on vegetation species distribution and diversity

According to the backward and forward selection of environmental variables for constrained analysis using RDA, the variations in vegetation were associated significantly with 14 environmental conditions (longitude, altitude, latitude, CEC, EC, SAR, ESP, pH, Av. P, sand, silt, clay, Av. K and aspect) significantly. However, few environmental parameters impacted vegetation fairly (e.g., disturbance with p-value = 0.08) and there was no pronounced impact was shown by some others (OM, TN, OC, BD, and slope with p-values > 0.25) on vegetation parameters, respectively (Table 1).

Table 1
Backward and forward analysis of geophysical, disturbance (grazing) and soil variation impacts on vegetation attributes

Environmental variables	AIC	F	Pr (> F)	Significancy
Altitude	50.200	3.970	0.005	**
Longitude	50.270	4.710	0.005	**
CEC	49.990	1.960	0.005	**
pH	450.010	1.820	0.005	**
Av. P	449.970	2.080	0.005	**
Latitude	496.740	3.470	0.005	**
Sand	498.310	1.880	0.010	**
Silt	498.380	1.804	0.015	*
Clay	498.340	1.847	0.030	*
ESP	450.020	1.730	0.040	*
SAR	450.020	1.730	0.040	*
EC	450.020	1.730	0.040	*
Aspect	498.790	1.400	0.050	*
Av. K	498.720	1.470	0.050	*
Disturbance	450.050	1.410	0.080	.
TN	450.080	1.130	0.250	-
Note: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 are significant at 0, 0.001, 0.01, 0.05 and 0.1, respectively.				

The correlation analysis indicated that the plant diversity of the study area was impacted by soil texture (sand and silt), TN, OM, OC, BD, slope, altitude, and disturbance strongly ($r^2 > 0.56$). Plant diversity was also impacted by richness and evenness significantly (p-values < 0.05, $r^2 = 0.94$). Similarly, plant species equitability (evenness) was affected by Av. K, Av. P, and species richness positively and significantly ($r^2 = 0.44$, p-value < 0.05). The number of species (richness) was impacted by plant diversity, evenness, silt, and sand significantly and positively (p-value < 0.05, $r^2 = 0.44$) (Table 2).

Table 2
The correlation between plant biodiversity and environmental variable

	Sand	Silt	TN	OM	OC	BD	Slope	Aspect	Graz.	Alti.	H	R	E
Sand													
Silt	0.00												
TN	0.01	0.06											
OM	0.01	0.06	-										
OC	0.01	0.06	0.00	-									
BD	0.01	0.06	0.00	0.00	0.00								
Slope	0.04	0.12	0.85	0.85	0.85	0.85							
Aspect	0.59	0.42	0.89	0.89	0.89	0.89	0.94						
Graz.	0.01	0.04	0.04	0.04	0.04	0.04	0.86	0.97					
Alti.	0.00	0.00	0.82	0.82	0.82	0.82	0.52	0.90	0.06				
H	0.68	0.62	0.10	0.10	0.10	0.10	0.34	0.53	0.65	0.01			
R	0.39	0.72	0.14	0.14	0.14	0.00	0.48	0.27	0.39	0.04	0.0		
E	0.65	0.67	0.96	0.96	0.96	0.96	0.70	0.46	0.51	0.41	0.0	0.11	

Note: Graz = grazing, Alti = altitude, H = Shannon diversity, R = richness, and E = evenness

As shown in the following figure (Fig. 3), the impact of altitude, latitude, and texture (clay, silt, and sand), CEC, and SAR were strong on distributing plant species. Similarly, the impact of Av. K, pH, slope, grazing, and TN were reasonably strong. The first and second CCA axis explained 68 and 57% of the variation, respectively. The longest arrows were observed in altitude, longitude, latitude, sand ESP, CEC, clay, and silt while the smallest in Av. K, pH, slope, TN, aspect, and grazing values. Specifically, the level of disturbance (grazing) was higher for plots 37 to 50, which are taken with few samples from Ambo-Fiel-Maderia and majority from Bir-Adeg forest patches. Relatively, altitude also played a strong role in the pots from the Ambo-Fiel-Maderia forest patch (Fig. 3).

Furthermore, RDA ordination analysis indicated that silt, Av. P, altitude, Shannon diversity (H), and the number of species (richness) are correlated more with RDA axis 1. RDA axis 2 was also correlated with altitude, Shannon diversity (H), and the number of species (richness). Axis 3 was highly correlated with EC and sand. Three parameters (pH, aspect, and grating), four parameters (Av. K, CEC, Slope, and SAR), and one parameter (TN) were correlated with RDA axes 4, 5, and 6, respectively. Hence, this result suggested that soil texture (silt), Av. P, altitude, are the most determinant factors followed by pH, aspect, and grating associated with the dynamics of vegetations in the study area. The variation in Av. K, CEC, slope, SAR, and TN also played in the distribution of plant species in the Este District (Table 3).

