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SPECIES COMPOSITION AND FLORISTIC DIVERSITY OF WEST TAIZ, YEMEN

ABDUL WALI A. AL-KHULAIDI[1, 2*], ARIF S.A. AL-HAMMADI[3], KHALEELAH D. NOMAN[4]

[1]Department of Biology, College of science and art, Albaha University, Baljurashi, Saudi Arabia

[2]Agricultural Research & Extension Authority (AREA), Republic of Yemen

[3]Department of Biology, College of Science, Sana'a University, Sana'a, Republic of Yemen

[4]Department of Biology, College of Science, Taiz University, Taiz, Republic of Yemen

***Corresponding author: E Mail: abdulwali20@yahoo.com**

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ABSTRACT

There is general agreement that biodiversity in Yemen is under threat due to mechanized rain-fed agricultural expansion, urban expansion, wood logging and overgrazing. For all these reasons, this study finds it urgent to provide this ecological assessment for the plant diversity and vegetation conservation in Taiz. The floristic composition and habitat information were recorded in 150 sample sites. The description of the floristic composition and diversity patterns of the study area was achieved by using of a range of species richness and abundance methods as well as diversity indices. The study area of West Taiz contains about 252 species (about 168 species per hectare) belonging to 57 families, with 12 dominant species (5 %), 5 endemic species, 14 near endemic species and 17 rare species. The investigated areasare estimated 1.5 ha, which corresponds to 150 samples X 100 m² sample sites. The largest families in terms of species in the study sites are*Poaceae (Graminea)* with 25 species, *Euphorbiaceae*with 20 species, *Apocynaceae* with18 species, *Acanthaceae* with18 species, *Fabaceae (Papilionoideae)* with 12 species and*Mimosaceae* with 11 species. The occurrence of species in different landforms of the study area shows a characteristic pattern: the total richness of 186 for mountains, 171 for hills, 155 for wadis and 118 for plains.

Keywords: Floristic composition, Species diversity, Vegetation, Taiz, Yemen

1. INTRODUCTION

The biodiversity conservation in Yemen has become an issue of increasing priority at national level. Yemen vegetation was recognized as the most important site for Arabia and northeast Africa flora (Al-Hubaishi & Müller-Hohenstein, 1984; Ghazanfar & Fisher, 1998). Yemen has a rich biodiversity, including about 3000 plant species (Scholte et al., 1991). It also supports high rates of endemism, large numbers of rare species and many species with restricted distributions. Endemic plant species in Yemen have been estimated to be about 429. This is approximately 14% of the total and 307 of them occur in the Soqotra Archipelago (Al Khulaidi *et al*., 2010). A study by Al Khulaidi (2013) estimated the total number of plant species of Yemen to be 2810, belonging to 1006 genera and 173 families, of which 457 are endemic (307 in Soqotra), 2559 naturalized, 121 cultivated and 111 introduced.

The plant diversity of West Taiz is proportionately substantial and hence forms a significant contribution to the overall biodiversity of the Yemen. However, the vegetation of West Taiz has been exposed to various human induced impacts that have diminished its diversity. The area underwent a decline in vegetation due to timber exploitation, grazing and urban expansion. The conservation and sustainable management of natural resources in Taiz region needs a holistic approach in which ecological concerns, socio-economic and agricultural are taken into consideration. The attention given to vegetation conservation and sustainable use has so far been inadequate. The plant species diversity of West Taiz is poorly documented, except for short inventory studies giving a general description of vegetation types and comments (Al-Khulaidi, 1990; Al-Khulaidi, 1997).

For these reasons, this study is designed with a view towards assessing the species diversity of West Taiz, describing the floristic composition and exploring the differences in species distribution and diversity in the four major landforms of the area.

2. MATERIAL AND METHODS

2.1 Study Area

The study area is located within the governorate of Taiz, west of Taiz city, in the far south western part of the country. It is located between 13°18' and 13°39' North and 43°33' and 43°56' East, covering an area of approximately 692.937 km^{2}. The largest part of the study area lays in Tihama Foothills on altitude ranges between 300 m and 1000 m above sea level. The remaining part is located in the Lower Escarpment of Western Mountains on altitude between 1000 m -1200 m above sea level (Figure 1).

The topography of the study area comprises of steep to moderate steep sloping mountains, flat to undulated and stony to gravelly plains, stony hills and small inter mountain wadis or unfilled wadis (Figure 2). These great topographic variations contributed to distinctive species distribution patterns and vegetation types of each of these landforms. These factors strongly influence the study area's range of terrestrial ecosystems, and they have contributed to a good diversity and rate of endemism. The existence of such diversity has contributed to the study area's diverse vegetation types.

The study area surveyed is estimated 1.5 ha, which corresponds to 150 X 100 m² sample sites. The number and abundance of the species in the 150 sample sites are divided into four landforms: Mountain (48 sites), Hill (45 sites), Plain (31 sites) and Wadi (26 sites).

