Pak. J. Bot**., 55(4): 1483-1495, 2023.** **DOI: http://dx.doi.org/10.30848/PJB2023-4(30)**

PHYTODIVERSITY IN RELATION TO ECOVARIABILITY OF THAWR AND EIR MOUNTAINS, AL-MADINAH AL-MUNAWARAH, SAUDI ARABIA

USAMA K ABDEL-HAMEED[1,2*], WAEL A. OBAID[1] AND TAHAR BOUTRAA[1]

[1]Biology Department, College of Science, Taibah University, Kingdom of Saudi Arabia
[2]Botany Department, Faculty of Science, Ain Shams University, Egypt
[*]Corresponding author's email: uabdelhameed@taibahu.edu.sa

Abstract

Thawr and Eir mountains are two of the main important and historical mountains in the region of Al-Madinah Al-Munawarah. However, floristic studies on these mountains have not been conducted. In this study, human activities and their impacts on the species diversity and soil characteristics of these mountains were considered. The current study aims to investigate: plant species distribution, species richness, life forms of plant species and the impact of soil composition on these parameters across the scanned mountains. A total of 48 species belonging to 44 genera and 23 families are recorded**.** The largest represented families were Fabaceae and Asteraceae. The spectrum of life-form showed that the most frequent life form was Therophyte. The major chorotypes distribution in the two studied mountains was investigated. Using of A Two-Way Indicator Species (TWINSPAN) technique on the relative importance values (IV) of the recorded species in 20 sampled stands distinguished six vegetation groups: two were representing Thawr mountain communities and four were representing Eir mountain communities, which was visualized through Detrended Correspondence Analysis (DCA). A Canonical Correspondence Analysis (CCA) was applied on the six TWINSPAN groups to explore the correlations between the generated vegetation groups and the different environmental parameters; stands of Eir mountain were highly correlated with elevation, longitude, latitude and pH while Thawr mountain stands showed a correlation with Ca^{++}, TDS, EC, Carbonate, Nitrate and Mg^{++}. It was found that Eir mountain gained the highest species richness and dominance according to the Berger-Parker formula while evenness, abundance and diversity reached their maximum values at Thawr mountain. It is concluded that human impacts may have a negative effect on species abundance, evenness and diversity at Eir mountain as compared with those of Thawr mountain. So authors recommend planning an ecological restoration strategy to maintain the diversity level at Eir mountain.

Key words: Life forms, Soil composition, Chorology, Richness, Biodiversity indices.

Introduction

Thawr and Eir mountains are two of the main important and historical mountains in the region of Al-Madinah Al-Munawarah. While Thawr mountain is situated in northern of Al-Madinah city directly behind of Ohud mountain, Eir mountain is situated in the southern of Al-Madinah city. Thawr in Arabic means 'bull' and therefore the mountain named after the bull appeared-shape, with flatted peak. Eir is also a distinguished mountain in Al-Madinah city for its black color. In comparison, Thawr mountain is clearly smaller than Eir mountain.

The largest country in the Arabian Peninsula is the Kingdom of Saudi Arabia (KSA), covering a total area of 2.225.000 km^2. Geographically it is situated at (15º45′N - 34º35′N and 34º40′E - 55º45′E), with a several distinct physiographical regimes (AlNafie, 2008; Alsherif & Fadl, 2016). The whole area of the KSA divided into two main geographical regions; rainy highlands that located in the western and southwestern regions and the arid and hyper-arid lands that located in the interior regions (AlNafie, 2008; Osman *et al.*, 2014), where the average annual rainfall is 82.29 mm (Almazroui, 2011). The climate of KSA differs significantly between the coast, characterised by high humidity and moderate temperatures, and the interior regions, characterised by extreme temperatures and low humidity (Feldman, 2006). Due to the vast area, the flora is considered to be among the richest biodiversity in the Arab peninsula, with a wide range of plant genetic resources (Rahman *et al.*, 2004).

