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PLANT DIVERSITY IN SAINT CATHERINE, SOUTH SINAI, EGYPT

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Abstract

The present study aims to assess the plant diversity in seventeen different locations including 275 studied stands in Saint Catherine area, South Sinai. The vegetation survey resulted in identification of seventy different plant species. The plant cover of each species was measured and twenty-one environmental factors in different landforms were measured in the study area. Species richness, Shannon diversity index, and Simpson diversity index were calculated in all studied locations. In addition, the relation between the environmental factors and plant diversity was estimated statistically using linear model. Results of the present study showed that Simpson index agreed with species richness that Mt. Elsarw has the highest diversity value where the exposure degree ranges from 130° to 340° and the average elevation is 1703 m.a.s.l and a wide range of landforms are present (terraces, slopes, fissures, gorges, and ridges). According to Shannon index, W. El-Arbaein has the highest diversity value where the exposure degree ranges from 110° to 330° and the average elevation is 1736 m.a.s.l. According to richness, Simpson, and Shannon indices, Mt. Catherine has the lowest diversity value where the exposure degree ranges from 40° to 200° and the average elevation is the highest of all the studied locations (1840 m.a.s.l.) where it only supports the growth of a small number of plant species that prefer high elevation, low temperature, and fissures present on the walls of the mountainous regions such as *Chiliadenus montanus*, *Stachys aegyptiaca*, *Tanacetum sinaicum*, and *Centaurea scoparia*. In addition, elevation is found to be the most important environmental factor affecting distribution and diversity of plant species in the study area.

Key words: Plant diversity, Species richness, Shannon diversity index, Simpson diversity index, Saint Catherine, South Sinai.

Introduction

South Sinai is characterized by having a great diversity in landforms, geological structures (Said, 1990), and climate (Abd El-Wahab, 2003) giving it a unique diversity in vegetation types that is mainly characterized by dominance of shrubs and sub-shrubs and the paucity of trees, and a great variety in soil properties (Ramadan, 1988; Kamh *et al*., 1999; and Abd El-Wahab, 1995). There are few studies that have dealt with assessing the diversity of the plants in south Sinai. Moustafa *et al.* (1999) studied the environmental factors affecting endemic species and species richness and diversity in Saint Catherine Protectorate, South Sinai. Ayyad *et al.* (2000) studied the plant biodiversity in Saint Catherine area. In addition, Moustafa *et al.* (2001) evaluated plant diversity and endemism in Saint Catherine Protectorate, resulting in several vital recommendations for conservation practices in the area. Zaghloul (2008) studied diversity in soil seed bank of Sinai and implications for conservation and restoration, while Ali (2009) made his study on the conservation of plant diversity of Serbal Mountain, South Sinai. Zaghloul *et al.* (2013) made an important study concerning choosing the right diversity index to apply on mountainous arid environments of Gebel Serbal, South Sinai. In addition, Moustafa *et al.* (2014) studied plant diversity, vegetation conditions and landforms of Gebel Serbal, South Sinai.

One of the most important indicators of the overall quality of an ecosystem for biological conservation is its high diversity within the plant community (Soulé 1986; Primack 1998). Therefore, it is very important to understand the spatial patterns of plant diversity to decide conservation priorities. This would not be fulfilled unless an appropriate diversity index has been applied which is capable of prioritising or differentiating between potential target entities (plant assemblages, habitats, locations, etc.) (Zaghloul *et al*., 2013). Zaghloul *et al*. (2013) classified diversity indices according to their aspects into three groups where the first group includes the dominance indices which are sensitive to the abundance of the most common species rather than to species richness which means that they weigh towards abundance of the commonest species. As a result, the total species richness is down weighted relative to evenness such as Simpson (1949) and Berger and Parker (1970) indices. The second group includes richness indices that are focusing on the number of species in relation to the number of individuals such as Margalef (1958) and McIntosh (1967) indices. The third group includes indices based on the information theory such as Shannon's (Shannon and Weaver, 1949) and Brillouin indices (Magurran, 2004), which take into consideration both of the components of diversity: evenness and species richness. Clarke and Warwick (2001) stated that Shannon diversity index is the most used index for comparing diversity between different habitats.