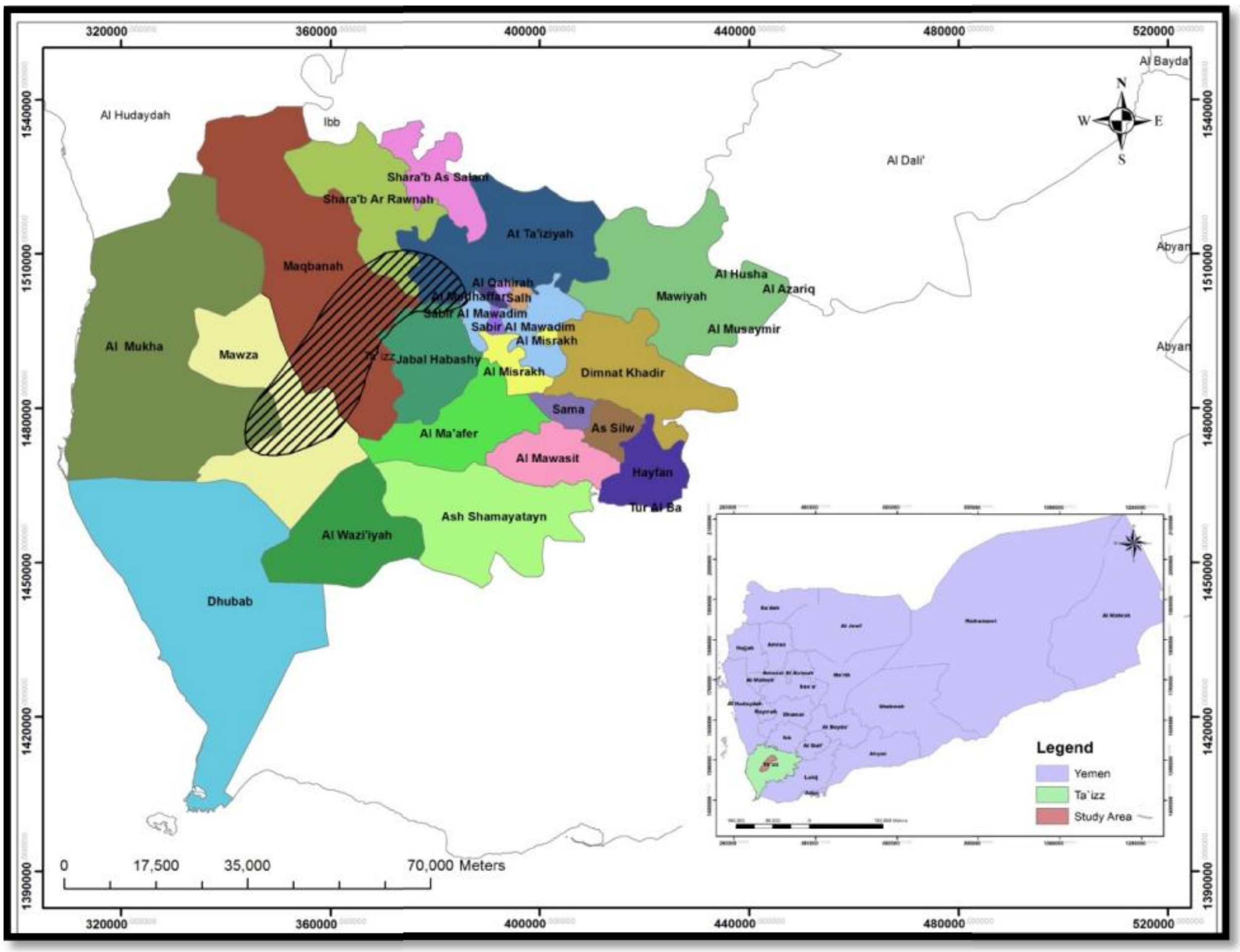

Figure 1: Location Map of the Study Area

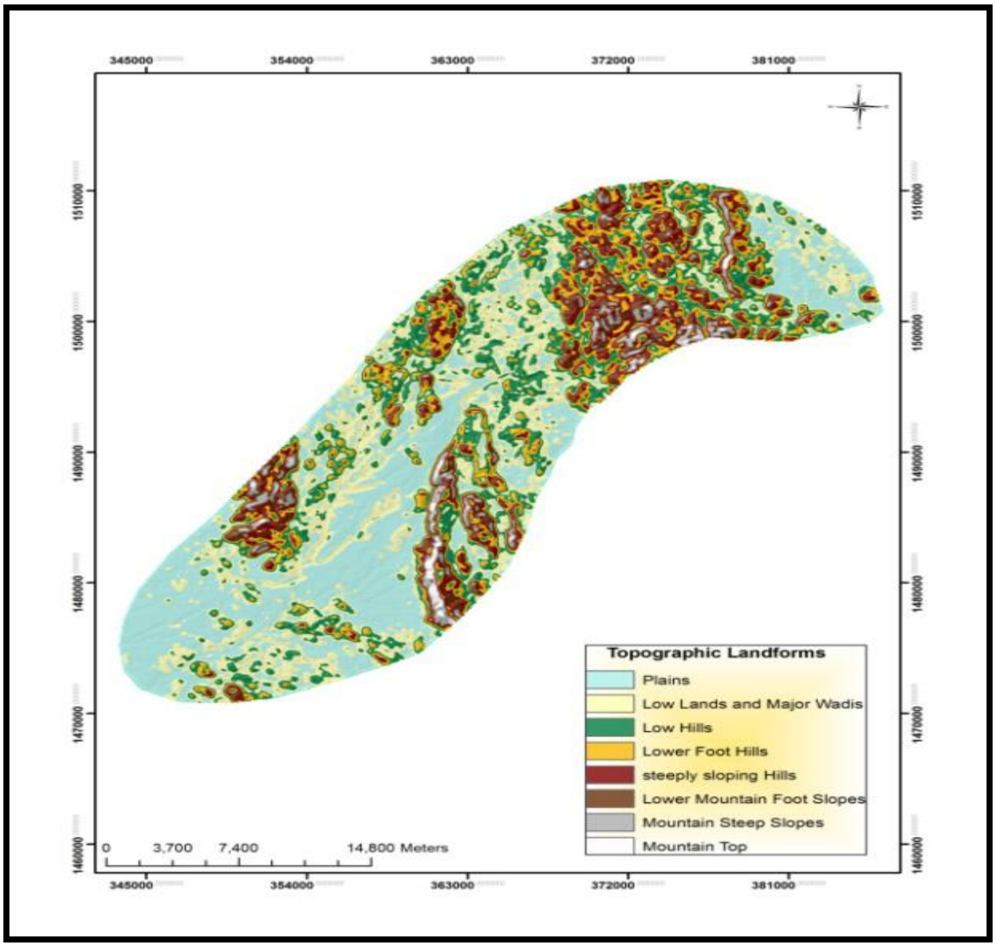

Figure 2: Topographic Landforms/Units of the Study Area. This map generated from the Shuttle Radar Topography Mission (SRTM_3Arc) georeferenced image file, downloaded from USGS (2012)

2.2. Measurements of Species Diversity

For measuring species diversity, three main measureswere used: species richness, abundance models and diversity indices (Shannon's and Simpson's indices) that combine the two components (richness and evenness).

Species Richnesswas computed based on the plot (site) spatial scale, in which the average number of species in all 10 x 10 m sites (150 site) within a habitatwas counted.To measure the efficacy and completeness of sampling protocols for the study area and investigate differences in the total number of species (species richness) in the different landforms, this study constructed species accumulation curves (a special type of regression technique for estimating species richness (Colwell & Coddington, 1994; Gotelli & Colwell, 2001) for the different landforms and compared the curves. Calculating species accumulation curve for each landform of the dataset separately yields 4 figures (curves) representing the total species richness values for each of the landforms: mountain, hill, plain and wadi.