Although, there is lack of investigations on the flora of such vast country; a number of studies embarked on the floristic of different geographical patterns, such as highlands, valleys, mountains, dunes. These investigations have a range of interests including a large scale and specific regions. For example, the flora of KSA (Mandaville, 1965; Collenette, 1985; Chaudhary, 2001), phytogeography of KSA and plant ecology and vegetation types (Zahran, 1982; AlNafie, 2008), Hijaz region, and in particular Meca region (Batanouny & Baeshin, 1983; Baierle *et al.*, 1985; Fayed & Zayed, 1989; Abd El-Ghani, 1993; El-Demerdash *et al.*, 1995; Alsherif & Fadl, 2016), Northwest coast - Tabuk region - (Alharbi, 2010), Eastern Province of Saudi Arabia (Barth, 1999), dunes in central Saudi (Boulos, 1985), south-western region (Al-Robai *et al.*, 2019) and Northern borders Province (Gomaa, 2012; Osman *et al.*, 2014). Despite the early beginning of such important field of study, the goal of the outcome still far from satisfactory. It is worth mentioning that while the flora of different regions of KSA were investigated, the only available published-study of the flora of Al-Madinah Al-Munawarah is the study conducted by (Obaid *et al.*, 2020) on the flora of Ohud mountain. Therefore, there is a large gap regarding the flora of Al-Madinah city.

Mountains cover about 25% of the land surface of the terrestrial plant species (Barthlott *et al.*, 1996). In general, plant species richness decreases with altitude (Gentry, 1988; Shaheen *et al.*, 2015), with temperature and precipitation as they were considered among the main environmental factors that shape the species richness across altitudinal gradients (Kharkwal *et al.*, 2005). The plant species composition in the same elevation zone is controlled by temperature, topography, slope, soil structure, soil texture and soil nutrients composition (Ramsay & Oxley, 1997; Muik *et al*., 2012; Chau & Chu, 2017). Because slopes dominate the structure of the mountains, the conditions of the biota are available at low altitudes more than high altitudes (Korner, 2000). In the same regions, it has been reported that the distribution and diversity of plant species were greatly affected by elevation of mountains and soil compositions (Osman *et al*., 2014; Al-Robai *et al*., 2019). Richness of plant species is significantly affected by mountainous structure, due to elevation and different composition of soils (Korner, 2000). The plant species distribution is affected by elevation, soil pH, organic matter, and by number of nutrients; i.e., Phosphorus (P), Potassium (K^+) and Aluminium (Al^+) (Mota *et al*., 2018). Other elements of the soil characteristics that could affect the vegetation properties, are K^+ and SO_4^{2-} nutrients and organic matter (Lozano-García *et al*., 2016; Liu *et al*., 2017).

Soil structure, soil pH and EC gradients are main factors in plant species distribution in semi-arid and arid regions (El-Keblawy *et al*., 2015). Soil properties can shape the plant growth and plant distribution related to water retention capacity (Ludwig *et al*., 2004). Poor soil in arid and semi-arid areas causes vegetation to be distributed as isolated patches (McAuliffe, 1994). Little attention has been given to the investigation of the relationships between vegetation and soil structure in the Arabian Gulf regions, with fewer studies reported that soil characteristics are important in defining the types of vegetation in some local regions (Verboom *et al*., 2013). Desert soils are characterised by lack of water availability to mesophytic plants to survive long rainless periods of time, the plants in such arid regions are refrained by lack of water, extreme temperatures and deflation by wind (Verheye, 2009). High wind speeds prevents smooth settlement of vegetation, because of the erosion of surface soils especially in sandy lands, as in desert regions, while at low speeds, there is an opportunity for the plants to get established (Bradley *et al*., 2019). Altitudinal gradients are powerful factor for determination of vegetation distribution, and can control different parameters that contribute to plant species distribution, including wind (Körner, 2007).

Throughout the scientific investigation of biodiversity across the different environments settings, many acoustic indices have been applied (Sueur *et al*., 2014). Two key classifications of biodiversity have been established, according to the partitioning regional diversity of the biodiversity, one is acoustic indices inside groups, alpha diversity (alpha-diversity), and the other is acoustic indices between groups, beta diversity (β-diversity) (Deichmann *et al*., 2018; Gibb *et al*., 2019; Hayashi *et al*., 2020). β-diversity can be affected over time, by any changes in biotic and abiotic environmental factors, that consequently affect the presence of species (Mori *et al*., 2018). In dry regions, plant β-diversity is affected mostly by soil fertility and precipitation variability (Ulrich *et al*., 2014). The β-diversity can also be greatly affected by human activities, compared with the natural habitats (Socolar *et al*., 2016).

The goals of this study are to examine the distribution of plant species, species richness, life forms of plant species and the impact of soil composition on these parameters across ones of the most famous mountains in Al-Madinah Al-Munawarah, Thawr and Eir mountains.