Table 3
The correlation of environmental variables with RDA execs in the study area

	RDA1	RDA2	RDA3	RDA4	RDA5	RDA6
PH	-0.192	0.030	0.156	-0.553	-0.027	0.064
EC	0.148	0.085	0.556	0.161	-0.477	0.013
Sand	-0.310	0.254	0.370	0.055	-0.211	-0.060
Silt	0.461	-0.115	-0.323	0.007	0.332	-0.006
TN	0.044	0.137	0.233	-0.041	0.060	0.340
Av. P	-0.451	-0.308	-0.009	-0.272	-0.443	-0.037
Av. K	-0.201	-0.037	0.059	-0.358	-0.368	-0.065
CEC	0.340	0.172	0.415	-0.064	-0.623	0.069
Slope	-0.028	-0.132	0.199	0.098	0.252	-0.044
Aspect	-0.027	0.119	-0.234	0.534	-0.107	-0.405
Grazing	0.207	0.007	-0.042	-0.411	0.151	-0.226
Altitude	-0.820	0.498	0.013	-0.004	0.089	-0.013
SAR	0.252	0.336	0.262	0.144	-0.460	0.375
H	-0.665	-0.349	0.033	-0.206	0.194	0.072
Richness	-0.645	-0.448	0.189	-0.212	0.202	0.063

The correlation coefficients of Av. P, altitude, richness, and diversity with RDA 1 indicated that the sites and associated plants are negatively impacted by these parameters. Although altitude was correlated with axis 1 negatively, it was positively correlated with axis 2, impaling altitude impacted some sites and associated species negatively and other sites and associated plants positively in the study area (Table 3).

Four vegetation community types were identified in the study area. The impact of the slope, CEC and Av. K. and sand, TN, and OM on the community types varied as shown in the following figure (Fig. 4). Even though there were outliers, the impact of slope on community 3 and community 4 is minimal. However, its influence on community 1 and community 2 was strong. The impact of CEC and sand was near the same trend. They both highly impacted community 1 and community 2 while they showed less impact on community 2 and community 3. Av. K showed relatively high variation in the three vegetation community types (community 1 to community 3) while little variation in community 4. The variation in organic matter was high in community 1 while low in the three communities (2 to 4) (Fig. 4).

The range for plant species richness was from four to more than 40 species per plot, respectively. Similarly, the EC values ranged from nearly 0.1 to 0.5 dS/m). Even though, the impact of electrical conductivity (EC) on plant diversity is weak ($r^2 = 0.25$), the association between EC and species richness was negative as shown in the figure (Fig. 5). Similarly, the relationship between richness and SAR is inverse. However, the association between elevation and species richness was strong and of two types. The first association was positive while the second was a negative relationship. The association between richness and α-diversity was positive and exponential function (Fig. 5).

Among the many soils, geophysical, and disturbance variables, CEC, pH, disturbance, and altitude were the major determinants of plant species' local diversity. A parameter CEC ranged from 25 to 55 Cmol(+)/Kg and had a negative relationship with plant diversity. Similarly, pH ranged from around 6 to 7. It had a positive influence on diversity. There were three degrees of disturbance in the study field. These were areas that had been slightly disturbed (1), lightly disturbed (2), and moderately disturbed (3). In lightly disturbed areas, plant species diversity was low. However, both slightly and moderately disturbed areas have high levels of plant diversity. There were three forms of altitude effects on plant diversity: low at both low and high elevational scales, but high at the middle level of elevation (Fig. 6).

Discussion

As this study suggested, the plant species diversity (H = Shannon diversity index) was strongly and positively impacted by four environmental variables (sand, silt, aspect, and grazing) while plant species richness (R = richness) by two ecological variables (silt and slope). The equitability of the species (E = evenness) was impacted by several environmental variables (Sand, Silt, TN, OM, OC, BD, Slope, and grazing). A study in line with our research was recorded by Dölarslan et al. (2017), in the semiarid grassland of Turkey, which showed a positive correlation between H and clay and silt. The similarity may be due to the similarity in several environmental parameters, such as climatic, geophysical, and soil properties of different research sites (Duniway et al. 2010).