Besides species richness, natural communities also differ in abundances, and hence the additional dimension of species evenness has been used in the measurement of biodiversity. For quantitative assessment of **Species Relative Abundance**, several important measures were used: frequency and density (Greig-Smith, 1983).For the purpose of this study, the number of individuals (***density***) of each species per hectare in the different landforms was calculated. This was accomplished by dividing the total number of individuals into the total areas surveyed in the different landforms.

$$\text{Density} = \frac{\text{Total number of individuals of a species in all sites}}{\text{Total number of sites studies}}$$

Frequency was also calculated by dividing the number of sites in which a species occurs by the total number of sites sampled.

$$\text{Frequency} = \frac{\text{Number of sites in which the species occurred} \times 100}{\text{Total number of sites studies}}$$

However, the relative species abundance was best illustrated with ***Rank-abundance curves***, which were constructed using Biodiversity R software (Kindt & Coe, 2005), for comparing patterns of species richness and evenness between the different landforms.

For a more comprehensive measure of diversity, this study calculated species diversity of the different landforms of the study area by using Shannon and Simpson **Diversity Indices** that utilize both species richness and evenness (Magurran, 2004). The calculation used the software Biodiversity R (Kindt & Coe, 2005). The use of these indices provided an important measure of species diversity that allowed comparison between the different habitats of the study area. ***Shannon Diversity Index (H′)*** **(**Shannon & Weaver, 1949) is calculated from the equation:

$$H' = \sum_{i=1}^{S} p_i \ln p_i$$

Where *S* is the number of species and *pi* is is the proportion of individuals represented by the i^{th} species, i.e. $pi = Ni/N$, where *Ni* is the quantity of the i^{th} species (e.g. its abundance, biomass), and $N = \Sigma\, Ni$, i.e. total of values for all the species (e.g. total abundance, total biomass) (Whittaker, 1972; Pielou, 1975). Increased values of the Shannon index indicate increased diversity.

Simpson's Index (D)(Simpson, 1949) is defined by the formula:

$$D_S = \sum_{i=1}^{S} \frac{(n_i(n_i-1))}{(N(N-1))}$$

Where D = Simpson's Index, n_i = number of individuals of species *i* and N = the total number of individuals. Both Shannon and Simpson diversities increase as richness increases, for a given pattern of evenness, and increase as evenness increases, for a given richness, but they do not always rank communities in the same order (Colwell, 2009).

Plants Distribution and Diversity Mapping

Mapping of plants distribution and diversity patterns is an important medium of presentation of information and scientific data on plants in relation to environmental conditions (Pedrotti, 2013; Bartholomé & Belward, 2005). For these reasons, the GIS methods were used to consolidate the plant diversity analysis of West Taiz. Using Diva-GIS 7.5.0 (Hijmans et al, 2012) and ArcGIS

10 (ESRI, 2011), this study followed the spatial richness analysis as the most appropriate method to map species distribution and diversity patterns of the study area, with special focus primarily on rare, endemic and near-endemic species.

3. RESULT AND DISCUSSION

3.1 Floristic Composition

West Taiz area contained about 252 species (about 168 species per hectare) belonging to 155genera and 57 families, in which 5 endemic and 14 near endemic.The maximum number of species per sample sites is 54 and the minimum is 7. The largest families in terms of species are:*Poaceae (Gramineae)* with 25 species, *Euphorbiaceae* with 20 species, *Apocynaceae*and *Acanthaceae*with18 species each, *Fabaceae (Papilionoideae)* with 12 species, and *Mimosaceae* with 11 species (Table 1).

Out of 252 species, the following 12 species (5 %) are present in more than 20 % of the sample sites: *Acacia asak, A. mellifera, A. tortilis, Acalypha fruticosa, Aerva javanica, Anisotes trisulcus, Cissus quadrangularis, Cymbopogon jwarancusa, Indigofera spinosa, Jatropha spinosa, Sarcostemma viminale* and *Ziziphus spina-christi*.

The following endemic species are found in the study area: *Campylanthus yemenensis, Ceropegia rupicola, Euphorbia uzmuk, Plectranthus arabicus* and*Zygocarpum yemenense,*. There are about 14 near endemic species:*Abrus bottae, Aloe austroarabica, A. niebuhriana, A. sabaea, Barleria bispinosa, Cyanotis nyctitropa, Euphorbia inarticulata, Euphorbia qarad, Leucas alba, Monolluma cicatricosa, Monolluma quadrangula, Rhytidocaulon macrolobum subsp. macrolobum, Saltia papposa,*and *Sulcolluma hexagona*.

The following plant species were considered rare, because they were only recorded once: *Acacia edgeworthii, Aloe austroarabica, Barleria hochstetteri, Bidens bipinnata, Cadaba glandulosa, Chloris barbata, Euphorbia qarad, Euphorbia triaculeata, Grewia trichocarpa, Heliotropium aegyptiacum, Hyphaene thebaica, Jatropha glauca, Ledebouria revoluta (syn. Scilla hyacinthina), Polygonum aviculare, Rhamnus staddo, Selaginella yemensis* and *Tephrosia purpurea*.

3.2 Species Diversity of the Study Area

The occurrence of species in different landforms of the study area shows a characteristic pattern.As shown in the combined species accumulation curves of the four landforms (Figure 3), species accumulate more slowly in the plain and hill sites, and more quickly in the wadi and mountain. The output shows that the total species richness for the mountain sites is 186, with 171 for hill sites, 155 for wadi sites, and 118 for plain sites. The mountain is the richest in terms of number of plant species and the plain is the poorest.

Figure 4 shows the density of species across the different landforms. The species *Acacia tortilis, Anisotes trisulcus* and *Indigofera spinosa* are common in the four landforms, while *Acacia mellifera, Aerva javanica, Aristida adscensionis, Cymbopogon jwarancusa* and *Seddera arabica* are common in slopes of hills and mountains and in the plains. Compared to these three habitats, *Arundo donax, Phoenix dactylifera, Salvadora persica*and *Tamarix aphylla* are common in the wadi. Some species occur at high numbers in one landform and at low numbers or are absent in other landforms. For example, the numbers of individuals of *Phoenix dactylifera* and *Prosopis juliflora*are high in wadi beds while *Acacia ehrenbergiana, Aloe vera* and *Campylanthus yemenensis* are high in the plains.

Based on the calculation of the frequency of each species in the different landforms, the frequency of the most dominant species across the different landforms can be shown graphically in Figure 5.This output of the frequency of each plant species is useful for comparing the different landforms of the study area, in which variations in frequency can be observed. Some species occur at high frequencies in one landform and at low frequencies or absent in other landforms.