Materials and Methods

Study area and meteorological parameters: Thawr and Eir mountains are among of the main and well-known mountains in Al-Madinah Al-Munawarah (Fig. 1). Thawr is a small red mountain, located directly behind the most famous mountain in Al-Madinah, Ohud mountain, in the north of Al-Madinah, and known by its bull-like shape. It is located between the latitudes of 24^o.32'.08" and 39^o.37'.45"N and longitudes 39^o.37'.47" and 24^o.31'.49"E. Thawr mountain dimensions are 585 m in length, 370 m in width, and rise to about 690 m above the sea level. Eir is a huge mountain located in the southern of Al-Madinah and featured with its black color. It is located between the latitudes of 24^o.21'.40" and 39^o.35'.40"N and longitudes 39^o.33'.26" and 24^o.23'.12"E. Eir mountain dimensions are 2000 m in length, 70 m in width, and rise to about 1000 m above the sea level.

The study was conducted during February–April 2019, after the exceptionally rainy season of the year 2019–2020. The meteorological parameters for the period of the study are presented in Table 1.

Vegetation sampling and soil analysis: Vegetation was sampled using a transect/quadrant method according to the method described by (Greig-Smith, 1983). A total number of 20 stands has been applied. The stands were applied at all the four directions of the mountains as indicated in the map; Figure 1. Identification and authentication of the gathered plants were performed according to previous information dealing with flora of Saudi Arabia including (Migahid, 1996; Collenette, 1999; Chaudhary, 2001). Life forms of the collected plants were recognized according to the method described by (Raunkiaer, 1934). The affinities of biogeography of the gathered plants were determined in accordance with (Zohary, 1973). The collected plant samples were preserved in the Herbarium of Biology Department, College of Sciences, Taibah University.

From each stand, soil samples were collected with a total of five samples per stand. Samples were collected at about 25 cm depth, after removing any debris from the surface and the upper layers of soil. Samples of each stand were mixed together to form the collective samples. Collected samples were aerially dried and cleaned from any leftover remains to a constant weight, thoroughly mixed, and finally grounded and sieved to a 2 mm sieves before the chemical analysis take place. The elevation, latitude and longitude were determined for each stand, and the following soil parameters were analysed; total dissolved salts (TDS), pH, $N\text{-}NO_3$, K^+, organic matter (OM), $CaCO_3$, Mg^{++}, Cl^-, SO_4^{--}, Na^+, Ca^{++} and electric conductivity (EC). The sulphate content (SO_4^{--}) and organic matter (OM) were determined according to (Piper, 1950). The total dissolved salts (TDS), calcium contents (Ca^{++}), calcium carbonate contents ($CaCO_3$) and chlorides (Cl^-) were measured according to (Jackson, 1969). Mg^{++} contents were estimated as described by (Allen *et al*., 1986). The pH was determined using electrical pH-meter (model Lutron pH 206), and the electric conductivity (EC) was measured using conductivity meter (YSI Incorporated Model 33). Potassium (K^+) and sodium (Na^+) ions were measured using Flame Photometer (Model PHF 80 Biologie Spectrophotometer). Nitrogen, in the form of nitrates ($N\text{-}NO_3$) was quantified using micro-Kjeldahl following the method of (Allen *et al*., 1986).

