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VEGETATION PATTERNS AND PLANT COMMUNITIES DISTRIBUTION ALONG AN ALTITUDINAL GRADIENT AT ASIR MOUNTAIN, SOUTHWEST SAUDI ARABIA

ABDULLAH M. FARID GHAZAL

King Abdulaziz University, Faculty of Environmental Design, Jeddah, Saudi Arabia
Corresponding e-mail: aghazal@kau.edu.sa, abghazal@gmail.com

Abstract

Vegetation composition, main plant communities and altitudinal vegetation zones at Asir Mountain southwest Saudi Arabia were studied, and in relation to various environmental factors including climatic, geological, ecological and topographic. A total of 74 plots were sampled according to Braun-Blanquet method along an altitudinal gradient. Floristic and environmental (topographic, geological and climatic) data were collected and analyzed using numerical classification and ordination. Two main climatic regions, four altitudinal vegetation zones and fifteen vegetation groups were identified: (1) two groups in an arid coastal plains mainly on an alluvial substratum between 0 and 200m (2) seven groups in the interspersed hills and plateaus of Tihamah arid region from 200 to 1100m; (3) three groups in the escarpments from 1100 to 2000m in the semi-arid region; and (4) two groups in a semi-arid high mountains zone from 2000m to the summit. Geo-altitudinal gradient was affected by the climatic factors (rainfall and temperature) and vegetation structure (species richness and coverage) on a regional scale, while edaphic factors played the leading role in the distribution of different vegetation groups on a local scale. These findings coincide with those reported about the distribution of vegetation at other tropical mountains. Human activates have a significant effect on modifying the distribution and abundance of plant species.

Key words: Vegetation, Distribution, Asir Mountains, Saudi Arabia

Introduction

Arid and semi-arid regions of the world are widely scattered and 97% of Saudi Arabia is extremely arid while the remaining 3% belong to a semiarid climate, which is located in the Asir Mountains (El-Hassan, 2004). Many limitations could be seen in arid and semi-arid regions especially the low and inconsistent precipitation, poor soil and special types of vegetation. The structure and variation of the vegetation of the landscape in relation to altitudinal change could be investigated to understand changes on three levels: environmental factors, species populations and the characteristics of communities (Whittaker, 1967).

The Asir Mountains and the Tihamah plains are located in the southwest of Saudi Arabia; they belong to the Afro-Mountains and Somalia-Masai regions, respectively (Chaudhary & Al-Jowaid, 1999; Al-Nafie, 2004). The area is unique in terms of its nature, landscape, climate and water availability (Abdulfatih, 1992). The literature on the vegetation of the study area received little attention. Several studies were carried out over the entire south-western region of the Asir Mountains to describe the vegetation, flora and phytosociology. Investigations into and descriptions of the vegetation can be found in several works, which have been prepared for the altitudinal zonation of the vegetation and the species composition in southwest Saudi Arabia (Vesey-Fitzgerald, 1955; Abdulfatih, 1992; Chalabi, 1996; Chaudhary & Al-Jowaid, 1999; Al-Nafie, 2004). Other studies provided a detailed description of plant communities from a phytosociological point of view in relation to some ecological factors e.g. edaphic, climatic, topographic in different approaches and geographical scales (Batanouny & Baeshain, 1983; El-Demerdash *et al*., 1994; Abd-El-Ghani, 1997; Al-Ghamdi *et al*., 2009; Al-Sodany *et al.*, 2011). On the other hand, several studies increased the scientific knowledge about the local flora in particular (Vesey-Fitzgerald, 1955; Abdulfatih, 1992; Al-Nafie, 2004), or as part of the overall flora of Saudi Arabia (Collenette, 1999; Chaudhary, 1999-2001).

The objectives of the present work of studying vegetation types are: (1) to describe the vegetation types and response patterns along the altitudinal gradient of the Asir mountain; (2) to recognize and characterize the plant types along the altitudinal gradient as to their distribution and floristic composition; (3) and to elucidate the major environmental factors of floristic and structural variation of the vegetation including altitudinal gradients, climatic, topographic, as well as edaphic and geological features of the study area.

Materials and Methods

The study focuses on a major part of the Tihamah province and escarpments of the Central Asir Mountains between sea level and up to more than 2350m above sea level (asl) at the south-western part of Saudi Arabia. The study area covers 12000km^2, extending between 19°40`-20°50`N & 40°70`-41°70`E (Fig. 1). It comprises diverse ecosystems with altitudinal change and provides interesting aspects for investigating vegetation composition and species diversity. The dominant topographic feature is the Red Sea escarpments, which has a north-western trend across the study area. The topographic decline to the west is steep, as the altitude decreases to less than 1100m few kilometres away from the edge of the escarpments where the Tihamah province is located. Tihamah is marked by numerous small Mountains and ridges, which range in height from 1100 to 2000m.

Geologically, the study area belongs to the greater Afro-Arabian fault and the Arabian shield, which is a part of the Precambrian crustal plate. It is predominated by metamorphic, volcanic and sedimentary rocks and plutonic rocks of late Proterozoic age of the three major groups of these Proterozoic rocks. Quaternary and Alluvial deposits consist of cobble and boulder gravel and course-grained sand, occupying the floors of Wadis, extensive flood-plain deposits are present along the lower ends of the major Wadis. The coastal plain is covered by eolian sand and pediment materials as a thin veneer of poorly sorted, fine to coarse-grained and gravel (Prinz, 1983).