Our study showed disturbance, such as grazing, promotes species diversity in the study area, first decreasing species richness and then beginning to increase the species richness as the level of disturbance increases. Other researchers have stated the importance of disturbance to increase diversity from low to intermediate levels of disturbance according to the intermediate disturbance hypothesis (Willig and Presley 2018). But, increasing disturbance further could reduce plant species diversity and could not be applied to higher plant species (Bongers et al. 2009). This contrasts with findings by Härdtle et al. (2006), which stated that disturbance, such as grazing, decreases species diversity. In contrast to all the above-listed findings, others state there was no impact of grazing on species richness (Cao et al. 2016). The possible reason why diversity decreased in the lower level of disturbance and increase at the intermediate disturbance could be indigenous plants alone could be affected initially but at the intermediate disturbance level, invasive species could appear and increase diversity. However, the disturbance severity could affect both indigenous and invading plant species at higher levels of disturbance. As a result, the study sites' overall diversity decreases (Chawla et al. 2008). The difference in the different research results could be also the difference in assigning disturbance levels of study sites by different authors via observation (Bongers et al. 2009; Cao et al. 2016).

A negative correlation between EC and plant species richness was observed in our study. The relationship between these parameters had a negative exponential trend. Similar findings were presented from a study in

Tibet Plateau, China (Tang et al. 2015). The impact of EC on plant diversity was less important in other studies (Tilk et al. 2017). The difference or similarity in findings of the different researches could be due to the unique or common characteristics defining different ecosystems (Elmqvist et al. 2010).

The possible explanations for why the forest patches with a sandy loam type of soil may be suffered less from erosion may be due to the plant relatively good plant cover in the study area. The association between soil erosion and plant cover was well explained as efficient and negative interaction (Zuazo et al. 2006).

There is conflicting data on the impact of elevation to plant species richness. In this study, plant species richness increased as elevation increased to a height of 2700 m a. s. l. with the richness averaging 26 species/plot. Then, as elevation continued to increase to 4200 m a. s. l., plant species richness decreased averaging 5 species/plot. The association between altitude and plant species richness was studied by several studies in Ethiopia (Mesfin and Tamru 2020; Zerihun et al. 2018). However, similar findings to this study's results were not obtained in the other studies from Ethiopia. Here, we saw similar findings to those seen in other studies worldwide with richness increasing to a certain altitude above which richness decreases (Chawla et al. 2008; Grytnes and Vetaas 2002). Studies showing a one-directional association, that is a negative association between richness and elevation are available (Kflay et al. 2019; Zerihun et al. 2018). An inverse relationship between elevation and plant species richness was found in Bale Mountains National Park (Zerihun et al. 2018) and Abune Yosef (Kflay et al. 2019). However, contrasting findings have been reported from the Yancun watershed, China, which showed the richness always increases as elevation increases (Zhanga and Dongb 2010). A possible reason for the variation may be due to the absence of data from all possible ranges of elevations: lower (lower than ~ 1600 m a. s. l.), medium (between ~ 1600 and 3000 m a. s. l.), and higher (3800 m a. s. l. and above) elevations (Gilbert and Pulsipher 2006).

Conclusion

The objective of this research was to investigate the interactions between plant attributes (species richness and small-scale plant diversity) and soil, geophysical and human disturbances in dry tropical forest patches of Este district, South Gondar, northwestern Ethiopia. The findings indicated that plants interact with most of the environmental characteristics in the range of 41% (altitude) to 97% (disturbance). Plant attributes have strong negative interactions with EC, SAR, and CEC. However, they have a strong positive interaction with pH and plant diversity. However, other factors, including altitude and disturbance, showed both negative and positive interactions with plant attributes depending on their values. As altitude increases species diversity and richness increase parallelly, but start above their maximum level. The impact of disturbance on the plant species attributes is somewhat in contrast to the influence of altitude. At a minimum disturbance intensity, the species attributes decline but as disturbance increases the plant species richness and diversity also increase. This research ignites the importance of identifying the major and minor factors associated with plant species. This research also encourages further study covering larger geographical areas, such as zonal, regional or national levels with larger sample sizes to synthesize the orderly rank of factors for plant species in the conservation and management of ecosystems. As this research confirmed, plants species diversity and richness vary along with the range of geographical (elevational) gradients. Hence, concerned bodies such as the local community, community leaders, and government and non-government organizations have to be aware of the importance of the conservation of forest patches with different geophysical properties that need to be conserved rather than giving high emphasis to single or few forest patches.

Declarations

Author contribution D. G. was responsible for conceptualization, methodology, data collection, sample analysis, data analysis, validation, data curation, writing – the initial draft, and correcting a revision. Z. W., S. N., and E. A. participated in conceptualization, student supervision, project leadership, and project management.

Ethical issues Authors declared that no animal research, plant reproducibility, or clinical trials registration was needed for this research. All participants have been included and acknowledged and the parties agreed to the publication.

Conflict of Interest All possible conflict of research interest has been addressed by the researchers, and any contribution from a third party has been mentioned in the Acknowledgement.