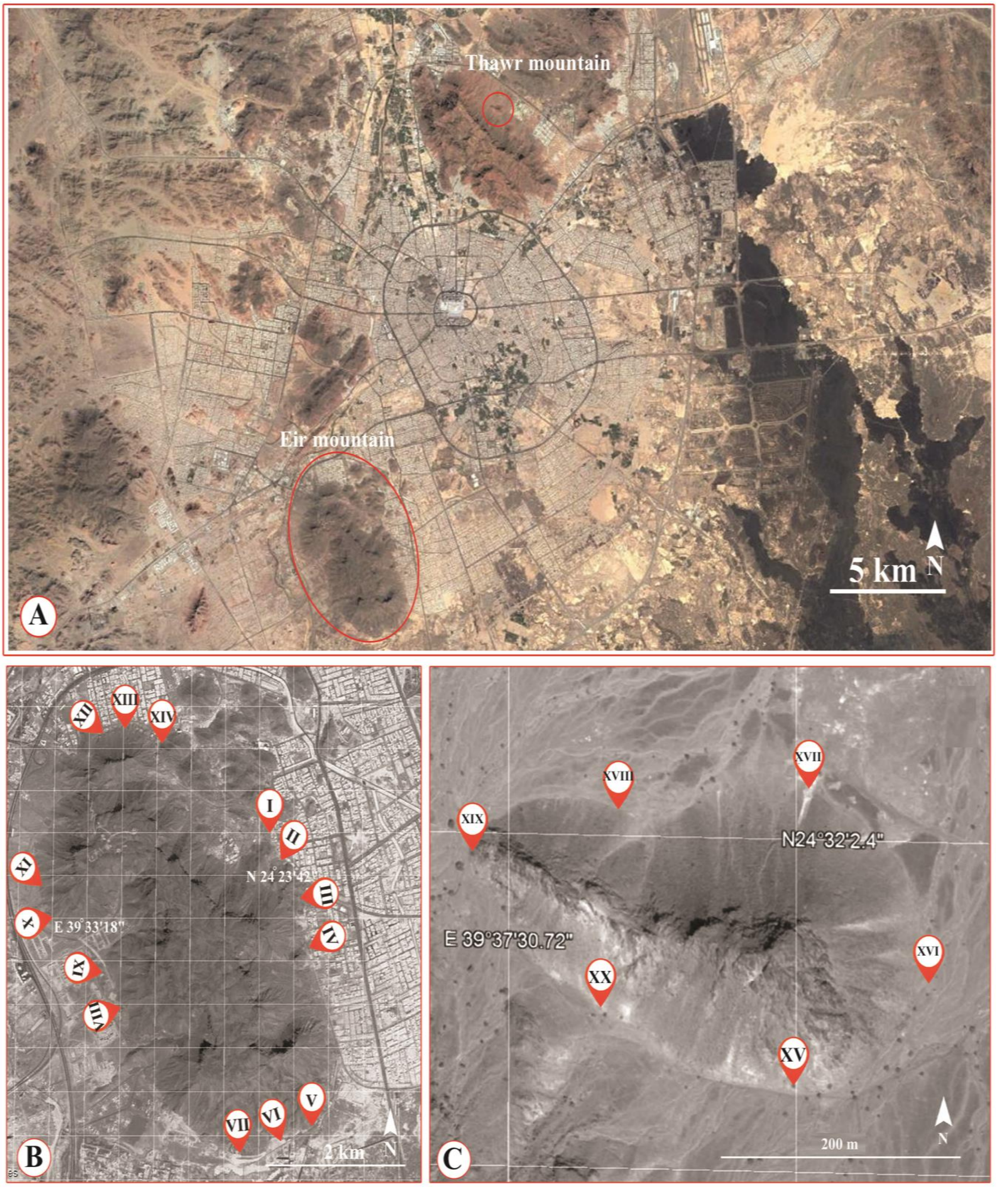

Fig. 1. Map of the study area. A. Map showing borders of Al-Madinah Al-Munawarah. B. Eir mountain. C. Thawr mountain. The map is georeferenced using QGIS Desktop 3.63.

Table 1. Meteorological parameters in the study area over the 3-month period of study; February - April 2019. Variation in temperature (°C), precipitation (mm), wind speed (knots), relative humidity (%) and solar brightness. Data recorded at Prince Mohammad Bin Abdulaziz Airport Meteorological station.

Month	Temperature (°C) Max/Min	Precipitation (mm)	Wind speed (knots)	Relative humidity (%)	Solar brightness (hours)
February	24.8/14.6	5	7	34	8
March	28.1/15.6	0	2	22	9.5
April	33.9/20.8	2	7	22	9.2

Vegetation analysis: Within each stand, the presence of all plant species (annual and/or perennials) was recorded to estimate the abundance of vegetation in which each plant was determined according to the method described by (Canfield, 1941). Absolute density and frequency for each area were calculated according to (Ellenberg and Mueller-Dombois, 1974) and Raunkiaer (1934) respectively. Relative density (R.D.), relative frequency (R.F.) and relative cover (R.C.) were estimated for each recorded plant species. The sum of the three parameters represent the importance value (I.V.), using the equation: I.V. = R.F. + R.D. + R.C., was also estimated following (Ludwig *et al.*, 1988). The importance values were implemented to express stands versus species IV data.

Species diversity in each investigated stand was estimated using Matrix Paleontological Statistics (PAST) software program, Version 3.14 according to (Hammer *et al.*, 2001) in addition to some diversity indices including; Simpson_1-D, Shannon_H, Menhinick, Berger-Parker and Chao-1, following (Simpson, 1949; Shannon & Weiner, 1963; Menhinick, 1964; Berger & Parker, 1970; Chao, 1984).

A Two-Way Indicator Species Analysis (TWINSPAN) is a classification technique and it is commonly applied-method for the purpose of vegetation composition (Hill, 1979; Rothfritz *et al.*, 1997; Franklin *et al.*, 1999; Vermeersch *et al.*, 2003). Canonical Correspondence Analysis (CCA) and Detrended Correspondence Analysis (DCA) ordinations were applied to investigate the structure of vegetation and plant species distribution in relation to the environmental factors. TWINSPAN technique works by visualizing results through DCA; that serve to compare the media values of the abiotic environmental factors in each TWINSPAN group (Hill & Gauch, 1980), and DCA-values, an indirect ordination method that serve for the description of changes in the vegetation along the environmental gradients (Ter Braak & Smilauer, 2002). Community Analysis Package ver. 1.2 was used for TWINSPAN and DCA analyses (Henderson & Seaby, 1999), and PAST ver. 3.14 was used for CCA analysis (Hammer *et al.*, 2001).