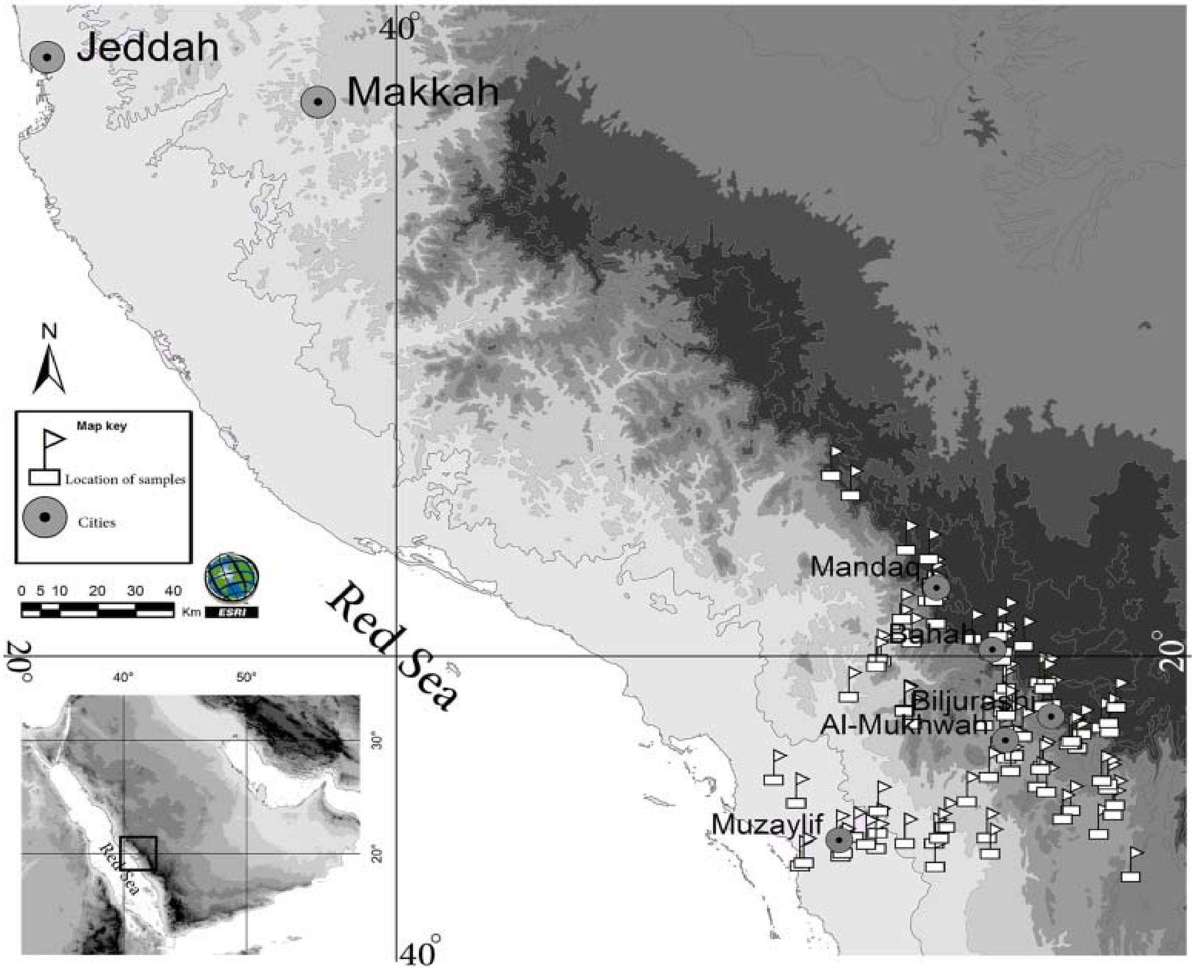

Fig. 1. The study area at Asir Mountains southwest of Saudi Arabia with the locations of sample plots that were observed.

Saudi Arabia climate in general is hot and dry, but the study area lies on the northern tropical climate belts. The local climate is influenced by two types of climates, namely: Monsoon and Mediterranean. The Monsoon climate affects the southern part in summer while the northern part is affected by the Mediterranean climate during winter (Abdullah & Al-Mazroui, 1998). The climate of the study area is hot during the summer with the mean monthly temperature ranging between 22 and 32°C, and minimum temperature ranging between 16 and 24°C while the maximum temperature ranging between 28-39°C (Subyani *et al.*, 2010). The mean annual rainfall in the Tihamah province ranges between 75 and 100mm, but on the mountains it reaches 400mm, falling mainly during winter, with limited rainfall detected in summer (Abdullah & Al-Mazroui, 1998). Based on annual rainfall, the area of Tihamah was classified as arid while the high mountains as semiarid (Abdullah & Al-Mazroui, 1998; Subyani *et al.*, 2010).

A phytosociological investigation was performed through carrying out relevés (plots: quadrates 20×20m each) between 2010 and 2013 according to Braun-Blanquet (1965). With the increase in altitude, a number of plots were selected at each site in relation to the physiographic and physiognomic homogeneity of habitat and vegetation, and to the physical features of the study area. Environmental data including altitude (Alt, m asl), slope (Sl, %) and aspect were collected from the site. Climatic data (annual rainfall (P, mm) and mean annual temperature (T, °C)) were interpolated from a network of several meteorological stations (Abdullah & Al-Mazroui, 1998; Subyani *et al*., 2010).

The collected plant specimens were identified and authors for species were given according to the Saudi Arabian floras (Collenette, 1999; Chaudhary 1999-2001). Life form and cover abundance data for all vascular plants were recorded in the field. The data represented an ordinal transformation of the Braun-Blanquet scale, (i.e. the values *r*, +, and 1 to 5 of the Braun-Blanquet scale were replaced by values 1 to 7). The percentage of the total coverage of each stratum: trees, shrubs and ground layer cover (>300cm, 300-70cm and <70cm high, respectively) were recorded. The average height of trees and shrubs was also recorded. A synthesis table was prepared for studied all plots. The constancy percentage was calculated for all plant species and listed in descending order.

Soil samples, down to a depth of 30cm, were collected from each stand. These were analysed in the laboratories of the Saudi Geological Survey organization as was outlined by Jackson (1962) and Allen *et al.* (1986) to define the following: soil texture (percentage of sand, silt and clay), total organic matter (OC. %), pH, electrical conductivity (EC), content (K_2O, % and P_2O_5, %).

The data collected were used to identify the main physiognomic vegetation types along the altitudinal gradient, where multivariate compatible approaches of classification and ordination were used to define vegetation groups and to explore their relationships with the environmental variables. A total of 74 plots (containing 225 vascular plant taxa) were classified according to the stand-species data matrix and were subject to a multivariate analysis using the two way indicator species analysis (TWINISPAN version 2.3; Hill, 1979) that was employed based on defining species with the same frequency, in order to define vegetation groups and their floristic composition. Hence, characteristic species for each vegetation group were determined using the fidelity coefficient of Tichy & Chytry (2006). After that, the analysis was aimed to relate the species composition of communities with their environmental variation to stratify the vegetation altitudinally and lastly to select the appropriate ordination techniques where species matrices for the entire gradient (except for a single mono-species plot) were analysed using Canonical Correspondence Analysis (CCA; Lepš & Šmilauer, 2003). The entire dataset was analysed as a whole and again carried out separately for each climatic region (22 plots, 166 species for the arid region and 51 plots, 115 species for the semiarid region) taking into consideration all environmental factors. Hence, Hill's scaling method on inter-sample distances, which is appropriate for data with large species turnover across samples, was used. A Monte Carlo permutation test was performed to determine the accuracy of the relationship (999 randomizations) between species and explanatory variables. The trace was used to build the F-ratio statistic (Ter Braak, 1990) and the relationship between the two data sets was considered significant when $P < 0.05$.

Moreover, environmental variations, the total number of species and species diversity indices (species richness (alpha-diversity), species turnover (beta-diversity) (Whittaker, 1972) and average Shannon and Simpson indices (Legendre & Legendre, 1998) were also identified.

All analyses were performed using CANOCO software for windows version 4.56. Among the vegetation groups that were identified in the study area, one-way analysis of variance (ANOVA) was done between the vegetation groups to estimate the significance of separation. These techniques were accomplished according to the SPSS programme for Windows (PASW statistics18, 2009).

Results

The 74 analyzed plots comprised a total of 224 species, 124 genera and 62 families. Therophytes constituted 66 species (29% of the total species) followed by nanophanerophytes, chamaephytes and phanerophytes (49, 44 and 34 species; 22%, 20%, and 15% respectively) and finally 32 species of hemichyptophytes (14%).

TWINSPAN dendrogram divided the data into two regions at levels two and three (except the monospec seashore plot, which was distinct at level one) and four vegetation zones were separated: high mountains, escarpments, Tihamah plains and coastal plains. At level seven, 15 vegetation groups (communities) were characterized (Fig. 2).

The ordination diagram of CCA showed that the plots of high mountains were grouped among themselves within the high values of the first axis, and these were followed by the escarpment's plots at the intermediate level when compared to the Tihamah's plots, and finally the plots of the coastal plains were grouped in the lower values of the first axis. The CCA diagram for all datasets indicated a high correlation between species and environment for all axes as well as the existence of a gradient related to altitude from west (coastal and Tihamah plains) to east (high mountains and escarpments) on the first axis (Fig. 3a). The environmental variables strongly correlated with the first environmental axis were (alt r=0.98), (P r=0.98) and (T r=-0.95). The second axis was correlated with Sl and K_2O. The weight correlation matrices were shown high correlation between Alt and both of T and P, and between soil texture with pH and P_2O_5. Consequently, two CCA ordinations were done for each group: arid region (Tihamah with coastal plains) and semi-arid region (high mountains with escarpments). These were obtained by the agglomerative cluster depending on the climate types of the regions (Table 1). Each one was presented separately to distinguish vegetation groups, which were identified in the TWINSPAN and their correlation with environmental variables.