The relative species abundance of the study area is best illustrated with the model of ranked abundance curve, which accurately describes the proportional abundance of all species recorded within the four landforms of sample sites.The resulting rank-abundance curves for the four landforms show how the proportional abundances of species are plotted on the vertical axis against the species rank number in the horizontal axis (Figure 6). The output is used for comparing patterns of species diversity in the different landforms.

The resulting rank-abundance curves for the four landforms (Figure 6) show decreasing curves, differing in their shape and length. We can see, from the length of the curves, that rank-abundance curves for the plain and wadi are shorter – fewer species -- than the rank-abundance curves for the other two landforms: mountain and hill, which have high richness. In terms of species richness (expressed by length of the curve), the mountain is the richest landform (the longest curve) and the plain is the poorest (shortest curve).In fact, the basic difference between the four landforms is shown by the shape of the rank-abundance curves, which clearly indicates their differences in species evenness. As shown in the Figure 6, the rank-abundance curves for the mountain and hill are much steeper than the curves for the plain and wadi, which means to a higher degree of dominance – less evenness. The plain and wadi have more horizontal profiles and show a more even distribution of individuals among species. In terms of species evenness (shape of the curve), the wadi is most even landform (the most horizontal curve) and the hill is least even (steepest curve). Based on this information, we can classify the wadi as the most evenly distributed landform.

The resulting output of both **Shannon and Simpson diversity indices** (Table 2) provides an important measure of species diversity,which that allows comparison between the different habitats of the study area.The Shannon diversity index calculated for the main landforms is generally high and ranges from 4.40 for wadis to 3.94 for plains. On the other hand, the Simpson's index values follows and confirms the pattern of diversity given by Shannon index as it varies from 0.981 for wadis, 0.979 for mountains, 0.976 for hills to 0.969 for plains. As indicated in the output of the diversity indices (Table 2), both Shannon's and Simpson's diversity indices rank the wadis highest in diversity followed by the mountains, hills and the plains the lowest. The Shannon's and Simpson's diversity indices show that the wadi is more diverse than the mountain, despite greater richness and abundance/density values in the mountain. This is because the abundance in the wadi is equitably distributed among the species. In other word, the wadi has more evenness than the mountain and the hill.

The diversity patterns of evenness are clarified when comparing the relative abundance distributions patterns for the landforms at the plot scale (Figure 7). In the wadi sites, 50 % of the individuals belong to 19 species (Figure 7), while in the mountain sites, 50% of the individuals belong to only 17 species. In the hill sites, 50 % of the individuals are distributed among 15 plant species.Finally,in the plain sites, 50 % of the individuals are distributed among 12 plant species. This indicates the effect of the evenness component over the effect of the richness component on both Shannon's and Simpson's diversity indices. The Shannon's and Simpson's indices take into consideration the relative contribution of all species. The more the abundance is equitably distributed among the species, the higher the value of diversity (Kutiel, *et al*, 2000).

Furthermore, to clarify and confirm the diversity patterns of the study area, the result of the rank-abundance curves for the four landforms (Figure 6) supports the Shannon's and Simpson's indices result shown earlier in Table 2 and confirms the conclusion that the wadi has higher diversity than the other three landforms.

3.3 Plants Diversity

The resulting map of plants diversity (richness) distribution consolidates the already explained plant diversity result. The map (Figure 8) shows the species diversity pattern, based on species presence points, in which each cell was assigned to one of four classes, each representing a range in number of species, increasing from 5 to 73. It shows how the species are distributed across all landforms and habitats. Based on the map, it is also possible to identify the areas that have the highest diversity. A higher number of species are shown to occur in the north towards the centre of the study area. The map clearly shows that cells in north of the study area contain up to 73 different species, and in the centre and south up to 26 species. Two areas are indicated as possessing the highest diversity of plant species: the north of the study area, namely Hidran, Al-Rubay'i and around Hajdah, and the centre of the study area, namely Khuzaigah and around Maqbanah junction. The high diversity of these two territories is related to water availability and the altitudinal ranges of the study area. Altitudinal distribution of species shows that the number of species are increasing with the increasing altitude. The two high diversity areas occur in the altitudinal zone between 700 m to 1100 m.

Table 1: List of families with number of endemic and near endemic species

Family	No of species	Endemic	Near-endemic	Family	No of species	Endemic	Near-endemic
Acanthaceae	18		1	Fabaceae	12	1	1
Actiniopteridaceae	2			Lamiaceae	7	1	1
Aizoaceae	4			Liliaceae	1		
Aloeaceae	5		3	Lythraceae	1		
Amaranthaceae	8		1	Malvaceae	5		
Amaryllidaceae	1			Meliaceae	3		
Annonaceae	1			Mimosaceae	11		
Apocynaceae	18	1	4	Moraceae	5		
Araceae	1			Nyctaginaceae	5		
Arecaceae (Palmae)	3			Orchidaceous	2		
Aristolochiaceae	1			Pandanaceae	1		
Asteraceae	9			Passifloraceae	1		
Bignoniaceae	1			Poaceae	25		
Boraginaceae	5			Polygalaceae	3		
Brassicaceae	1			Polygonaceae	1		
Burseraceae	4			Portulacaceae	1		
Cactaceae	2			Rhamnaceae	2		
Caesalpiniaceae	8			Rubiaceae	1		
Capparaceae	7			Salvadoraceae	2		
Celastraceae	1			Scrophulariaceae	2	1	
Chenopodiaceae	1			Selaginellaceae	2		
Cleomaceae	2			Solanaceae	6		
Combretaceae	1			Tamaricaceae	2		
Commelinaceae	3		1	Tiliaceae	8		
Convolvulaceae	2			Urticaceae	1		
Cucurbitaceae	3			Verbenaceae	2		
Cyperaceae	1			Vitaceae	2		
Dracaenaceae	2			Zygophyllaceae	3		
Euphorbiaceae	20	1	2				