Results

Floristic richness and taxonomic diversity: A total of 48 species (33 annuals and 15 perennials) belonging to 44 genera and 23 families are recorded (Tables 2 and 3). Eir mountain shared with 44 species, 40 genera and 22 families while Thawr mountain shared with 28 species, 28 genera and 19 families. The largest represented families were Fabaceae and Asteraceae (9 and 6 species respectively), Poaceae (4), Chenopodiacea, Boraginaceae and Zygophyllaceae (3 species for each), Brassicaceae, Caryophyllaceae and Illicebraceae (two species for each), and only one species was represented for fourteen families. Four genera include two species *viz*. *Acacia*, *Pulicaria*, *Tephrosia* and *Trichodesma*. It is also noted that the distribution of species among genera (S/G ratio) is 48/44= 1.09, 44/40= 1.1 and 28/28= 1 for the two mountains, Eir mountain and Thawr mountain respectively.

Biological spectrum: The life-form spectrum of the studied areas showed that the most frequent life form was Therophyte, with 28 species, Chamaephyte was in the second rank, with 14 species, Phanerophyte, with 4 species, Cryptophytes and Hemicrytophytes were represented with one species each (Table 3). The distribution of the diverse life forms appeared in the two studied mountains separately was investigated, where Eir mountain had the highest share of therophytes (24 species) while Thawr mountain had 18 species that belonging to the same life form.

Chorological affinities: Phytogeographical evaluation of the scanned species revealed the supremacy of bi-regional species, 25 species, overall other phytogeographical elements. This was followed by 17 mono-regional species being native to Saharo-Arabian or Sudano-Zambezian chorotypes, while the pluri-regional taxa were three species and three was cosmopolitan. 28 of the recorded species were bi-regional and pluri-regional, extending their distribution allover the Saharo-Arabian, Tropical, Saharo-Sindian, Irano-Turanian, Sudano-Zambezian and Mediterranean chorotypes (Table 3). The major chorotypes distribution in the two studied mountains was investigated in which Eir mountain had the highest share of Saharo-Arabian / Sudano-Zambezian chorotypes (13 species) followed by Saharo-Arabian chorotype (11 species), while six species belonging to Saharo-Arabian chorotype and five species to Saharo-Arabian / Sudano-Zambezian chorotypes in Thawr mountain.

Vegetation classification: The TWINSPAN application on the importance values (IV) of the 48 species recorded in the scanned areas differentiated six vegetation groups (Fig. 2). The first TWINSPAN dichotomy distinguished the 20 stands into two major groups; the first one comprised six stands (Thawr mountain), while the second group comprised 14 stands (Eir mountain). At the second hierarchical level, the stands of Thawr mountain were bifurcate giving four stands (group A) on one side and two stands (group B) on the other side. The stands of Eir mountain were split into four stands (group F) and ten stands that were bifurcate at third hierarchical level into four stands (group E) and six stands that in turn were divided at fourth hierarchical level into two groups (C and D), three stands per each. The six groups comprised leading dominant species (those have the highest relative IV); *Stipa capensis* could be used as indicator species for group (A), *Aizoon canariense* could be considered as indicator species for group (B), *Zygophyllum simplex* for groups (C, D and F), while group (E) was indicated with *Stipagrostis hirtigluma*.

Table 2. List of the reported plant species and family names at the scanned mountains.