The Monte Carlo test results were significant for most of variables in all datasets (Alt, Sl, Sp, P, T, Loam, Clay, K_2O, OC and pH). On the other hand, results were significant for Alt, T, Sl, Loam, OC, EC and Sp in arid region, and for T, Sp, Sl and TC in semiarid region.

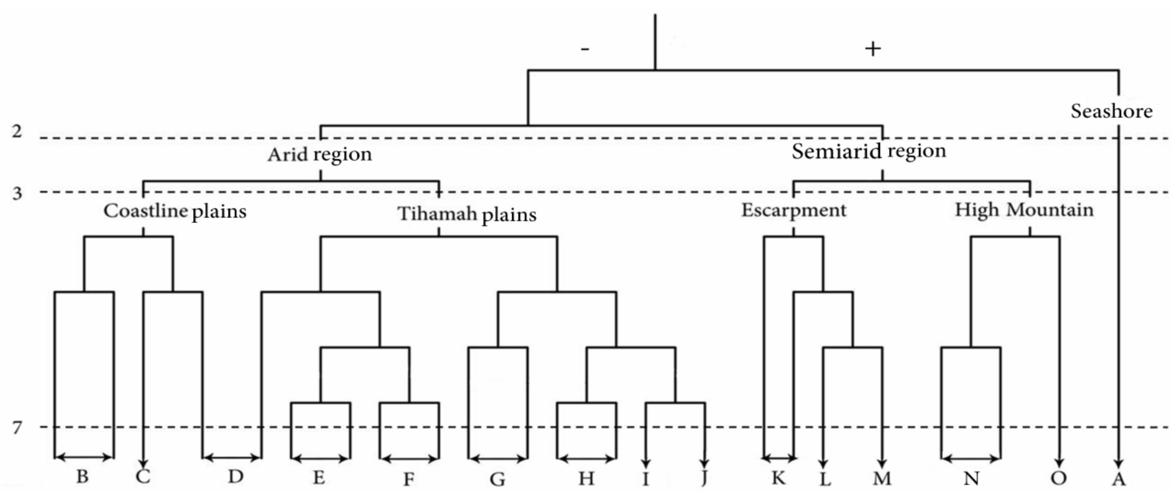

Fig. 2. The results of the Dendrogram from the application of TWINSPAN.

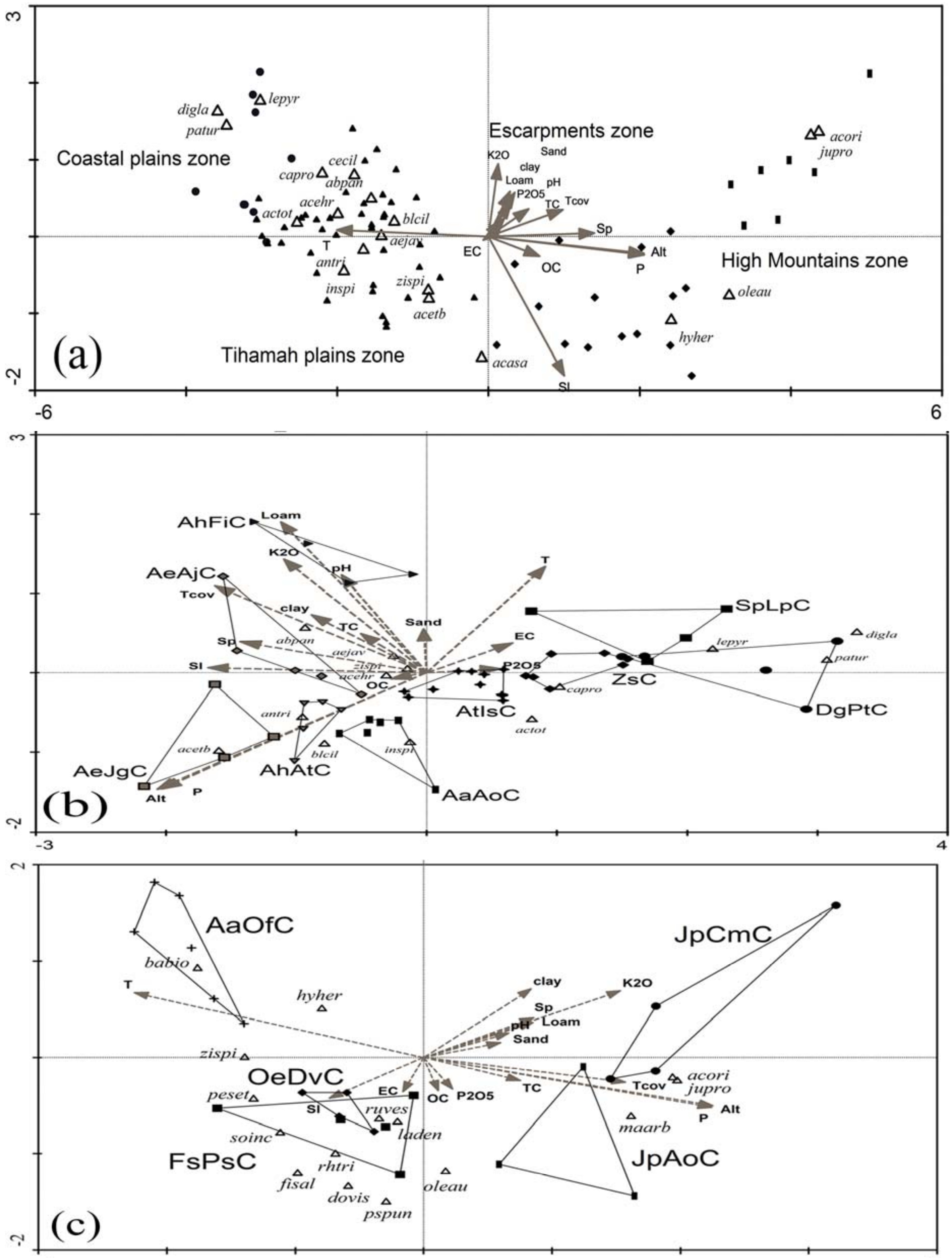

Fig. 3. The CCA ordination diagram for: (A) whole data set (73 plots except for one plot which is a mono-species) sampled in study area; (B) 51 plots in the arid region (Tihamah and Coastal plains plots, except for one plot which is a mono-species); (C) 22 plots in the semiarid region (high mountains and escarpments plots) sampled. The species–plots and retrospective projection of the environmental variables were presented (empty triangles for species, other solid shapes for plots and arrows for environmental variables). Only species with the highest weight are shown. Plots of each of the group were indicated by enclosed line.

Table 1. Means ± standard deviations of all variable for the ten vegetation groups of the arid region (The minimum and maximum values of soil characters are shaded).