Debate on the advantages and disadvantages of various diversity indices has been continued over the last five decades (e.g. Hurlbert, 1971). Richness is the oldest and most fundamental concept of diversity and is roughly equivalent to species number. One difficulty associated with this measure is that it depends on the sample size (larger sample = more species). This phenomenon is popularly known as the species-area curve (Whittaker, 1962, and Mueller-Dorabois and Ellenberg, 1974, Krebs, 1985 and Rosenzweig, 1995). The larger the sample size, the greater the number of species found. Ideally, indices of richness would be independent of sample size (Peet, 1974). Various methods exist whereby the actual number of species in a given community can be estimated from extrapolation of the measured number of species (Peet, 1974, Krebs, 1985, Magurran, 1988, and Palmer, 1990). While biologists tend to measure species richness, by calculating one or more indices that combine measures of the number of species in a sample together with the relative abundance of those species, ecologists often wish to include, in addition, information on commonness and rarity (Peet, 1974 and Taylor, 1978). The Shannon-Wiener function is most sensitive to changes in the rare species in the community, while the Simpson's index is most sensitive to changes in abundant species (Peet, 1974, and Magurran, 1988). The present study aims to assess the plant diversity in seventeen different locations including 275 studied stands in Saint Catherine area, South Sinai through: (a) Measuring the plant cover of each species and twenty-one environmental factors in different landforms in the study area, (b) Calculating species richness, Shannon diversity index, and Simpson diversity index in all studied locations, and (c) estimating the relation between the environmental factors and plant diversity using linear model.

Materials and Methods

Study Area

The study was carried out in Saint Catherine Protectorate which is located between 33°30’ and 34°30’ E and 27°50’ and 28°50’ N and covers about 4350 km^2 with elevation ranges from 396 to 2642 m a.s.l. Due to the wide range of altitude, South Sinai is characterized by a wide range of variation in air temperature (Moustafa *et al.*, 1999). Abd El-Wahab (2003) described Saint Catherine to be the coolest area in Sinai and Egypt as a whole due to its high elevation. The region is characterized by outcrops of smooth-faced granite upfilled to form several mountain peaks. Its diversity in landforms, geologic

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structures, and climate resulted in different number of microhabitats, each of special environmental conditions and relatively rich and unique flora (Moustafa and Klopatek, 1995 and El-Alqamy, 2002).
The study area includes: Mountain Catherine, Wadi El-Rutig, Wadi El-Arbaein and its surrounding mountains namely Mountain El-Rabba and Mountain Elsarw, Mountain Mousa and Garagnia, Wadi El-Tofaha and its surrounding mountains namely Mountain El-Tofaha and Mountain El-Talaa, El-Meserdy ridge, Mountain Abu Giffa, Wadi Gibal, and Wadi Tobug (Figure 1).

I. Location and stand selection

The main criteria in the selection of stands and determination of their sizes were abundance of *Chiliadenus montanus*, presence of reasonable degree of physiognomic homogeneity in topography and vegetation type, low levels of vegetation disturbances and different levels of grazing intensity. 46 transects with 275 stands each 5x5 m ($25m^2$), in 17 different locations were selected to study *Chiliadenus montanus*, representing as much as possible the prevailing environmental variations associated with the distribution of the study species.