No.	Plant species	Family name	Mountain
1.	*Acacia ehrenbergiana* Hayne -- Getreue Darstell. Gew. x. t. 29. (IK) =*Vachellia flava* (Forssk.) Kyal. & Boatwr.	Fabaceae	Eir
2.	*Acacia tortilis* Hayne -- Getreue Darstell. Gew. ix. I. 31. (IK) =*Vachellia tortilis* (Forssk.) Galasso & Banfi	Fabaceae	Eir and Thawr
3.	*Aerva javanica* Juss. -- Ann. Mus. Natl. Hist. Nat. 2: 131. 1803 (IK)	Amaranthaceae	Eir and Thawr
4.	*Aizoon canariense* L.-- Sp. Pl. 1: 488. 1753 (IK)	Aizoaceae	Eir and Thawr
5.	*Astragalus eremophilus* Boiss. -- Diagn. Pl. Orient. ser. 1, 2: 54. 1843 (IK)	Fabaceae	Eir
6.	*Blepharis ciliaris* (L.) B.L. Burtt. -- Notes Roy. Bot. Gard. Edinburgh 22: 94. 1956 (IK) =*Alectis ciliaris* (Bloch, 1787)	Acanthaceae	Eir and Thawr
7.	*Boerhavia diffusa* L. -- Sp. Pl. 1 3. 1753 [1 May 1753] (IK)	Nyctaginaceae	Eir
8.	*Centaurea sinaica* DC. -- Prodr. [A. P. de Candolle] 6: 592. 1838 (IK) = *Calcitrapa sinaica* (DC.) Holub = *Centaurea procurrens* DC.	Asteraceae	Eir
9.	*Chenopodiastrum murale* (L.) S.Fuentes, Uotila & Borsch--Willdenowia 42(1): 14. 2012 ≡ *Chenopodium murale* L.	Chenopodiaceae	Eir and Thawr
10.	*Citrullus colocynthis* (L.) Schrad. Linnaea 12:414. 1838	Cucurbitaceae	Eir
11.	*Cometes surattensis* L. -- Mant. Pl. 39. 1767 (IK)	Illecebraceae	Eir
12.	*Cuscuta hyaline* Roth -- Nov. Pl. Sp. 100. 1821 (IK) =*Cuscuta planiflora* W.D.J. Koch	Convolvulaceae	Eir and Thawr
13.	*Cynanchum radians* Lam. -- Encycl. [J. Lamarck & al.] 2(1): 236. 1786 (IK) =*Cynanchum radians* (Forssk.) comb. ined. =*Asclepias radians* Forsk. =*Odontanthera radians* (Forsk.) D.V. Field =*Odontanthera reniformis* R.Wight =*Steinheilia radians* (Forsk.) Decne.	Asclepiadaceae	Eir and Thawr
14.	*Cynodon dactylon* (L.) *Pers., Syn. Pl. [Persoon] 1: 85 (1805).*	Poaceae	Thawr
15.	*Echinops spinosus* d'Urv. -- Mém. Soc. Linn. Paris 1: 374. 1822 (IK) = *Echinops spinosissimus* subsp. *spinosissimus*	Asteraceae	Eir
16.	*Echium rauwolfii* Delile -- Descr. Egypte, Hist. Nat. 195, t. 19, f. 3. 1813 (IK)	Boraginaceae	Eir
17.	*Fagonia bruguieri* DC. -- Prodr. [A. P. de Candolle] 1: 704. 1824 (IK)	Zygophyllaceae	Eir and Thawr
18.	*Farsetia longisiliqua* Decne. -- Ann. Sci. Nat., Bot. sér. 2, 4: 69. 1835 (IK)	Brassicaceae	Eir
19.	*Forsskaolea tenacissima* L. -- Opobalsamum 18. 1764 (IK)	Urticaceae	Eir and Thawr
20.	*Indigofera spinosa* Forssk. -- Fl. Aegypt.-Arab. 137. 1775 (IK)	Fabaceae	Eir
21.	*Lotononis platycarpa* (Viv.) Pic.Serm., Webbia 7 331 (1950)	Fabaceae	Eir
22.	*Lycium shawii* Roem. & Schult. -- Syst. Veg., ed. 15 bis [Roemer & Schultes] 4: 693. 1819 (IK)	Solanaceae	Eir
23.	*Malva parviflora* Huds. -- Fl. Angl. (Hudson) 268. 1762 (IK) = *Malva parviflora* L.	Malvaceae	Thawr
24.	*Morettia parviflora* Boiss. -- Ann. Sci. Nat., Bot. sér. 2, 17: 60. 1842 (IK)	Brassicaceae	Eir and Thawr
25.	*Ochradenus baccatus* Delile -- Descr. Egypte, Hist. Nat. 236, t. 31. (IK)	Resedaceae	Eir