Variables	Coastal plains			Tihamah plains						
	AmG	DgPtG	SpTnG	ZsG	AtIsG	AhFiG	AhAjG	AhAtG	AeJgG	AaAoG
Altitude (Alt, m)	14	132 ± 55	155 ± 23	147 ± 85	409 ± 105	580 ± 161	350 ± 48	464 ± 86	715 ± 146	988 ± 167
Rainfall (P, mm)	70	84 ± 7	87 ± 2	84 ± 10	111 ± 11	128 ± 16	105 ± 4	115 ± 11	142 ± 16	168 ± 17
Temperature (T, C°)	32	31 ± 0.5	31 ± 0.5	32 ± 0.6	30 ± 0.5	30 ± 1	31 ± 0.5	30 ± 0.5	29 ± 0.5	29 ± 1
Slop (Sl, %)	0	0	0	0	8 ± 13	22 ± 20	16 ± 36	10 ± 22	26 ± 21	60 ± 14
Total cover (Tcov, %)	70	15 ± 10	37 ± 23	38 ± 19	47 ± 12	48 ± 21	58 ± 29	60 ± 25	50 ± 20	32 ± 19
Number of species (Sp)	1±	7.7 ± 2.1	6.5 ± 1	10 ± 4.5	9.6 ± 2.1	15 ± 2	11.6 ± 5.7	14.1 ± 6.9	14 ± 3	10 ± 2.8
Soil characters										
P2O5 (%)	0.41	0.26 ± 0.01	0.2± 0 .01	0.36 ± 0.2	0.24 ± 0.05	0.3 ± 0.02	0.05 ± 0.01	0.05±0.01	0.13±0.01	0.26 ± 0.02
K2O (%)	0.10	0.16 ± 0.1	0.55 ± 0.5	1.41 ± 0.02	1.55 ± 0.1	1.79 ± 0.8	1.5 ± 0.1	1.45±0.5	1.58±0.2	0.16 ± 0.02
Total organic Carbon (TC, %)	0.14	0.06 ± 0.01	0.15 ± 0.1	0.90 ± 1.1	0.24 ± 0.1	0.75 ± 0.1	0.21 ± 0.1	0.19±0.1	0.50±0.1	0.08 ± 0.05
Organic matter (OC, %)	0.24	0.10 ± 0.01	0.22 ± 0.2	0.82 ± 1	0.2 ± 0.05	0.71 ± 0.1	0.09 ± 0.01	0.13±0.1	0.47±0.3	0.14 ± 0.01
EC (mS cm-1)	20.20	1.99 ± 2.1	1.13 ± 0.3	0.54 ± 0.3	0.72 ± 0.2	0.58 ± 0.3	0.49 ± 0.2	0.74±1.1	0.56±0.1	0.65 ± 0.01
pH	8.11	7.12 ± 0.1	7.45 ± 0.5	7.79 ± 0.4	8.05 ± 0.01	7.98 ± 0.02	7.83 ± 0.1	7.71±0.1	8.31±0.3	7.35 ± 0.04
Sand (%)	90	89 ± 6	67 ± 18	75 ± 7	45 ± 10	65 ± 8	41 ± 7	59±25	54±8	53 ± 5
Loam (%)	2	9 ± 8	29 ± 17	19 ± 6	45 ± 12	25 ± 5	53 ± 7	35±25	36±8	42 ± 4
Clay (%)	8	3 ± 2	4 ± 1	6 ± 1	10 ± 3	10 ± 4	7 ± 1	7±2	10±1	5 ± 3
Texture	sand	loamy-sand to sand	Sandy loamy	Loamy sand to sandy loam	loam	Sandy loam	silt-loam to loam	Sandy loam to loam	Sandy loam	Sandy loam to loam

Zonation and vegetation types: By integrating the results of classification and ordination of this study with the description of the other studies (Vesey-Fitzgerald, 1955; Abdulfatih, 1992; Chaudhary & Al-Jowaid, 1999; Al-Nafie, 2004) the main geo-altitudinal vegetation zones and vegetation groups within each zone and their ecological aspects were identified (Fig. 4).

Arid region: The TWINSPAN classification and CCA ordination of arid regions have shown a clear-cut separation at level three between two vegetation zones: coastal and Tihamah plains. CCA showed more than one environmental gradient, as reflected by percentage of variation explained by axis (eigenvalues 59.3%, 37.3% and 32.5% for axes 1, 2 and 3, respectively). The first canonical axis in species ordination was negatively correlated with many variables and the highest were (Alt r=-0.67) and (P r=-0.66) as well as Tcov, Sl and Sp, but it was positively correlated with (T r=0.25), (EC r=0.22) and (P_2O_5 r=0.19). The second canonical axis was correlated positively with loam, K_2O, and pH and negatively with Alt and P. The CCA diagram for arid region plots showed that group plots of TWINSPAN classification were grouped among themselves. On the other hand, coastal plains groups were grouped at the high value of the first axis while Tihamah plains groups were grouped at the low value (Fig. 3b).

The vegetation of the coastal plains zone: This zone, which is the driest part in this study, is located on coastal plains from seashore to 200m. The rainfall is very low (<100mm) and the temperature is the highest (≥32°C). In fact, xerophytes vegetation is the most dominant with a low converge. The coastal plains are covered by a thin veneer of poorly sorted, fine to coarse-grained sand and gravel that was reflected on the vegetation groups which recorded the highest texture percentage and low values of TC and K_2O (Table 1). The analysis has identified three vegetation groups (Table 2). ANOVA has shown a high significance between these groups in this zone.

***Avicennia marina* group (AmG):** Very special environmental conditions could be seen along the seashore, e.g. soil salinity (EC=20.2 mS cm^{-1}, Table 1), water holding capacity and available water in the soil, height above sea level and deluge by high tide, distance from the shore and texture deposits. It consists of halophytic formations, which are featured by *Avicennia marina*. This group was identified in the field but excluded from the classification analysis because it is always represented by a mono-specific coenoses (Table 2). This group was noticed at several small patches on the coastline in muddy and salty depressions. In fact, most areas of this group, which is scattered along the seashore, are affected by human activities such as fishing, new infrastructure and tourism; activities that threaten this group, which faces reduction by time (El-Juhany, 2009).

***Dipterygium glaucum-Panicum turgidum* group (DgPtG):** This group spreads in the low lands in the inner areas of the coastal plains where the altitude doesn't exceed 200m and it occupies an area as far as 20-30km from the sea-shore. It is covered by quaternary deposits substratum consisting of eolian sand dunes which can reach a height of 4m (Table 2).