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Figures

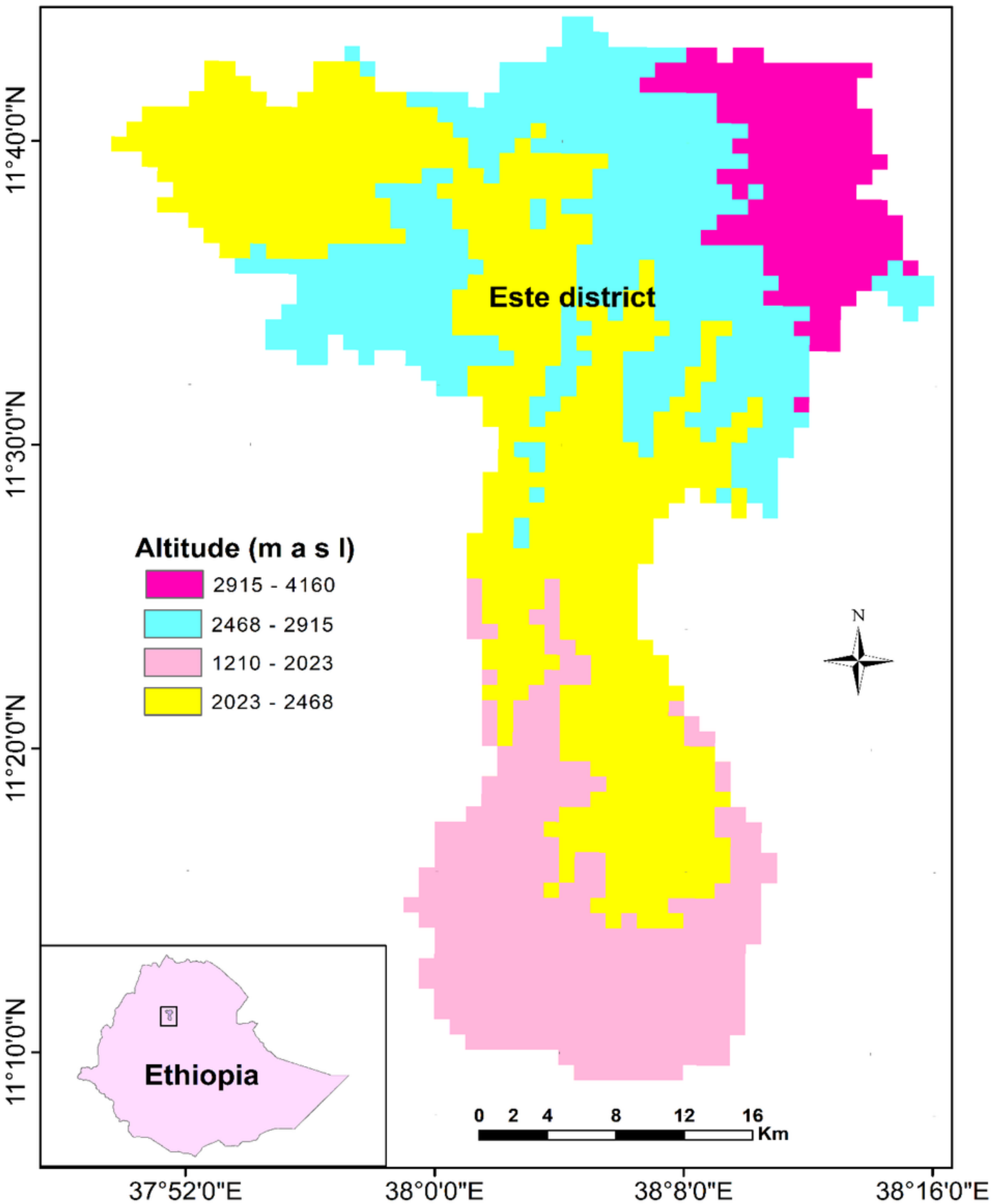

Figure 1

Elevational ranges of Este district