26.	*Pennisetum glaucum* (L.) R.Br. -- Prodromus Florae Novae Hollandiae 1810 (APNI) =*Cenchrus americanus* (L.) Morrone	Poaceae	Eir and Thawr
27.	*Plantago ciliate* Desf. -- Fl. Atlant. 1: 137, t. 39. 1798 (IK)	Plantaginaceae	Eir and Thawr
28.	*Pulicaria undulate* (L.) C.A. Mey., Verz. Pfl. Casp. Meer. (C.A. von Meyer). 79 (1831)	Asteraceae	Eir
29.	*Pulicaria incise* DC. -- Prodr. [A. P. de Candolle] 5: 479. 1836 (IK)	Asteraceae	Eir and Thawr
30.	*Reichardia tingitana* Roth -- Bot. Abh. 35. (IK)	Asteraceae	Eir and Thawr
31.	Retama raetam (Forssk.) Webb & Berthel., Hist. Nat. Iles Canaries (Phytogr.). 3(pt. 2, sect. 2, livr. 62): 56 (1842)	Fabaceae	Eir
32.	*Rhazya stricta* Decne. -- Ann. Sci. Nat., Bot. sér. 2, 4: 80. 1835 (IK)	Apocynaceae	Eir and Thawr
33.	*Rumex vesicarius* L. -- Species Plantarum 2 1753 (APNI)	Polygonaceae	Eir and Thawr
34.	*Salsola imbricate* Forssk. -- Fl. Aegypt.-Arab. 57. 1775 (IK) = *Caroxylon imbricatum* (Forssk.) Akhani & Roalson	Chenopodiaceae	Eir
35.	*Sclerocephalus arabicus* Boiss. -- Diagn. Pl. Orient. ser. 1, 3: 12. 1843 (IK) = *Gymnocarpos sclerocephalus* (Decne.) Ahlgren & Thulin	Illecebraceae	Eir and Thawr
36.	*Senecio flavus* Sch.Bip. -- in Webb & Berth. Phyt. Canar. ii. 319. t. 107. (IK)	Asteraceae	Eir and Thawr
37.	*Senna italic* Mill., Gard. Dict., ed. 8. n. 2 (1768) Basionym of *Cassia italic* (Mill.) Sprengel, cf. D.J. Mabberley in Taxon 30(1): 9 (1981): (1800)	Fabaceae	Eir and Thawr
38.	*Silene arabica* Boiss., Fl. Orient. [Boissier] 1 593 (1867)	Caryophyllaceae	Eir
39.	*Spergularia diandra* (Guss.) Boiss. -- Fl. Orient. [Boissier] 1: 733. 1867 (IK) = *Spergularia diandra* (Guss.) Heldr.	Caryophyllaceae	Thawr
40.	*Stipa capensis* Thunb. -- Prodr. Pl. Cap. 1: 19. 1794 (IK) = *Stipellula capensis* (Thunb.) Röser & Hamasha	Poaceae	Eir and Thawr
41.	*Stipagrostis hirtigluma* (Steud.) De Winter -- Kirkia 3: 134. 1963 (IK)	Poaceae	Eir and Thawr
42.	*Suaeda vermiculata* Forssk. ex J.F.Gmel. -- Syst. Nat., ed. 13[bis]. 2(1): 503. 1791 (IK) = *Suaeda mollis* (Desf.) Delile	Chenopodiaceae	Thawr
43.	*Tephrosia apollinea* Link -- Enum. Hort. Berol. Alt. 2: 252. 1822; DC. Prod. 2: 254 (1825) (IK) = *Tephrosia apollinea* (Delile) DC.	Fabaceae	Eir and Thawr
44.	*Tephrosia nubica* Baker, Fl. Trop. Afr. [Oliver *et al.*] 2: 125 (1871)	Fabaceae	Eir
45.	*Tribulus macropterus* Boiss. -- Diagn. Pl. Orient. ser. 1, 1: 61. 1843 (IK)	Zygophyllaceae	Eir and Thawr
46.	*Trichodesma africanum* (L.) Lehm. -- Pl. Fam. Asperif. 195. 1818 (IK) = *Trichodesma africanum* (L.) R. Br.	Boraginaceae	Eir and Thawr
47.	*Trichodesma ehrenbergii* Schweinf. Ex Boiss., *Fl. Orient. [Boissier]* 4(2): 281 (1879).	Boraginaceae	Eir
48.	*Zygophyllum simplex* L. Mant. Pl. 68. 1767 = *Tetraena simplex* (L.) Beier & Thulin -- Pl. Syst. Evol. 240(1-4): 36 (2003)	Zygophyllaceae	Eir and Thawr