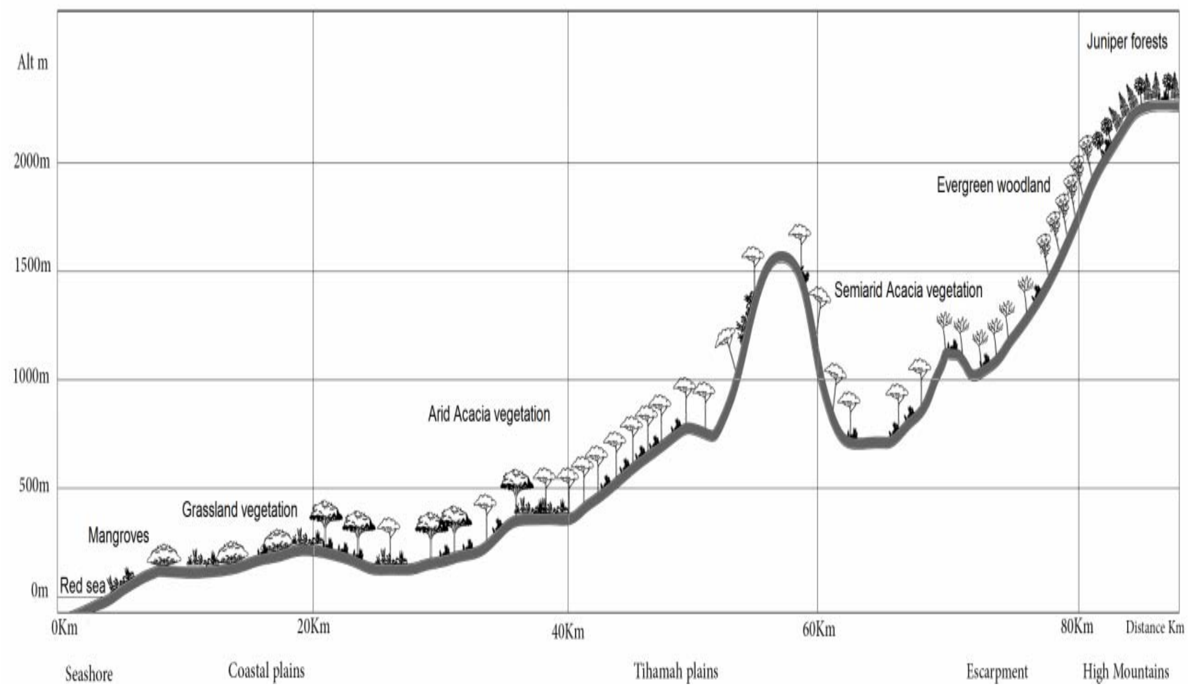

Fig. 4. Profile diagram of Asir Mountains and the main vegetation zones. East (right)-west (left), horizontal distance (km) from red sea.

***Salvadora persica-Leptadenia pyrotechnica* group (SpLpG):** It is located along coastal plains at downstream (deltas) of major Wadis where the flood plain silt deposits with deep and sandy loamy soil. Water abundance in these areas allows for more widespread agricultural activities however without any long-term continuation leads to the destruction of this vegetation group especially by felling and cutting the trees and shrubs strata (Table 2).

The vegetation of the Tihamah plateau zone: The altitude of Tihamah plateau is ranging from 200 to 1100m (Fig. 3b) and comprised topographically by an undulating plateau and flat areas interspersed with a variety of sediments and rocky hills and small mountains (e.g. Ghamad, Shada Al-Aala, Shada Al-Asfal) which are separated by watercourses and Wadis. The rainfall is low (100-180mm) and the temperature is high (29-32°C). Many terraces could be seen at the edge of the slopes, which are used for agriculture. This zone is dominated by many species of *Acacia* mainly *Acacia ehrenbergiana* which is presented in all vegetation groups by 80-100%, and could be shared by *Acacia etbaica*, *Acacia tortilis* and other arboreal species such as *Commiphora myrrha*. The environmental aspects were reflected on the vegetation structure along the Tihamah plateau by seven vegetation groups according to habitat and ecological aspect (Tables 1 and 2).

***Acacia tortilis-Indigofera spinosa* group (AtIsG):** It occupies the low lands of the Tihamah plains; starting at 300-600m with deep sediment soil and very gentle or almost flat slope. Sediment and metamorphic rocks like Gabbro and Fledsparthic are the dominant types. The total converge is low and Simpson and Shannon indices are 7.9 and 2.16 respectively. Field observations, showed that most elements of AtIsC especially *Acacia tortilis* had occupied in the past additional areas exceeding what it is currently occupying near the eolian sand towards the sea. The moving sand dunes had extended their areas of coverage to these locations, superseding the presence of this Acacia species, which is losing grip on sand dunes with a low percentage of renewal (Table 2).

***Acacia ehrenbergiana-Aerva javanica* group (AhAjG):** This is the main vegetation group in the Tihamah plains, it occupies most plains, and sometimes hills, at 300-400m where landscape is rocky with gentle slopes and shallow soils with high erosion. The parent rock is a share of sediment and metamorphosed basalt to green rocks and Diorite. The total coverage is (58±29) and the ground cover is the highest in Tihamah zone (Table 2).

***Acacia ehrenbergiana-Fagonia indica* group (AhFiG):** This group spreads on the rocky hilly areas of Tihamah at an altitude of 400-800m, it uses the soil among rocky cracks and holes. The parent rocks are Basaltic metamorphosed to green rocks and Monzogranite. Soil contains a high percentage of clay and K_2O. This group has the highest Simpson and Shannon indices in Tihamah (13.5, 2.59, respectively). The total coverage is (48±21) and the trees stratum is 30±18, (Table 2).

***Acacia ehrenbergiana-Anisotes trisulcus* group (AhAtG):** This group spreads on plains and open Wadis of Tihamah at altitude range of 350-550m, with deep sediment and a gentle slope. The parent rocks are Basaltic metamorphosed and Granite. Soil texture is sandy loam to loam with low percentage of P_2O_5 (Table 2).

Table 2. Synoptic table showing the percent constancy of diagnostic species (and their abbreviations) occurrence of the groups (shaded values) in the arid region (Tihamah and Coastal plains vegetation zones) identified by multivariate analysis. The diagnostic species are presented in a descending order of indicator value. The average values of diversity indices (species richness, species turnover, Shannon index and Simpson index) were presented

Diversity indices	AmG	DgPtG	SpTnG	ZsG	AtIsG	AhFiG	AhAjG	AhAtG	AeJgG	AaAoG
	Coastal plains			Tihamah plains						
No. of stands	1	6	4	7	7	6	5	6	6	4
No. of species	1	20	10	30	30	43	34	55	46	20
Species richness (alpha-diversity)	1	7.1	6.0	9.5	8.9	14.2	10.0	13.1	13.5	8.3
Species turnover (beta-diversity)	1	2.8	1.7	3.2	4.8	2.1	3.4	4.2	3.4	2.4
Shannon index	0	1.9	1.8	2.16	2.16	2.63	2.21	2.5	2.59	2.1
Simpson index	1	6.7	5.6	9.0	7.9	12.5	8.5	12	12.4	7.8
Avicenia mariana-avmar	100	.	.	.	.	.	.	.	.	.
Dipterygium glaucum-Panicum turgidum group (DgPtG)										
Dipterygium glaucum-digla	.	100	75	57	.	.	.	.	.	.
Panicum turgidum-patur	.	100	50	43	.	33	.	.	.	.
Polygala erioptera-poeri	.	50	.	43	.	.	.	.	.	.
Cyperus conglomeratus-cycon	.	83	.	.	.	.	.	.	.	.
Leptadenia pyrotechnica-Salvadora persica group (LpSpG)										
Leptadenia pyrotechnica-lepyr	.	33	100	29	29	33	.	.	17	.
Salvadora persica-saper	.	.	100	29	14	.	.	.	.	.
Tamarix nilotica-tanil	.	.	100	43	.	.	.	.	.	.
Cadaba rutandifolia-carut	.	.	50	43	.	17	.	.	.	.
Maerua obilongifolia-maobi	.	.	50	29	.	17	.	14	17	.
Zizyphus spina-christi-Calotropis procera group (ZsG)										
Zizyphus spina-christi-zispi	.	.	25	86	29	50	60	29	67	.
Calotropis procera-capro	.	33	.	43	57	33	20	14	33	20
Citrullus colocynthis-cicol	.	17	.	71	14	50	20	43	17	.
Capparis decidua-cadec	.	17	.	43	14	.	.	.	.	.
Cadaba farinosa-cafar	.	.	.	29	.	17	.	.	.	.
Acacia tortilis-Indigofera spinosa group (AtIsG)										
Acacia tortilis-actor	.	83	75	57	100	83	20	14	.	60
Indigofera spinosa-inspi	.	17	.	43	86	83	40	29	90	20

Table 2. (Cont'd.).