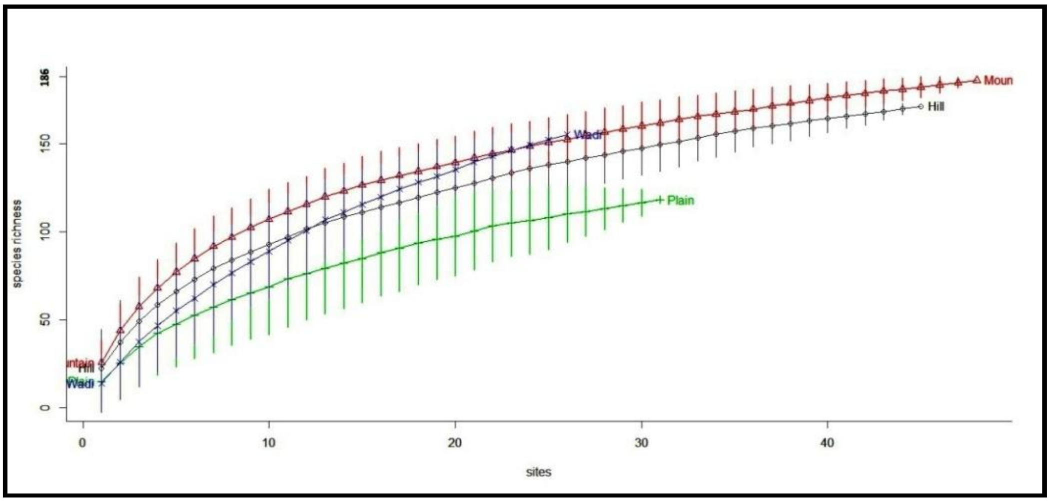

Figure 3: Curve of species versus number of sample sites for the different landforms in the study area. The mountain was the richest one and the plain was the lowest

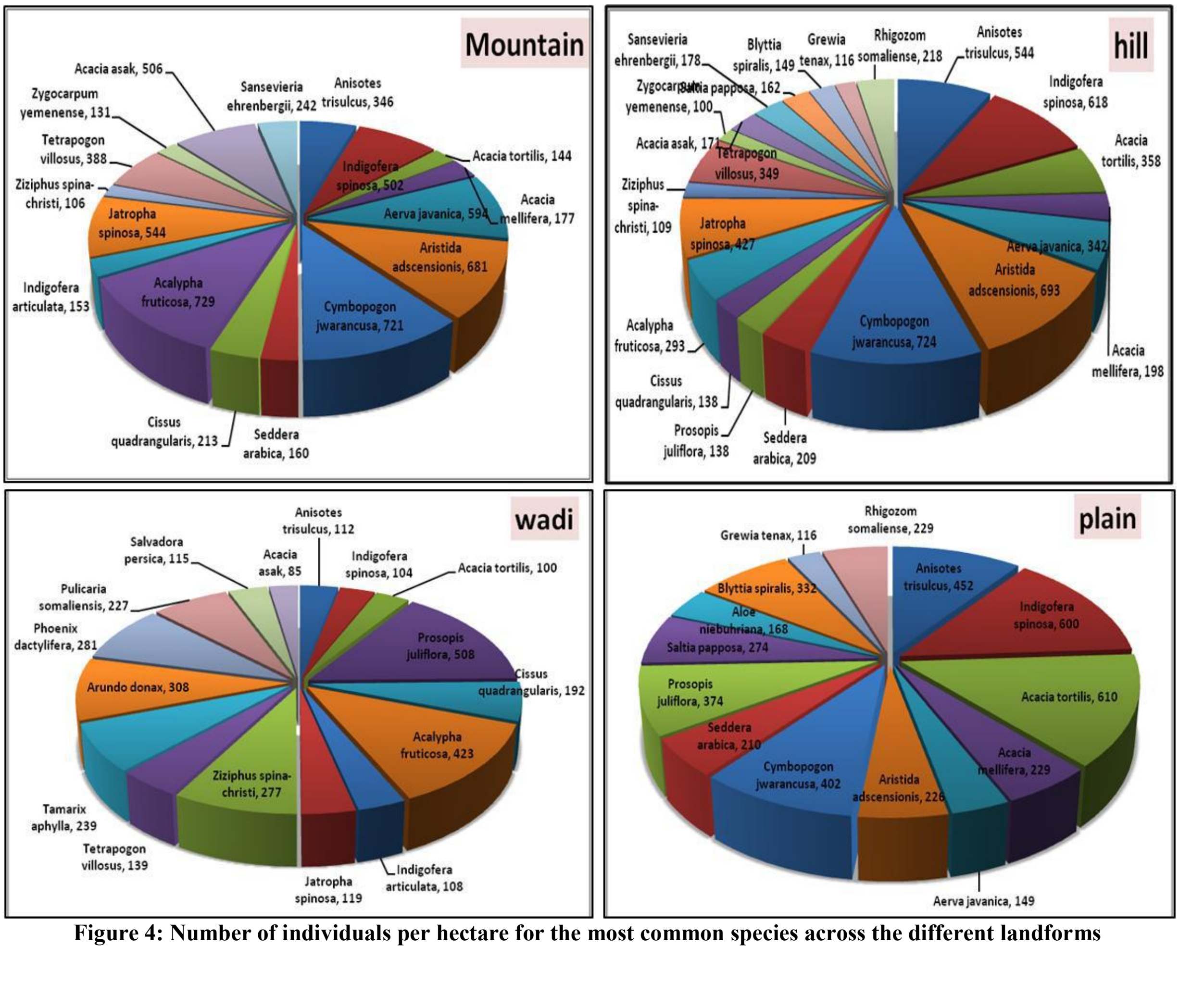

Figure 4: Number of individuals per hectare for the most common species across the different landforms

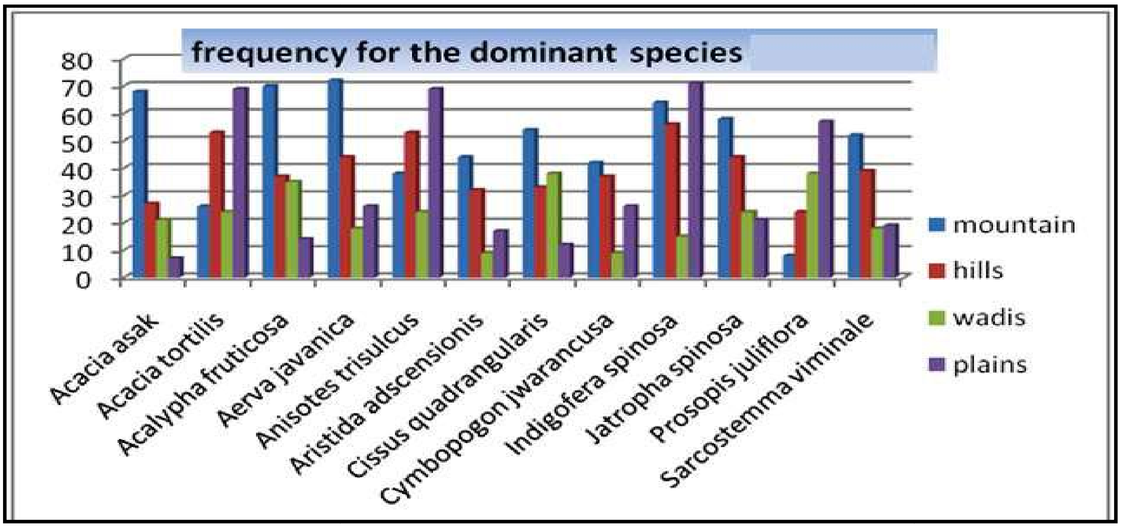

Figure 5: The frequency for the most dominant species in different landforms.