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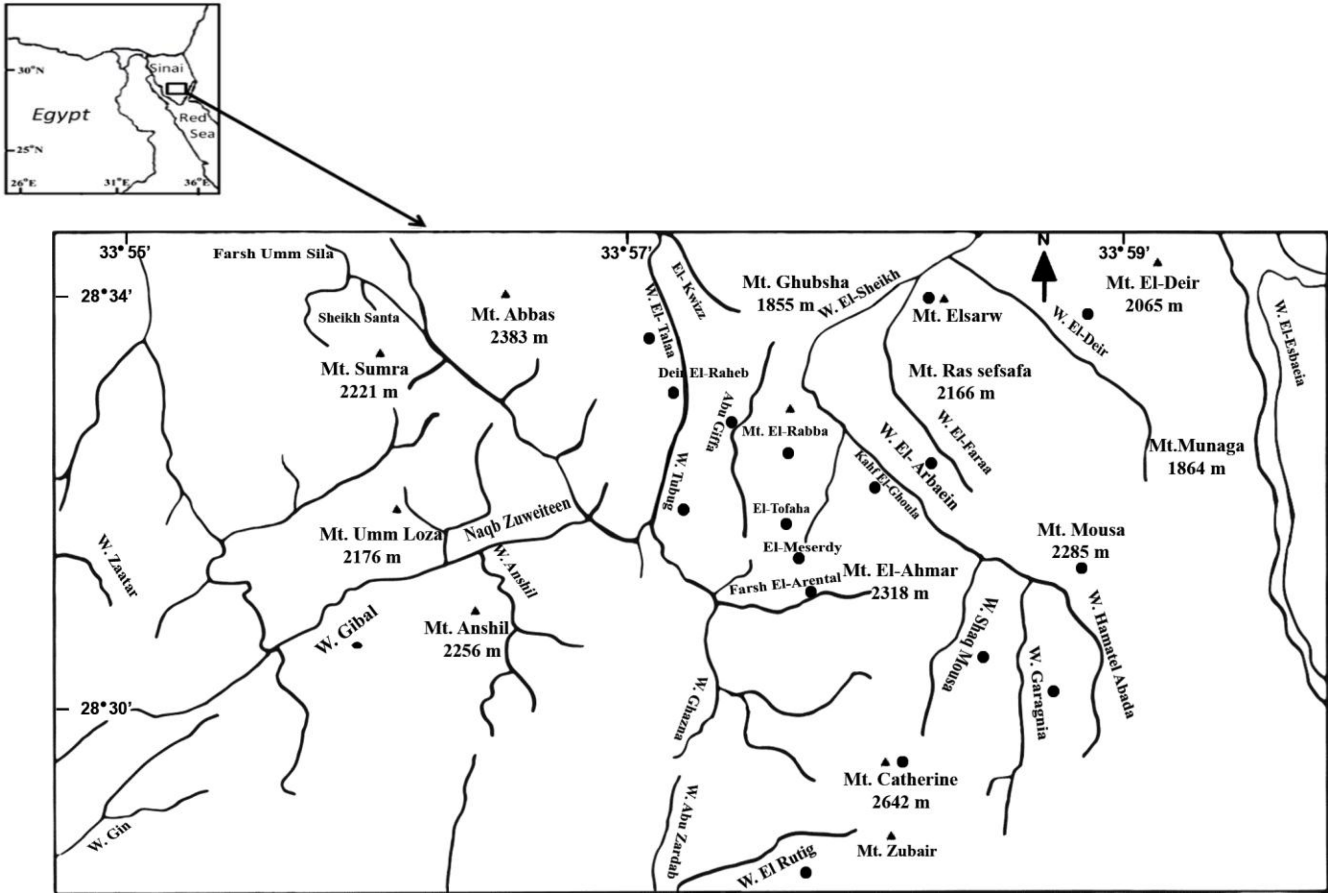

Figure 1: Location map of the study area (Saint Catherine Protectorate) in the southern part of Sinai. Mountain tops (Mt.) are represented by (▲), Wadis or valleys (W) and locations of the studied areas represented by (•).