Diversity indices	AmG	DgPtG	SpTnG	ZsG	AtIsG	AhFiG	AhAjG	AhAtG	AeJgG	AaAoG
	Coastal plains			Tihamah plains						
Stipa capensis-stcap	.	.	.	.	43	.	.	29	17	.
Senna alexandrina-seale	.	.	.	.	43	.	.	14	17	.
Acacia hamulosa-acham	.	.	.	.	29	.	.	29	17	.
Acacia ehrenbergiana-acehr	.	17	25	86	100	100	100	100	83	80
Acacia ehrenbergiana-fagonia indica group (AhFiG)										
Fagonia indica-faind	.	.	.	14	14	100	.	14	17	.
Heliotropium arbainense-hearb	.	33	.	14	29	67	40	14	.	.
Caralluma russelliana-carus	.	.	.	.	43	50	.	29	17	.
Commephora myrrha-comyr	.	.	.	.	.	33	.	14	17	.
Maerua crassifolia-macra	.	.	.	14	14	50	.	.	.	.
Acacia ehrenbergiana-Aerva javanica group (AhAjG)										
Aerva javanica-aejav	.	33	.	57	43	83	100	86	67	20
Cenchrus ciliaris-cecil	.	.	.	14	.	.	100	57	17	.
Abutulon pannosum-abpan	.	.	.	14	29	50	80	57	67	20
Acacia ehrenbergiana-Anisotes trisulcus group (AhAtG)										
Anisotes trisulcus-antri	.	.	.	.	71	83	40	86	67	60
Ficus salicifolia-fisal	.	.	.	.	.	.	.	43	33	.
Cassia italica-caita	.	.	.	.	14	.	20	43	17	.
Cissus quadrangularis-ciqua	.	.	.	14	.	33	20	43	17	.
Acacia etbaica- Jatropha glauca group (AeJgG)										
Acacia etbaica-acetb	.	.	.	.	29	17	.	57	83	60
Jatropha glauca-jagla	.	.	.	.	14	17	.	29	67	.
Blepharis ciliaris-becil	.	.	.	29	14	33	.	43	67	20
Grewia tenax-geten	.	.	.	.	14	50	.	14	33	20
Acacia asak-Adenium obesum group (AaAoG)										
Acacia asak-acasa	.	.	.	.	14	17	20	14	.	80
Adenium obesum-adobe	.	.	.	.	.	.	20	14	50	60
Parentuchellia latifolia-palat	.	.	.	.	.	.	.	.	.	40
Capparis spinosa-capspi	.	.	.	.	.	.	.	.	.	40

***Acacia etbaica-Jatropha glauca* group (AeJgG):** This group spreads near the lower slopes of western escarpments of the Asir Mountains and on the western and northern slopes of the Ghamed Mountain; the group occupies rocky steep slopes at an altitude of 550-900m. The parent rocks are Andesitic and Dacitic with Basaltic metamorphosed and alluvial deposits (Table 2).

***Acacia asak-Adenium obesum* group (AaAoG):** It is a transition group between Tihamah and the escarpments; four species of Acacia occur at different abundances. It spreads at an altitude of 800-1100m on the steep rocky hilly areas of Tihamah (60±14%), the soil is shallow and confined to areas among rocky cracks and holes with a high level of erosion. The parent rocks are Basaltic metamorphosed to green rocks and Monzogranite shared with Grano-diorite. The total coverage is low ranging between 20%-60% and similarly the trees stratum, and the Simpson and Shannon indices are the lowest in Tihamah (Table 2).

***Ziziphus spina-christi* group (ZsG):** This is the main group between Tihamah and coastal Wadis, it is spread as patches along the Wadis depending on the behaviour activity of the watercourse; it occupies most watercourses between 100 and 400m in the middle part of the watershed at very gentle or flat slopes where the sediments are deep. The group is affluent by many species from the neighbouring vegetation groups (Table 2).

Semiarid region: The TWINSPAN classification and CCA ordination of semiarid region (escarpments and high mountains) showed more than one environmental gradient, as reflected by percentage of variation explained by axis (eigenvalues 0.714, 0.481 and 0.408 for axes 1–3, respectively). The CCA diagram showed that the escarpments vegetation groups were grouped at the negative side of the first axis while the high mountain vegetation groups were at the positive side (Fig. 3c). The first canonical axis in species ordination was positively correlated with (Alt, r=0.92 and P, r=0.92), Tcov and K_2O, but it was negatively correlated with (T r=-0.92) and Sl. The second canonical axis was positively correlated with clay, K_2O and T, and negatively with Alt and P. The weights of correlation matrices showed a high correlation between Alt and T, P and between soil texture with pH, OC, K_2O and P_2O_5.

The vegetation of the escarpments zone: The vegetation of the escarpments appeared from 1100 to 2000m. The rainfall is more than 200mm and the mean temperature is between 22-29°C. The zone is facing the humid wind; hence the climate belongs to the semiarid region. The high extent of slopes/escarpments in this range exposes the soil to a high level of erosion; hence, rocks are widely exposed and this confines the vegetation to areas where soil is available at rock cracks and holes. In fact, soil characteristics of the percentage of OC, TC and K_2O have decreased (Table 3). The analysis has identified three vegetation groups (Table 4). ANOVA has shown a high significance between these groups in each zone.

***Acacia asak-Otostegia fruticosa* group (AaOfG) (Table 4):** It spreads in a zone between 1100-1600m where the rainfall is about 170-250mm and the mean temperature is between 25-29°C. The parent rocks are metamorphic consisting of Granite, Monzogranite, Diorite, Gabbro and Amphibolite. The soil is eroded and spread on rocky slopes where soil in holes and spaces is being protected by rocks. The total coverage is low and the tree stratum coverage is no more than 20% and the diversity indices are low in semiarid region (e.g. 2.7 and 14.3, Shannon and Simpson indices respectively, Table 4)

***Olea europaea-Dodonaea viscosa* group (OeDvG) (Table 4):** The coverage is highly affected by slope; it consists of many annual and perennial species that shared Juniper forest in the height. It is spread in a zone between 1600-2000m. The rainfall is about 230-270mm and the mean temperature is 22-25°C. The soil texture is sandy-loam. The total coverage is 60-80% mainly contributed by ground cover. The tree stratum height is 6-10m and it covers no more than 20%.

***Rhus retinorrhaea -Pennisetum setaceum* group (RrPsG) (Table 4):** It spreads along water-courses of the watershed upper stream along the escarpments which receive more water than the surrounding rocky areas where the OeDvC and AsOfC are widespread. The parent rocks are metamorphic and consist of Granite, Monzogranite, Diorite, and Gabbro. The soil characteristics are very low K_2O, TC and OC.

The vegetation of the high mountains zone: The high mountains vegetation zone, which extends from 2000m to summits, has a semiarid climate with annual rainfall exceeding 260mm and mean annual temperature less than 22°C. It is characterized by a juniper forest with *Acacia origena* and *Olea europaea* subsp. *cuspidata* and many other shrubs such as *Clutia myricoides*, *Maytenus arbutifolia* and several annual and perennial ground cover species. Two vegetation groups were identified in this zone and were present in the CCA diagram at the positive side of the first axis (Fig. 3c) (Table 4).

***Juniperus procera-Clutia myricoides* group (JpCmG) (Table 4):** It is the main vegetal unit in the high areas above 2000m. It is recognized by a high total coverage, number of species and Shannon index (>80%, 65, 3 respectively). The soil is developed and the soil litter layer can always be recognized and OC is the highest. The tree stratum mostly reaches a height of 10m ranging between 40-60% with high cover abundance, the shrubs stratum reaches a height of 2m and coverage of more than 30%, the ground layer cover is very dense not falling below 60%. The JpCmC represents the sub-climax vegetation in this zone; it is only reported from few limited stands such as Raghadan forest and some inaccessible sites with difficult terrain.