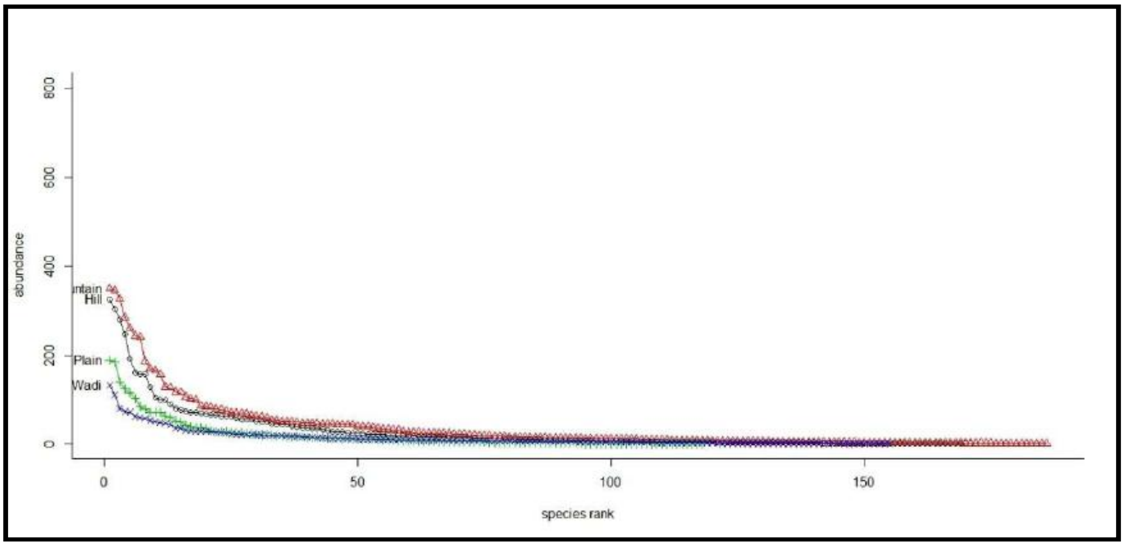

Figure 6: Rank-abundance curves for the four landforms of the study area

Table 2: Shannon's and Simpson's indices of the different landforms

Landform	No. of Sites	No. of Individuals	Richness	Evenness	Shannon Index	Simpson Index
Hill	45	5078	171	0.412	4.25	0.976
Mountain	48	6834	186	0.427	4.37	0.979
Plain	31	2479	118	0.435	3.94	0.969
Wadi	26	2151	155	0.526	4.40	0.981

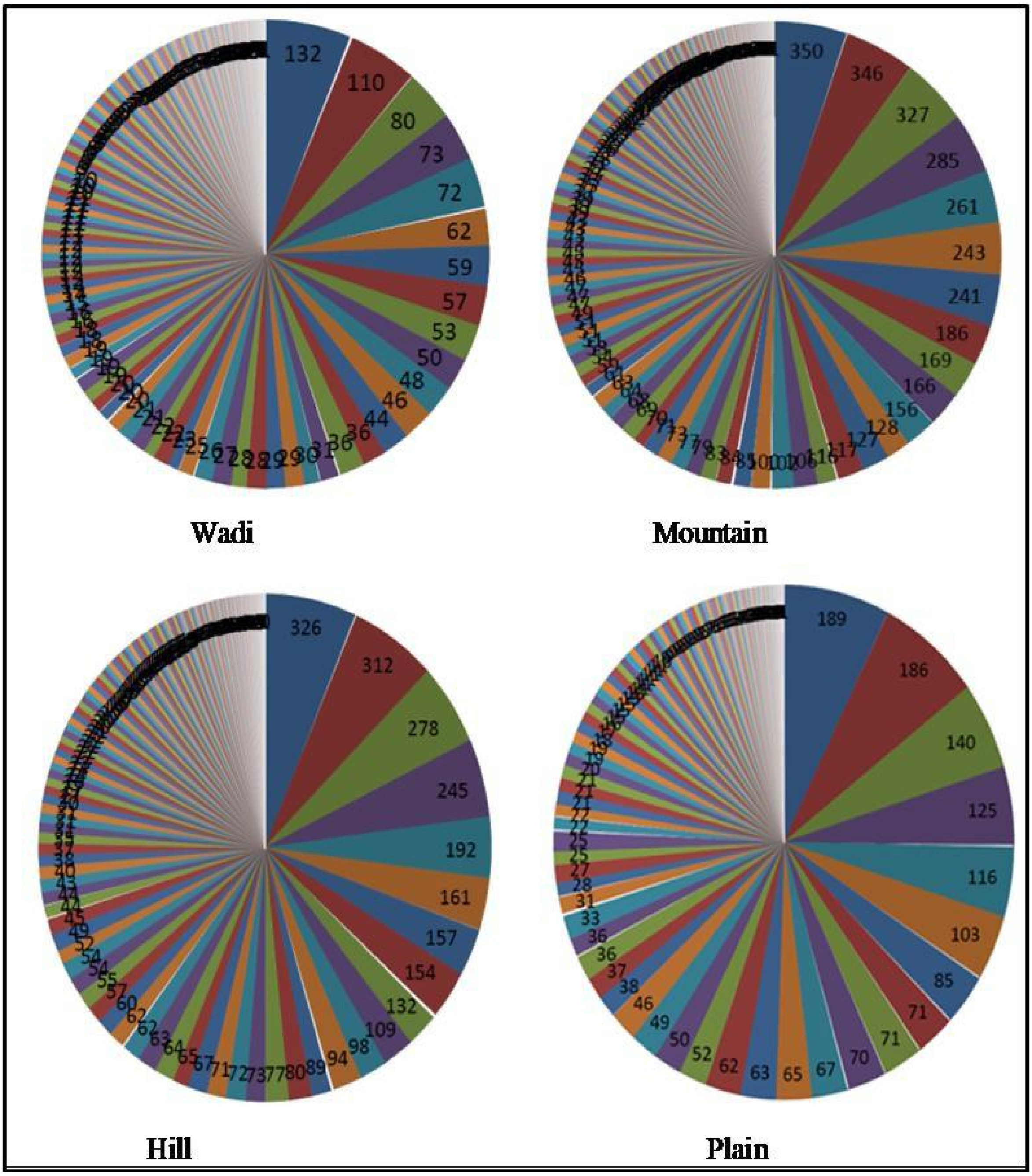

Figure 7: The distribution patterns of number of individuals between the plant species in the different landforms