II. Recording of environmental parameters

In each stand, the following parameters were measured: altitude (meters above sea level), slope degree, exposure degree, and land form type. Land form type was determined according to Mousata and Klopatek (1995) as: gorge, slope, Wadi, ridge, plain, and outcrop of smooth-faced rock and terraces. Nature of soil surface was described according to Hausenbuiller (1985) as follows: fine fraction (< 2mm), gravel (2-75 mm), cobbles (75-250 mm), stones (250-600 mm), and boulders (> 600 mm).

III. Soil Sampling and analyses

Soil samples were collected for quantitative physical and chemical analyses. Surface soil samples (as a mixture from 0 to 20 cm depth) were collected under canopy of dominant species. Analyses of soil samples included soil physical analysis (soil texture using sieving method of Gee and Bauder (1986), and moisture content according to Shah and Singh (2005)); and soil chemical analysis (organic matter content according to Sparks *et al*. (1996), soil reaction pH following the method of Allen *et al*. (1976), electrical conductivity described by Wilde *et al*. (1972), determination of cations (Ca^{+2} +Mg^{+2}), and determination of anions (HCO_3^- and Cl^-) by the titration method according to Baruah and Barthakur (1997).

IV. Diversity indices calculations and data analyses

Three different indices for describing the species alpha diversity and evenness of the species and stands were measured using Excel sheet functions programmed in VBA (Visual Basic for Applications). They are included in an Excel Add-in module Diversity.xla, guaranteed by the Statistical Services Centre of the University of Reading. After calculating different diversity indices, linear model was applied in order to explain the relation between these diversity indices and the significant measured environmental variables.

The total species density was calculated following Butler and Chazdon (1998) as the number of species in each plot per unit area. Species richness is measured for each of the 275 stands according to Barbour *et al.* (1987) as the total number of species, while the other three diversity indices were calculated as following:

a. The Shannon-Weiner index was evaluated by: $H' = - \sum_i (n_i / N) \times \log (n_i / N)$, where n_i are the individuals, N is total number of individuals

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(Zar, 1984).

b. Simpson's index D was calculated by: $D = \sum_i \{n_i \times (n_i - 1)\} / (N \times (N - 1))$ and was expressed in the output as both 1-D and 1/D (Simpson, 1949).

Results

Diversity Indices

A. Species Richness:

The relation between species richness and the environmental variables showed a significant positive relation with exposure (4.941± 0.001), cobbles of soil surface (3.515± 0.023), and moisture content (2.709 ± 0.12), whereas it showed a significant negative relation with pH (-4.607 ± 0.74), and elevation (-5.336± 0.002) (figure 2 and table 1).

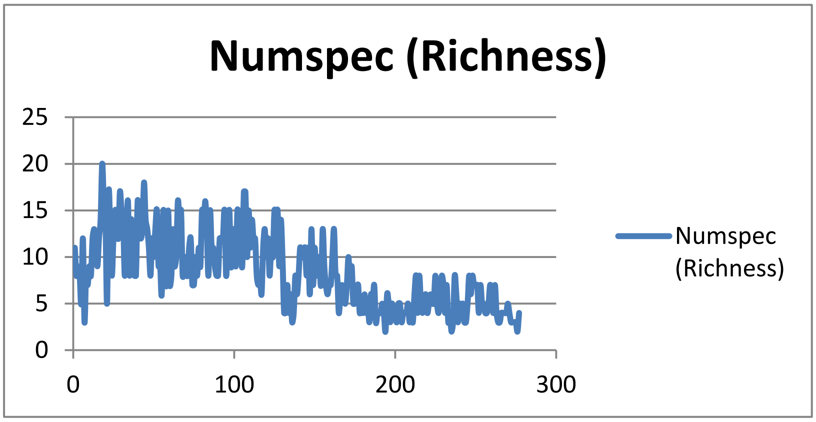

Figure 2: Species richness (no. of species) of the recorded stands during the study in Saint Catherine area.

Table 1: Summary of linear model output showing the relation between Species Richness and the significant measured environmental variables.