Table 3. Means ± Standard Deviations of all variable for the five vegetation groups of the semiarid region (The minimum and maximum values of soil characters are shaded).

Variable	Escarpments			High mountains	
	AaOfG	RtPsG	OeDvG	JpAoG	JpCmG
Altitude (Alt, m)	1397 ± 167	1665 ± 299	1735 ± 115	2111 ± 135	2140 ± 123
Rainfall (P, mm)	209 ± 17	236 ± 30	242 ± 11	281 ± 13	284 ± 14
Temperature (T, C°)	26 ± 2	25 ± 2	24 ± 1	22 ± 1	22 ± 1
Slop (Sl, %)	45 ± 26	70 ± 20	42 ± 28	28 ± 16	30 ± 17
Total cover (Tocv, %)	39 ± 7	53 ± 25	70 ± 7	60 ± 29	83 ± 6
Number of Species (Sp)	17 ± 4	26 ±8	20 ± 4	17 ± 4	27 ± 13
Soil characters					
P_2O_5 (%)	0.36 ± 0.05	0.18 ± 0.1	0.21 ± 0.05	0.21 ± 0.05	0.14 ± 0.1
K_2O (%)	0.24 ± 0.05	0.22 ± 0.2	0.32 ± 0.05	2 ± 0.05	1.08 ± 0.8
Total organic Carbon (TC, %)	0.42 ± 0.1	0.10 ± 0.1	0.74 ± 0.2	1.42 ± 0.2	0.49 ± 0.4
Organic matter (OC, %)	0.76 ± 0.1	0.17 ± 0.1	1.24 ± 0.2	1.30 ± 0.1	0.51 ± 0.3
E.C (mS cm^{-1})	1.83 ± 0.1	1.38 ± 1.6	0.31 ± 0.1	0.58 ± 0.3	0.28 ± 0.1
pH	7.8 ± 0.6	7.6 ± 0.1	7.5 ± 0.1	8.1 ± 0.3	7.5 ± 0.3
Sand (%)	64 ± 5	70 ± 3	66 ± 1	65 ± 3	60 ± 2
Loam (%)	29 ± 1	27 ± 2	29 ± 3	27 ± 0	33 ± 2
Clay (%)	8 ± 4	4 ± 1	6 ± 4	8 ± 1	7 ± 2
Texture	Sandy loam	Sandy loam	Sandy loam	sandy loam	Sandy loam

Table 4. Synoptic table showing the percent constancy of diagnostic species (and their abbreviations) occurrence of the groups (shaded values) in the semiarid region (escarpments and high mountains vegetation zones) identified by the multivariate analysis. The diagnostic species are presented in a descending order of indicator value. The average values of diversity indices (species richness, species turnover, Shannon index and Simpson index) were presented.

Diversity indices	AaOfG	RtPsG	OeDvG	JpAoG	JpCmG
	Escarpments			High mountains	
No. of stands	5	4	5	3	4
No. of species	44	62	56	45	65
Species richness (alpha-diversity)	15.9	25.2	21.3	16.6	21.7
Species turnover (beta-diversity)	2.8	2.5	2.6	2.7	3
Shannon index	2.7	3.2	3.1	2.8	3
Simpson index	14.3	23.9	20	15.2	17.3
Acacia asak-Otostegia fruticosa group (AaOfG)					
Acacia asak-acasa	100	.	.	.	.
Otostegia fruticosa ssp.*schimperi*-otfru	80	75	.	25	.
Barleria biospinosa-babio	80	75	20	.	.
Kickxia pseudoscoparia-kipse	60	50	60	.	.
Combretum molle-comol	60	.	.	.	.
Zehneria scabra-zesca	60	.	.	.	.
Rhus retinorrhoea -Pennisetum setaceum group (RtPsG)					
Rhus retinorrhoea-rhret	20	100	40	50	.
Pennisetum setaceum-peset	40	100	80	.	.
Solanum incanum-soinc	20	100	60	25	.
Ficus glumosa-figlu	20	75	40	.	.
Zizyphus spina-christi	60	75	50	.	.
Ficus salisifoia-fisal	.	75	60	.	.
Olea eauropaea ssp. *cuspidata-Dodoneae viscosa* group (OeDvG)					
Olea eauropaea ssp. *cuspidata*-oleau	.	75	100	75	67
Dodoneae viscose-dovis	.	75	80	25	.
Rumex vesicarius-ruves	40	50	100	50	33
Hyperhenia herta-hyhet	80	75	100	75	67
Psiadia punctulata-pspun	.	50	80	25	.
Pulicaria crispa-plcri	.	50	60	.	33
Juniperus procera-Acacia origna group (JpAoG)					
Juniperus procera-jupro	.	25	80	100	100
Acacia origna-acori	.	25	.	100	100
Lavandula dentate-laden	40	25	60	100	25
Sageretia thea-sathe	.	.	60	67	.
Ephedra foliate-epfol	.	25	20	67	33
Pluchea dioscoridis-pldio	.	.	.	67	25
Juniperus procera- Clutia myricoides group (JpCmG)					
Clutia myricoides-clmyr	.	25	20	67	100
Maytenus arbutifolia-maarb	.	50	40	75	100
Achillea bieberstrinii-acbie	.	.	.	.	75
Felicia dentata-feden	.	.	.	25	75
Euphorbia schimperiana-eusch	.	.	.	.	50

***Juniperus procera-Acacia origena* group (JpAoG) (Table 4):** It spreads in the same altitude (>2000m). The parent rocks are fine to medium-grained feldspathic greywacke, black carbonaceous and Amphibolite. The soil is also developed and the litter layer could be seen. In fact, this group is recognized by the total coverage, number of species and Shannon index (<60%, 36, 2.8 respectively), with a low abundance, and the tree stratum not exceeding 40% with *Acacia origena* as the main tree that shares *Juniperus procera* forest. The components of this group and in particular the arboreal stratum, are liable to disappear and hence the ground cover will decrease, where the arboreal density of juniper and acacia as well as several accompanied species is decreasing. This paves the way for other species of a degrading indication to appear and increase which will cause the dominance of another vegetation component that has an indication of deterioration. It is a sign of a disturbed situation of the Juniper forest when the human activities increase. This leads to a change of vegetation structures especially with the disappearance of most of the arboreal stratum and changes to the ground cover and shrubs stratum.

Discussion

Altitude is a complex gradient where several biotic and abiotic factors correlate (Whittaker, 1967). It represents the principal environmental factors such as temperature and rainfall in determining vegetal species distribution. Therefore, the decrease of rainfall produces dramatic changes in species composition and abundance (Blundo *et al*., 2011), and similarly this can be seen upon moving from the semiarid region (p>200mm) to the arid region (P, 70-200mm), and also when the temperature increases from 28 to 35°C (Table 2).

The results of this study showed that two main climate regions, four zones, 15 vegetation groups and five types of vegetation were recorded: juniper forests at the high mountain zone; evergreen woodland and semiarid Acacia woodland vegetation in the escarpment zone; Arid Acacia woodland vegetation in the Tihamah zone; grassland in the coastal zone; and mangroves along the seashore.