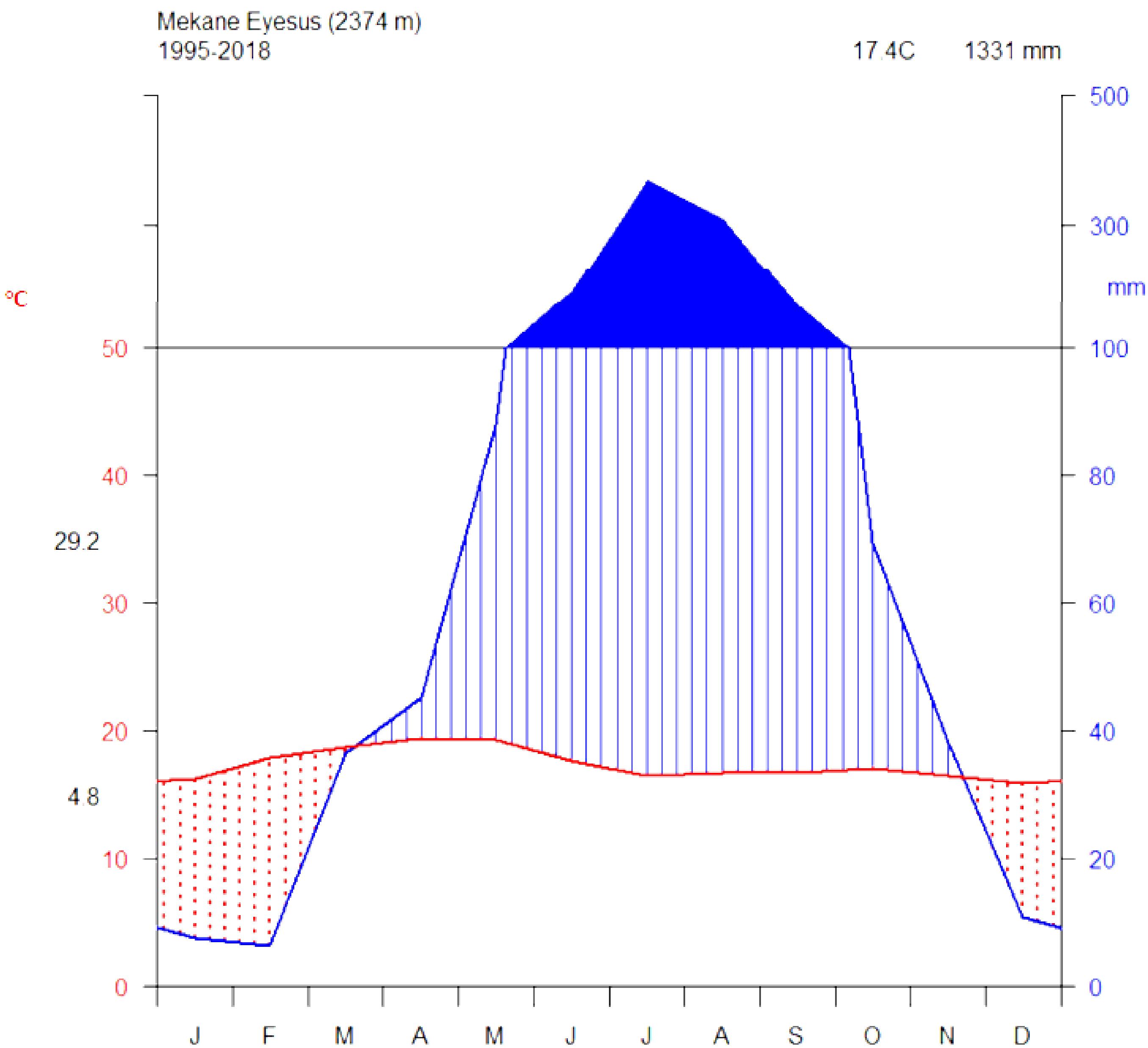

Figure 2

Climate diagram of Mekane Eyesus town (political center of Este District)