Environmental variables	**Estimate**	**St. Error**	**t -value**	**P**	**R^2**
Intercept	57.653837	8.540858	6.750	< 0.0001 (***)	25%
Exposure	0.009792	0.001982	4.941	< 0.0001 (***)	
pH	-3.426558	0.743752	-4.607	< 0.0001 (***)	
Elevation	-0.013474	0.002525	-5.336	< 0.0001 (***)	
NSS Cobbles	0.084092	0.023926	3.515	< 0.0001 (***)	
Moisture content	0.332035	0.122550	2.709	< 0.001 (**)	
Significant code: *** (< 0.001), ** (< 0.01).					

B. Shannon index:

The relation between Shannon index and the environmental variables showed a significant positive relation with exposure (3.492 ± 0.0002), cobbles of soil surface (2.112 ± 0.003), moisture content (2.766 ± 0.015), and gravel of soil texture (3.504 ± 0.002), whereas it showed a significant negative relation with pH (-2.967 ± 0.093), and elevation (-4.670 ± 0.0003) (figure 3 and table 2).

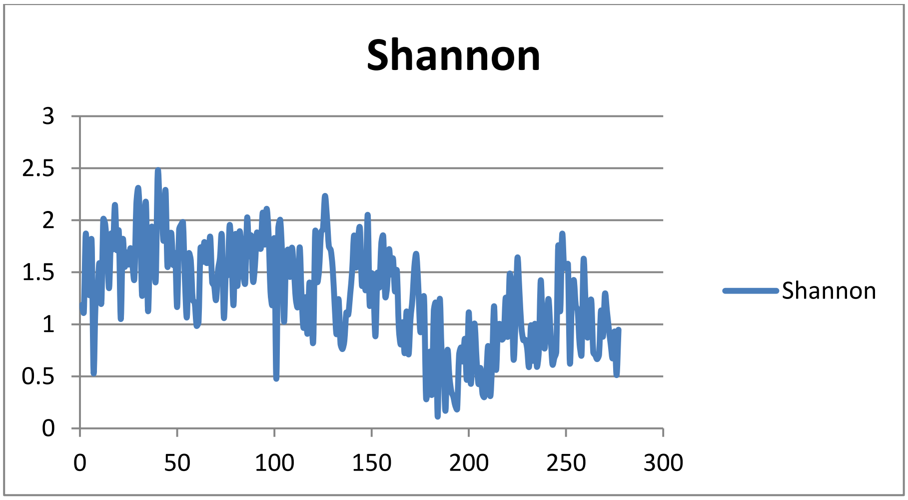

Figure 3: Shannon diversity index of the recorded stands during the study in Saint Catherine area.

Table 2: Summary of linear model output showing the relation between Shannon index and the significant measured environmental variables.

Environmental variables	**Estimate**	**St. Error**	**t -value**	**P**	**R^2**
Intercept	5.7287661	1.1150681	5.138	< 0.0001 (***)	24%
Exposure	0.0008947	0.0002562	3.492	< 0.0001 (***)	
pH	-0.2784009	0.0938205	-2.967	< 0.001 (**)	
Elevation	-0.0015346	0.0003286	-4.670	< 0.0001 (***)	
NSSCobbles	0.0064152	0.0030368	2.112	< 0.05 (*)	
Moisture content	0.0429176	0.0155153	2.766	< 0.001 (**)	
STGravel	0.0072637	0.0020728	3.504	< 0.0001 (***)	
Significant code: ***(< 0.001), ** (< 0.01), * (< 0.05).					

C. Simpson index:

The relation between Simpson index and the environmental variables showed a significant positive relation with calcium (1.931 ± 0.005), moisture content (2.263 ± 0.009), and gravel of soil texture (3.926 ± 0.001), whereas it showed a significant negative relation with chloride (-2.760 ± 0.014), and elevation (-3.966 ± 0.0001) (figure 4 and table 3).