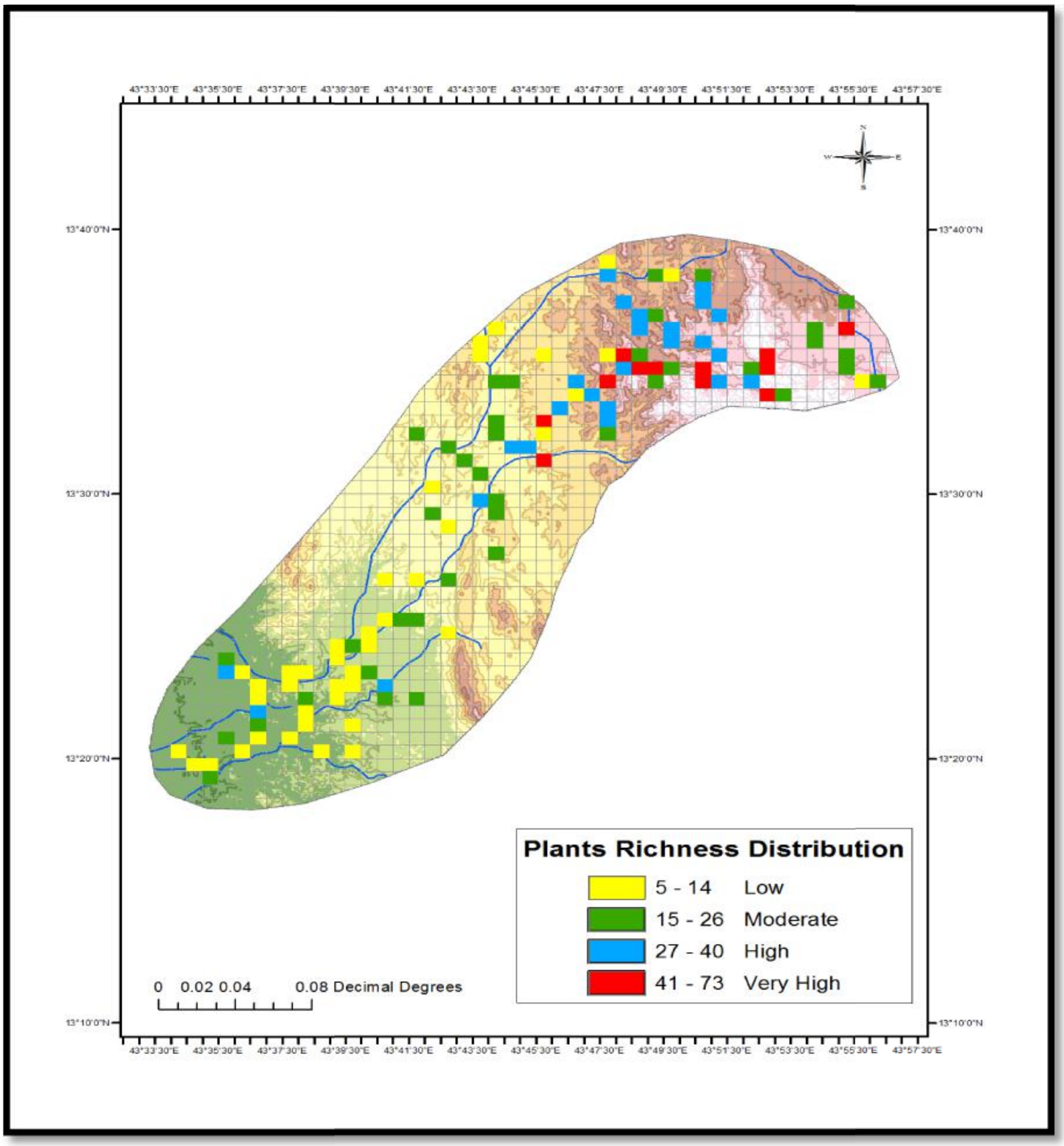

Figure 8: Map of species richness distribution of the study area, with a 0.00833 degree x 0.0083 resolution grid, based on a grid richness analysis of 252 species obtained from field survey of 150 sample sites

CONCLUSION

The results of this study indicate that the variations in the diversity are likely a result of mechanisms operating at the landform scale. In this study, effects at the landform scale are the most influential. The importance of landform (topographic gradient) is attributed to two factors: first, its controlling influence on water resources and soil surface; and second, the landform may make the area accessible for grazing and human interference or make it far from such destructive agencies (Zahran, 2009). It appears that differences in diversity at the landform scale are primarily due to anabiotic topographic gradient, which produces the observed effect on plants through water availability, soil surface and human interference. These physical conditions, along the topographic gradient, are important in determining diversity at this scale, because they are functions of conditions experienced by individual sites. The relative influence of these physical conditions depends on where along the topographic gradient processes are occurring. Moreover, the variation in the density of plant species is affected by timing of rainfall distribution and its influence on the species composition of the annual vegetation. For example, the density of *Becium filamentosum, Blepharis edulis, Ecbolium viride,* and *Ocimum forskolei*is high after the rain and the high density of *Acalypha indica*, *Alternanthera pungens* and *Xanthium strumarium* in wadi can be due to the increase of moisture.The local abiotic topographic gradient acts as a filter that prevents some species from occurring at a particular landform (Rajaniemi, et al, 2006).

In this study, we found a relatively low diversity measure in the plain and hill, where scarcity of water resources and human interference create stressful physical conditions, a relative high diversity in the mountain, which also experiences scarcity of water resources but relatively infrequent human interference, and the highest diversity in the wadi, where these physical conditions are less stressful.