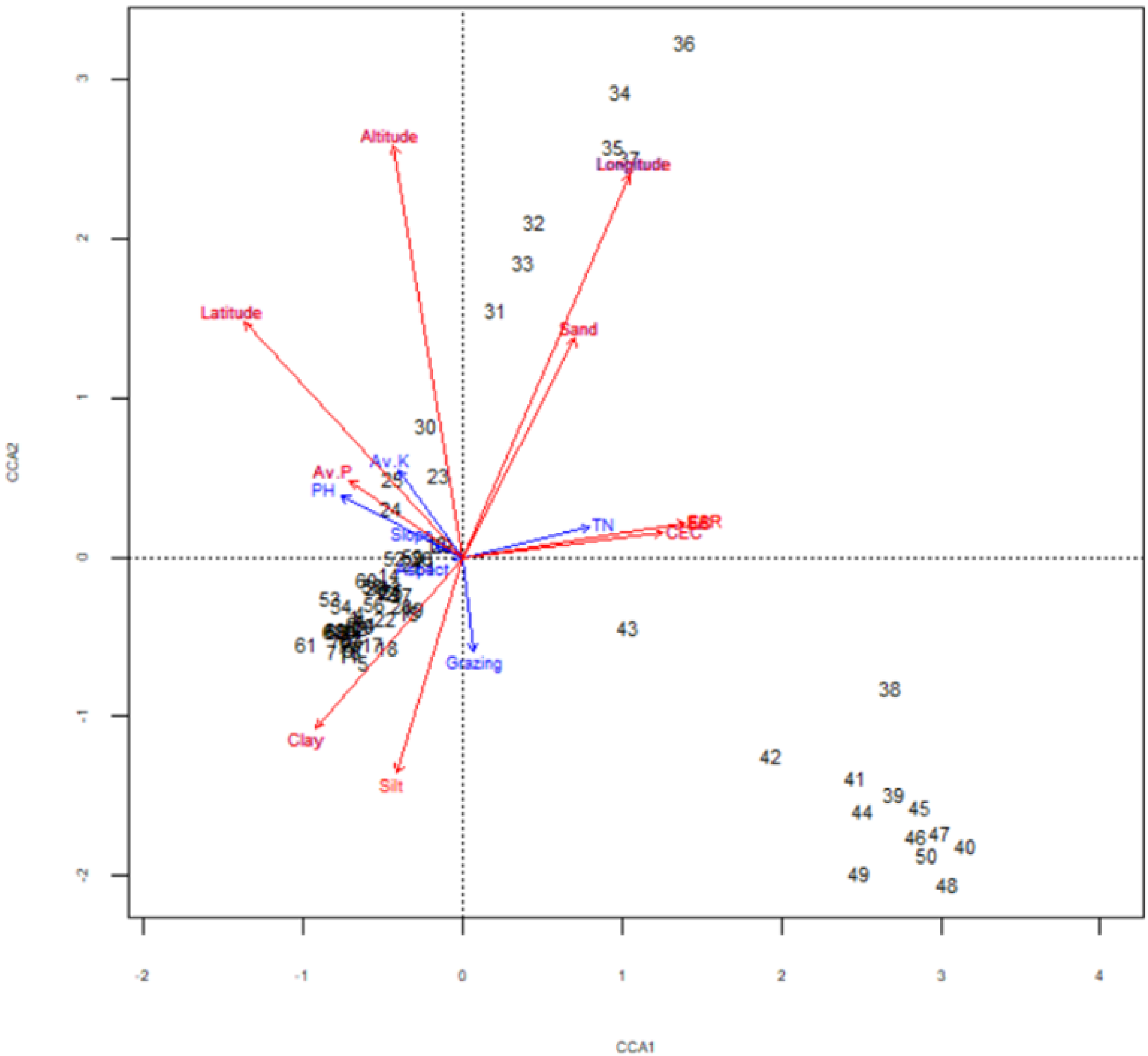

Figure 3

CCA showing the relationships between environmental conditions and sampling plots