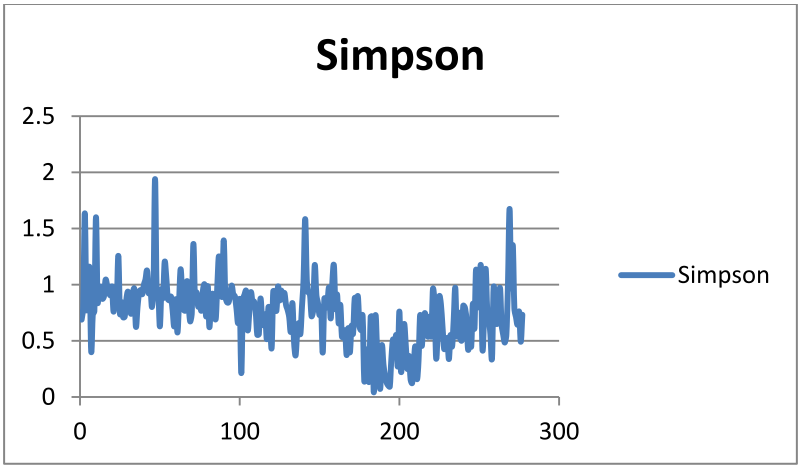

Figure 4: Simpson diversity index of the recorded stands during the study in Saint Catherine area.

Table 3: Summary of linear model output showing the relation between Simpson index and the significant measured environmental variables.

Environmental variables	**Estimate**	**St. Error**	**t -value**	**P**	**R^2**
Intercept	1.8868514	0.3422940	5.512	< 0.0001 (***)	18%
Calcium	0.0115283	0.0059692	1.931	< 0.1 (.)	
Chloride	-0.0406065	0.0147133	-2.760	< 0.001 (**)	
Elevation	-0.0007605	0.0001918	-3.966	< 0.0001 (***)	
Moisture content	0.0203769	0.0090024	2.263	< 0.05 (*)	
STGravel	0.0046162	0.0011758	3.926	< 0.0001 (***)	
Significant code: ***(< 0.001), ** (< 0.01), * (< 0.05), . (<0.1).					

Discussion

The present study aimed to focus on plant diversity in Saint Catherine area and how it is affected by the environmental factors and trying to explain the most environmental factors affecting the distribution and vegetation of plant species in order to contribute in establishment of a conservation plan for plant species growing in Saint Catherine. Results of vegetation survey of the present study identified 70 plant species in the selected 275stands in 17 different localities in Saint Catherine area during the study period. The identified species belong to 24 families. The families that are represented by the largest number of species were Compositae, Labiatae, Caryophyllaceae, and Leguminosae respectively. Compositae, Labiatae, and Graminae were the most represented families identified by Zaghloul (1997) out of thirty-one families comprising 132 species studied in Saint Catherine mountainous area. The present study in Saint Catherine area identified seven endemic species representing 10% of the seventy studied plant species (*Bufonia multiceps, Galium sinaicum, Hypericum sinaicu., Kickxia macilenta, Nepeta septemcrenata, Phlomis aurea, and Plantago sinaica*). These plant species were reported by Abd El-Wahab *et al*. (2004) to be endemic. This comes in agreement with many studied stating that Saint Catherine area represents a center of endemism (Zohary, 1973; Shmida, 1984; and Moustafa, 1990).

It has long been established that environmental conditions and human impacts have a significant influence on diversity and distribution of threatened, endemic, and medicinal plants (Zaghloul, 1997; Moustafa *et al.*, 2001; and Abd El-Wahab *et al.*, 2004). Biodiversity is well known to be an important measurement which contributes to conservation and management of natural resources. UNEP (1995) stated that rapid loss of species richness and viability creates the need for understanding the changes of biodiversity over time.