The plains generally have the lowest diversity. This could be explained by the fact that this habitat experiences stressful physical conditions such as scarcity of water resources and human interference. The surface of the plains is covered by extensive gravels and stones (30 % - 80 %), with shallow soil of loamy and sandy loam texture and high content of $CaCO_3$ (16 - 27.5 %). In general, the plains lay within areas of low precipitation, and the water supply (as rain) is the most important abiotic factor influencing the presence, composition and density of vegetation in these areas (Ghazanfar & Fisher, 1998). The rocky surface of the plains, which represents a habitat of aridity and less moisture, provides little opportunity for plant growth (Zahran, 2009). The plain is also subjected to wood logging and overgrazing by local herders.The diversity of this habitat is limited by these stressful physical conditions, and consequently the vegetation cover and species richness have been reduced dramatically. The average vegetation cover is about 26%. The plain is dominated by*Acacia mellifera, A. tortilis, Anisotes trisulcus, Prosopis juliflora,* and *Saltia papposa*.The ground flora of this habitat consists primarily of a number of tough, often spiny under shrubs, which are capable of tolerating these stressful conditions of water scarcity. They include *Indigofera spinosa* (with the highest frequency), *Blyttia spiralis, Blepharis edulis, Campylanthus yemenensis, Euphorbia* *triaculeata, Fagonia indica, Farsetia longisiliqua, Panicum turgidum* and *Seddera latifolia*.

The local a biotic environment acts as a filter that prevents some of the species found in the study area pool from occurring at this habitat. This filter was strong in this habitat, where only 46% of species from the study area pool were found at this habitat. The absence of some of the common species of the mountain slopes and hills such as *Tetrapogon villosus, Zygocarpum yemenense* and *Abrus bottae* from occurring in the plain was due to the effects of grazing herders. The low density of *Ziziphus spina-christi, Jatropha spinosa* and *Cissus quadrangularis* in plains may also be due to these high human activities.

The terrain of hills is moderately steep, very stony slopes with rock outcrop percentage of 10 % - 60 %. It is covered with loamy, sandy loam and silty loam soils. Due to the slopes, the soil is probably affected by runoff and exposed to direct evaporation as a result the lower moisture (Danin, et al, 1997), and the shallow soil cover is not sufficient to support some species that require much moisture. The hills are also subjected to infrequent grazing by local herders and wood logging, which limit the diversity and vegetation cover. The vegetation cover of the hills is mostly shrub lands and few locations of grassland and sparse grassland. The average vegetation cover of the hills is about 35 %.

In the hills, although the same physical conditions limit diversity as in the plains, it again appears that infrequent grazing, wood logging and the less aridity produce greater diversity in the hills than in the plains. This could also be the result of the little increase of moisture content of the sloping hills. The sloping surface of the hills forms networks of furrows, which guide the run-off water. These furrows are lined with water-borne silt and provide a favourable habitat, especially in the rainy season, for some annual herbs, e.g. *Blepharis edulis, Heliotropium* ramosissimum*, Ocimum forskolei, Pergularia tomentosa Ruellia patula,* and many ephemerals.

Like the hill, the mountain experiences relatively some of the physical conditions that limit the diversity of the habitat such as infrequent aridity and soil surface. The terrain consists of steep stony hillsides and shallow soil. The mountain slopes are usually covered with rock detritus of favourable texture. There are always little pockets among the surface fragments where some soil accumulates and where conditions permit the growth of plants. However, on the rocky surface rainfall produces shallow depressions, holes, or cavities where some water and perhaps some soil may collect during the rainy season. In these, some plants appear, especially in the rainy season, e.g. *Blepharis edulis, Ocimum forskolei, Pergularia tomentosa* and *Ruellia patula*.

The high diversity in the mountain, compared to the hills and plains, is explained by the fact that the absence of some of the stressful physical conditions, namely the grazing, has resulted in greater diversity. The mountain cliff-side habitat is a type inaccessible to grazing and human interference, which is an advantage (Zahran, 2009). The abiotic filters, namely the scarcity of water and human interference, are not strong in this habitat, where 74% (higher than the hill and the plain) of species from the study area pool are found at this habitat. The mountain habitats host many different vegetation types corresponding to the amount of rainfall, soil type and slope aspect. The vegetation cover ranges between 12 % and 85 % with an average cover of 52 % (a high rate). The high vegetation cover in this habitat may be attributed to the slope aspect. Most slopes are west oriented and, therefore, receive more amount of rainfall. Most of the species were recorded during the rainy period, so the ground flora of annual herbs flourished. The basic vegetation of this landscape is an open *Acacia-Commiphora* bush land (Wood, 1997). The most characteristic tree is undoubtedly *Acacia asak* that is often associated with *Acacia mellifera* and*Commiphora kua(syn. C. habessinica*). *Acacia tortilis* and *Commiphora myrrha* are also found but in less frequency. *Ziziphus spina-christi* and many species of *Ficus* are also present but as individual trees. A number of associated shrubs occur in abundance like *Acalypha fruticosa, Anisotes trisulcus, Flueggea virosa, Jatropha spinosa,* and *Zygocarpum yemenense*. In addition to *Grewia mollis,*the species*G. tembensis, G. tenax, G. trichocarpa* and *G. schweinfurthii,* although rather rare, are restricted to this mountain vegetation. Other shrubs restricted to this terrain are *Euphorbia schimperi* and *E. uzmuk*.

The wadi is considered the most diverse because it is the least habitat affected by the above-mentioned stressful physical conditions, namely the scarcity of water. The wadi has a great merit of being a drainage system collecting water from an extensive catchment area, so that the water supply in the immediate vicinity of a wadi is relatively higher than that of the slopes between which it runs (Zahran, 2009). Wadi beds are often seen to be covered with layers of fine materials that have a substantial influence on the water available to plants. The deep soil allows for the storage of some water in the subsoil. This will provide a continuous supply of moisture for the deeply seated roots of shrubs and trees. It appears that without the stressful physical conditions, many plants, mainly trees and shrubs, find favourable conditions in wadis. The total vegetation cover of the wadis in the study area ranges between 6 % - 100 %. The average tree cover is 27 %; the shrub cover is nearly 15 %; and the herbaceous cover is about 5 %.

The soil depth is by far the most important factor restricting the type of vegetation in the wadis. This high increase of moisture provides a favourable habitat for some tree species such as *Arundo donax, Phoenix dactylifera* and *Pulicaria somaliensis*and *Tamarix aphylla,* which are characteristic of the wadi. In the wadi, other species that require high moisture such as *Azadirachta indica, Ficus sycomorus,*and*Trichilia emetica* are also abundant.

As explained above, it appears that the wadi is the most diverse among the landforms. On the one hand, the highest diversity of the wadi is attributed to being the most even habitat, i.e., the total number of individuals in the wadi is almost equally distributed between most of the plant species. On the other hand, this high diversity is also explained in terms of abiotic topographic factors such as soil depth and high moisture, which provide a favourable condition for the formation of a high vegetation cover in this habitat. There is no doubt that the abiotic topographic factors account for the variation in species composition and diversity of the different landforms of the study area.

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