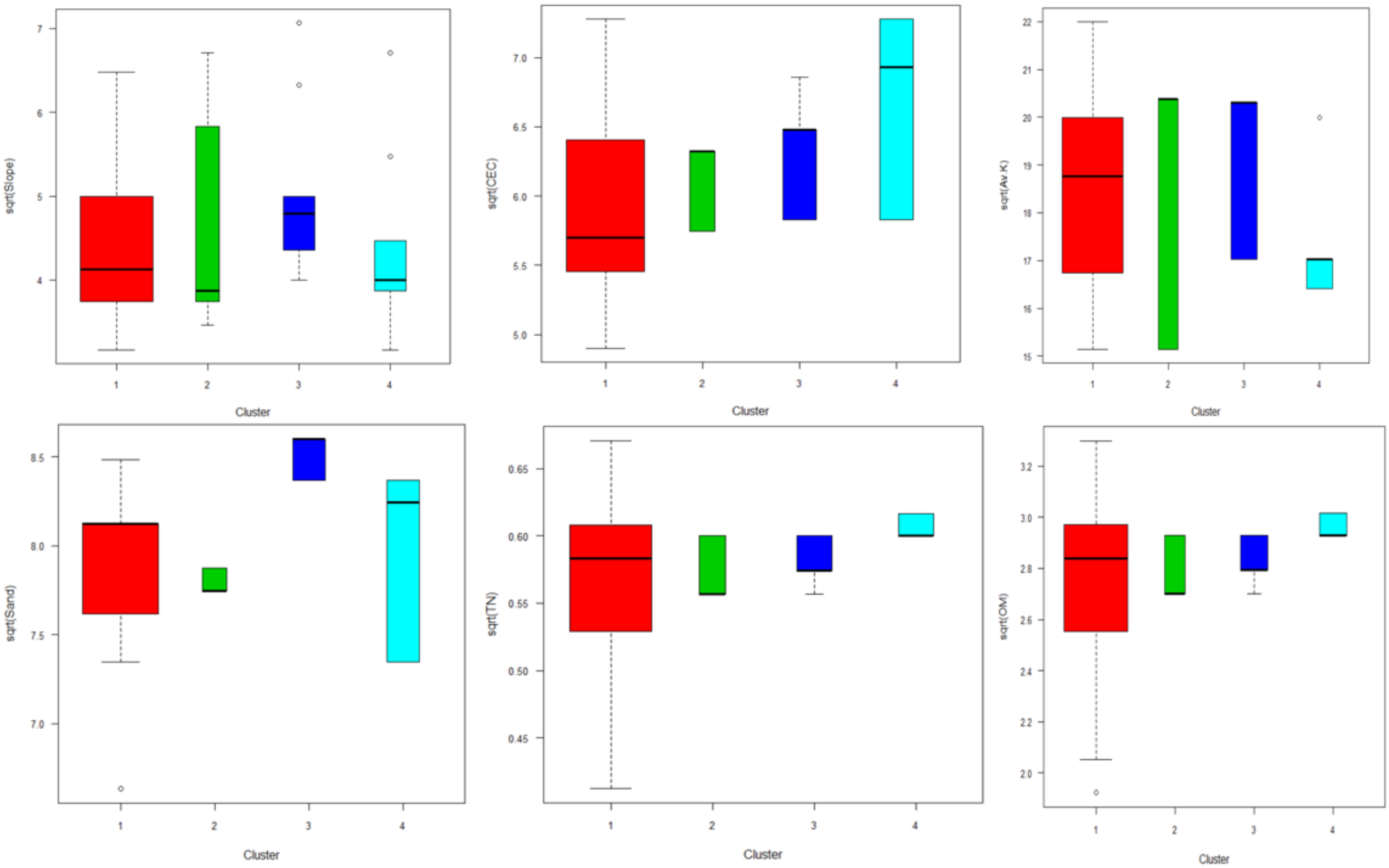

Figure 4

The impact of the slope, CEC and Av. K. (left, center and right (top), respectively) and sand, TN and OM (left, center, and right (bottom), respectively) on the vegetation communities