Biological diversity or biodiversity refers to the variety of distinct ecosystems or habitats, the number and variety of species within them, and the range of genetic diversity within the population of these species. Two attributes of biodiversity have attracted particular attention from the international conservation community: species richness (the number of species in an area), and endemism (the number of species in that area that occur nowhere else) (Caldecott *et al*., 1996).

Diversity measures need estimated species evenness within the community. The simplest diversity measures are numbers, biomass, cover, or productivity (Krebs, 1985). Various indices have been developed to describe the heterogeneity of species within a community. One of the problems encountered when selecting these indices is that study results can change considerably depending on sampling methods (Peet, 1974). Nevertheless, two common diversity indices are the Simpson's index and the Shannon-Wiener function. Both were developed in part because of the complexity of other indices and the associated lack of theoretical justification (Krebs, 1985). Both the Simpson's and the Shannon-Wiener indices are non-parametric measures of species heterogeneity that makes no assumptions about the normality of species-abundance curves (Magurran, 1988).

In the selection of a diversity measure, it is important to consider the ability of the index to discriminate between sites, the dependence of the index on sample size, the component of diversity being measured, and whether or not the index is widely used and understood (Magurran, 1988). Species richness, while giving valuable information about diversity, can mask shifts in evenness. Therefore, it is important to combine a measure of richness with a measure of evenness whenever possible (Magurran, 1988). Indices weighted towards species richness are more useful for detecting differences between sites than indices that emphasize the evenness component of diversity.

In the present study, different diversity indices were measured including species richness, Shannon index, and Simpson index. The relation between these diversity indices and the measured environmental parameters was shown by applying linear model where the results showed that the relation between the environmental variables and both species richness and Shannon index was significantly positive with exposure, cobbles of soil surface, and moisture content, whereas it showed a significant negative relation with pH, and elevation. Shannon index differed from species richness in that it showed an added positive relation with gravel of soil texture.

The relation between Simpson index and the environmental variables showed a significant positive relation with calcium, moisture content, and gravel of soil, whereas it showed a significant negative relation with chloride, and elevation. In contrary, Abd El Wahab *et al.* (2008) reported that plant diversity is positively correlated with altitude, silt and clay content and organic matter content, while it is negatively correlated with salinity and fine sand. Results of the present study showed that altitudinal gradient and edaphic conditions that control soil moisture have significant influences on species diversity.

In the present study, Simpson index agreed with species richness that Mt. Elsarw has the highest diversity value where the exposure degree ranges from 130° to 340° and the average elevation is 1703 m.a.s.l and a wide range of landforms are present (terraces, slopes, fissures, gorges, and ridges). About 50

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% of the soil surface of Mt. Elsarw is covered by boulders and 50% of its soil texture is composed of gravel.

According to Shannon index, W. El-Arbaein has the highest diversity value where the exposure degree ranges from 110° to 330° and the average elevation is 1736 m.a.s.l. Shannon index takes in consideration both eveness and richness and it is sensitive to rare species. According to richness, Simpson, and Shannon indices, Mt. Catherine has the lowest diversity value where the exposure degree ranges from 40° to 200° and the average elevation is the highest of all the studied locations (1840 m.a.s.l.). About 50 % of the soil surface of Mt. Catherine is covered by boulders and in some stands, boulder percent reached 100% where it only supports the growth of a small number of plant species that prefer high elevation, low temperature, and fissures present on the walls of the mountainous regions such as *Chiliadenus montanus, Stachys aegyptiaca, Tanacetum sinaicum,* and *Centaurea scoparia*.

In agreement with the hypothesis that species richness increases with decreasing altitude (Stevens, 1992; Colwell and Hurtt, 1994; Acar and Altun, 2004), the results of this study indicated that, species richness increases in areas where elevation is low (W. El-Arbaein and Mt. Elsarw), while it decreases in areas of very high elevation (Mt. Catherine). This comes in contrary with Moustafa *et al*. (2001) and Abdel Wahab *et al*. (2008) where their studies indicated that species richness increases with increasing altitude.

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