The first appearance of *Juniperus procera* is at 1800m, its abundance increases rapidly with elevation and becomes fully dominant at an altitude of 2000m in a juniper forest which is presented by JpAoG and JpMcG. The abundance of the *Juniperus procera* and *Acacia origena* in Juniper forests decreases gradually until their complete disappearance when rainfall decreases to less than 200mm. Subsequently with altitudinal gradients, different vegetation emerges with the start of the escarpments. These escarpments are featured by steep slopes, the erosion of soil to largely bare rock where the soil becomes confined to some holes and cracks that harbour the vegetal cover in that area. On these slopes, the vegetal dominance and composition changes with the increase in altitude. At the higher escarpments, (>1600m) the vegetation consists of AaOfG, which consists of evergreen vegetation that belongs to *Olea*, *Ficus*, *Rhus* and *Pistacia* species, while at the lower escarpments, where the elevation is less than 1600m, the vegetation is dominated by semiarid Acacias, such as *Acacia asak,* consisting of AaOfG as well as AaAoG as a transition group into the next zone. After that, the vegetation changes dramatically in Tihamah being replaced by a different vegetal composition consisting of arid Acacia vegetation, which consists of *Acacia ehrenbergiana, Acacia etbaica* and *Acacia tortilis*. Five groups were identified at the Tihamah plains; they are AtIsG, AhAjG, AhFiG, AhAtG and AeJgG. Then, in the coastal plains zone, different vegetation is present which is grassland vegetation consisting of special xerophytes perennial and annual species, such as *Dipterygium glaucum*, *Panicum turgidum*, *Cyperus conglomeratus, Polygala erioptera* which are identified by DgPtG.

In addition, the vegetation structure at watercourses on Wadies is affected by the altitudinal gradient. It can be seen that the upper-stream vegetation has RrPsG at the escarpments, then the vegetation of the watercourses on Tihamah province changes to ZsG, which is largely shared by *Acacia tortilis*. Furthermore, the conditions of downstream of the major Wadis watershed at the coastal plains, allow few leafy shrubs such as *Cadaba rotundifolia* with *Leptadenia pyrotechnica* and tree species such as *Tamarix nilotica* to become dominant through benefiting from water abundance with few species of perennials such as *Panicum turgidum*. This vegetation is the characteristic of SpLpG.

CCA ordination is a good method for reflecting correlations between the biotic communities and environmental gradients (Lepš & Šmilauer, 2003); it allows us to visualize the patterns of variation of the floristic composition along gradients generated by environmental variables. Diagrams obtained showed that the first axis was highly correlated with Alt, P and T, but the second axis was correlated mainly with soil conditions (texture, pH, EC and cations).

Species diversity also varies depending on elevation, This may explain the increase in species diversity with increase in elevation (for example Shannon index: DgPtG, AhFiG, AaOfG and JpCmG: 1.9, 2.63, 2.7, 3 respectively Tables 2 and 4) except for the Wadis where an increase in the diversity was noticed due to sharing more species from nearby groups as in RrPsG (Table 4). On the other hand, Tcvo and Sp of the groups have also increased. This result predicates that the relation between altitude and species composition is very strong, and the vegetation groups' structure and diversity have been associated mainly with climate and soil conditions (Batanouny & Baeshin, 1983; El-Demerdash *et al*., 1994; Abd-El-Ghani, 1997; Hemp, 2006; Al-Ghamdi *et al*., 2009; De Sanctis *et al*., 2013). Many of soil conditions (OC, pH, K_2O and texture) were significant in the Monte-Carlo test and they were very effective to distinguish between the groups of the Tihamah plains (e.g. AtIsG, from AeAjG and AeJgG, from AhAtG).

The topographical factors and geological substrata have a clear effect on the distribution of vegetation groups in the study area. This effect could be seen in the Tihamah and coastal plains, where the sediment is deep and the slope is gentle and AhFiG and AhAtG can be seen, but on shallow soil and steep landscapes other vegetation appears like AtIsG, AhFiG, AeJgG and AaAoG. On the other hand, DgPtG was recorded on eolian sand dunes and SpLpG on deposits in Wadis delta.

The groups identified in this study were similar to many others that were recorded around the area. For example, *Acacia tortilis*, *Acacia ehrenbergiana,* and *Commiphora myrrha*, were recorded on rocky hills in Tihamah, the Asir Mountains and Hejaz Mountains (Vesey-Fitzgerald, 1955; Abdulfatih, 1992; El-Demerdash *et al*., 1994; Abd-El-Ghani, 1997; Chaudhary & Al-Jowaid, 1999; Al-Ghamdi *et al*., 2009). On the other hand, many of these groups were recorded from areas on the western Coast of the Red Sea in Sudan (Kassas, 1957) and Egypt (Galal & Fahmy, 2012). Many authors have also described AmC along the coastline of the Arabian Peninsula (Chaudhary & Al-Jowaid, 1999; De Sanctis *et al*., 2013).

Diptergium glaucum was used to identify the group in the Wadis with sand deposits in Hejaz Mountains at 700m asl (Batanouny & Baeshin, 1983). However, the vegetation of Wadis was identified in three groups RrPsG, ZsG and SpLpG. Similarly, these groups were recorded using *Ziziphus spina-christi*, *Salvadora persica*, *Leptadenia pyrotechnica*, *Ficus salicifolia* (Batanouny & Baeshin, 1983; El-Demerdash *et al*., 1994; Chaudhary & Al-Jowaid, 1999).

Human interferences have a prominent role in changing vegetation structures. These effects were overgrazing, wood cutting for fuel and construction activities especially road and infrastructure (Batanouny & Baeshin, 1983; El-Demerdash *et al*., 1994; Abd-El-Ghani, 1997; Al-Ghamdi *et al*., 2009; El-Juhany & Aref, 2012). On the other hand, during the last two decades urban areas were extended widely around cities, which caused high disturbance in the vegetation; these cases could be seen between the cities of Al-Baha and Mandaqe.

High levels of soil erosion were recorded in the study area where vegetation was destroyed or removed from slopes and hills. This reason was distinguished by reducing the number of species in the ground cover as seen in AeAjG, CrAeG and AeAtG.

On the other hand, agricultural activities using terraces along the Wadis in Tihamah which depend on ground water for irrigation caused the removal of natural vegetation at the Wadis' banks in the transformation process. Other types of the agricultural terraces were seen on the slopes of the juniper forests of the high mountains zone. In fact, most of these terraces were protected under the traditional protection system, “the Tribal Hima”, which keeps forest trees for wood or protects the whole area for several activities like bee-keeping, grass producing and fuel gathering. These terraces need too much maintenance to keep the production conditions. However, with people now abandoning most agricultural work, the tribal Hima protection system has ceased and these terraces are now facing a high level of anthropogenic disturbance, which will lead to the loss of the soil on these terraces forever.

Conclusion

The present study is aimed at providing comprehensive phytosociologyical classification of plant groups along altitudinal gradients of vegetation zones in the central Asir Mountains and their relationships with environmental factors including climate, edaphic and geological components. The vegetation of the study area belongs to the Afro-Mountains and Somalia-Masai four vegetation zones and five types of vegetation were identified. Mangroves along the seashore and grassland vegetation in arid coastal plains mainly on an alluvial substratum between sea level and 200m; the interspersed hills and plateaus of Tihamah arid region Arid Acacia vegetation spread from 200 to 1100m; evergreen woodland and semiarid Acacia vegetation in the escarpments from 1100 to 2000m in the semi-arid region; and juniper forests occupying a semi-arid high mountains zone from 2000m to the summit. Within these zones, 15 vegetation groups were recognized and clearly separated among them. The relation between altitude and species composition is very strong; it was affected by the climate factors (rainfall and temperature) and vegetal structure (species richness and coverage), and the plant groups' structure and diversity have been associated mainly with edaphic factors which play the leading role in the distribution of the different vegetation group types on a local scale. Human and animal impacts have a significant effect on modifying the distribution and abundance of plant species.

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