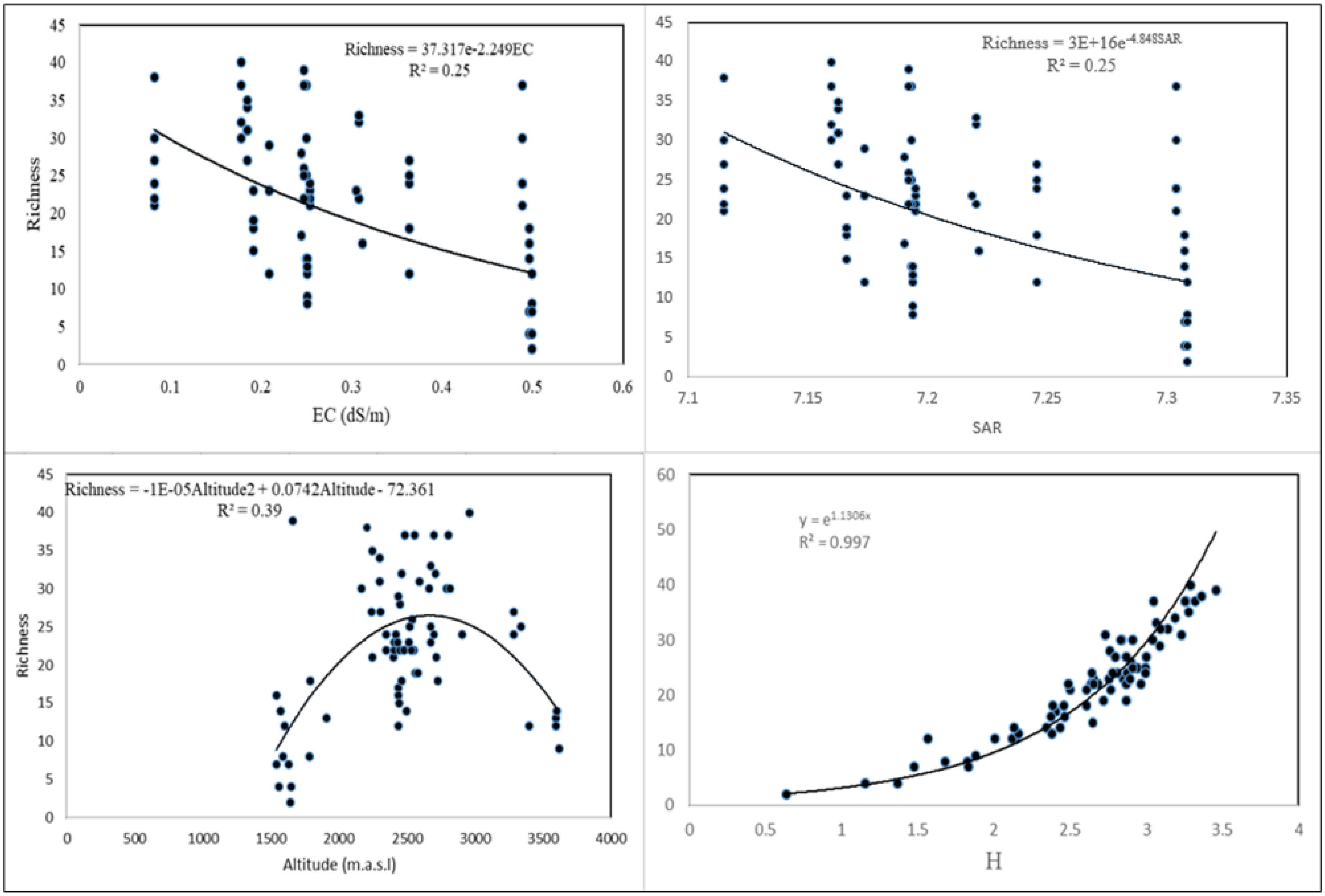

Figure 5

The impact of EC, SAR, Altitude, and diversity (H) on species richness

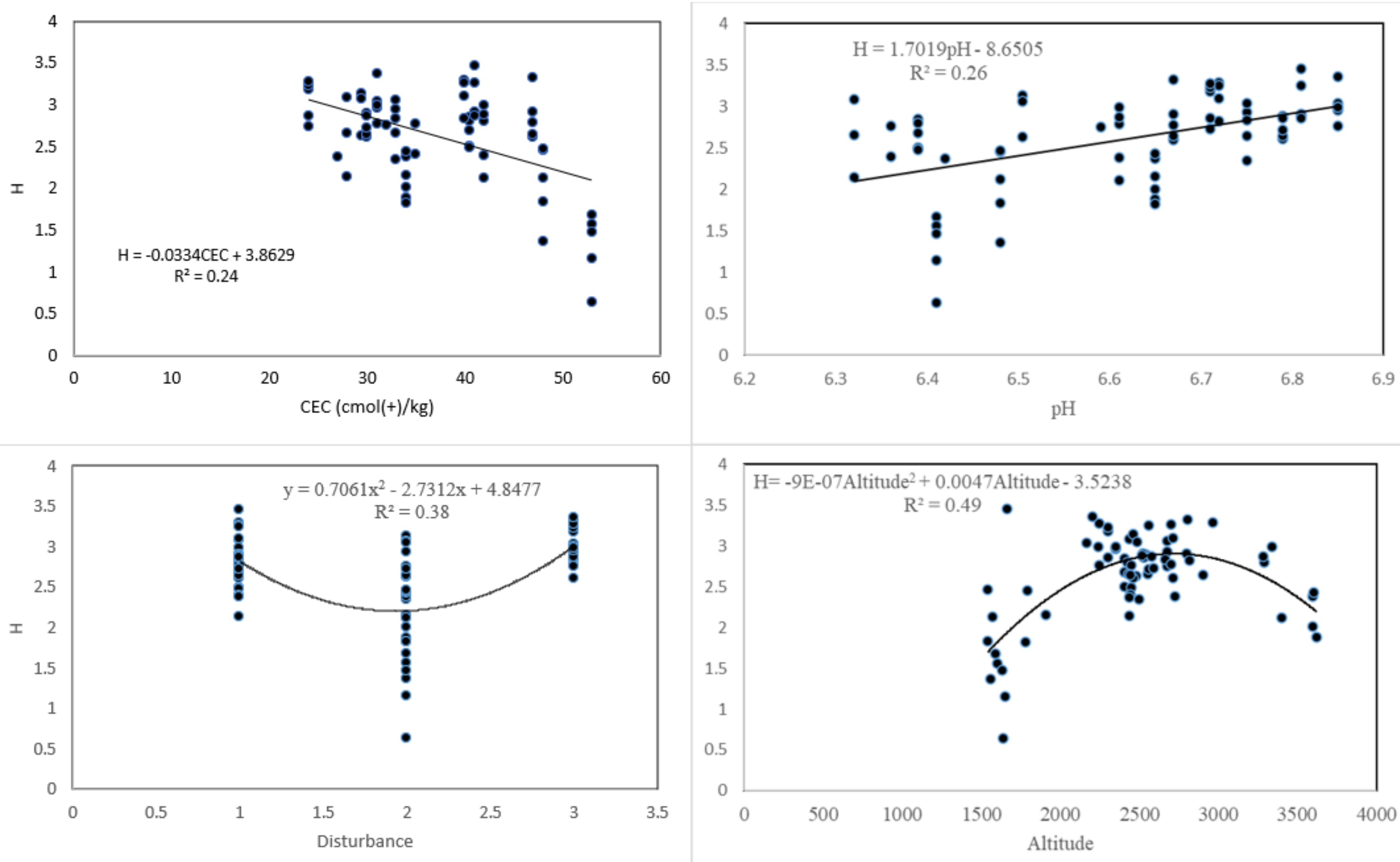

Figure 6

The impact of CEC, pH, disturbance, and altitude on plant species diversity