Table 3. List of plant species recorded at the scanned areas and their habitats, life forms, chorotypes and presence value (%).

No.	Plant species	Habitat	Life form	Chorotype	P%
1.	*Acacia ehrenbergiana*	Perennial	Phanerophyte	Sudano-Zambezian	83.33
2.	*Acacia tortilis*	Perennial	Phanerophyte	Sudano-Zambezian	16.67
3.	*Aerva javanica*	Perennial	Chamaephyte	Saharo-Arabian + Sudano-Zambezian	33.33
4.	*Aizoon canariense*	Annual	Therophyte	Saharo-Sindian + Sudano-Zambezian	66.67
5.	*Astragalus eremophilus*	Annual	Therophyte	Saharo-Arabian + Irano-Turanian	33.33
6.	*Blepharis ciliaris*	Annual	Therophyte	Saharo-Sindian + Sudano-Zambezian	83.33
7.	*Boerhavia diffusa*	Annual	Therophyte	Saharo-Arabian + Tropical	16.67
8.	*Centaurea sinaica*	Annual	Therophyte	Saharo-Arabian	16.67
9.	*Chenopodiastrum murale*	Annual	Therophyte	Cosmopolitan	33.33
10.	*Citrullus colocynthis*	Perennial	Hemicryptophyte	Saharo-Arabian	16.67
11.	*Cometes surattensis*	Annual	Therophyte	Saharo-Arabian	16.67
12.	*Cuscuta hyaline*	Annual	Therophyte	Saharo-Arabian + Sudano-Zambezian	66.67
13.	*Cynanchum radians*	Annual	Therophyte	Saharo-Arabian	33.33
14.	*Cynodon dactylon*	Perennial	Cryptophyte	Cosmopolitan	16.67
15.	*Echinops spinosus*	Perennial	Chamaephyte	Saharo-Sindian + Irano-Turanian	33.33
16.	*Echium rauwolfia*	Annual	Therophyte	Saharo-Arabian	33.33
17.	*Fagonia bruguieri*	Annual	Chamaephyte	Saharo-Arabian	100.00
18.	*Farsetia longisiliqua*	Annual	Chamaephyte	Saharo-Arabian + Sudano-Zambezian	33.33
19.	*Forsskaolea tenacissima*	Annual	Chamaephyte	Saharo-Arabian + Sudano-Zambezian	100.00
20.	*Indigofera spinosa*	Perennial	Chamaephyte	Saharo-Arabian + Sudano-Zambezian	16.67
21.	*Lotononis platycarpa*	Perennial	Therophyte	Saharo-Arabian + Sudano-Zambezian	16.67
22.	*Lycium shawii*	Perennial	Phanerophyte	Saharo-Arabian + Sudano-Zambezian	16.67
23.	*Malva parviflora*	Annual	Therophyte	Mediterranean + Irano-Turanian	16.67
24.	*Morettia parviflora*	Annual	Chamaephyte	Sudano-Zambezian	100.00
25.	*Ochradenus baccatus*	Perennial	Chamaephyte	Saharo-Arabian + Sudano-Zambezian	50.00
26.	*Pennisetum glaucum*	Annual	Therophyte	Cosmopolitan	66.67
27.	*Plantago ciliate*	Annual	Therophyte	Saharo-Arabian + Irano-Turanian	33.33
28.	*Pulicaria incisa*	Annual	Therophyte	Saharo-Arabian + Sudano-Zambezian	100.00
29.	*Pulicaria undulate*	Perennial	Chamaephyte	Saharo-Arabian	50.00
30.	*Reichardia tingitana*	Annual	Therophyte	Mediterranean + Saharo-Arabian + Irano-Turanian	50.00
31.	*Retama raetam*	Perennial	Phanerophyte	Saharo-Arabian	16.67
32.	*Rhazya stricta*	Perennial	Chamaephyte	Saharo-Arabian + Sudano-Zambezian	50.00
33.	*Rumex vesicarius*	Annual	Therophyte	Mediterranean + Saharo-Arabian + Sudano-Zambezian	66.67
34.	*Salsola imbricate*	Annual	Therophyte	Saharo-Sindian+Sudano-Zambezian	16.67
35.	*Sclerocephalus arabicus*	Annual	Therophyte	Saharo-Arabian	83.33
36.	*Senecio flavus*	Annual	Therophyte	Saharo-Arabian + Sudano-Zambezian	33.33
37.	*Senna italica*	Annual	Chamaephyte	Sudano-Zambezian	66.67
38.	*Silene arabica*	Annual	Therophyte	Saharo-Arabian + Irano-Turanian	16.67
39.	*Spergularia diandra*	Annual	Therophyte	Mediterranean + Irano-Turanian + Euro-Siberian	33.33
40.	*Stipa capensis*	Annual	Therophyte	Saharo-Arabian + Irano-Turanian	83.33
41.	*Stipagrostis hirtigluma*	Annual	Therophyte	Saharo-Arabian	100.00
42.	*Suaeda vermiculata*	Annual	Therophyte	Mediterranean + Saharo-Arabian	16.67
43.	*Tephrosia apollinea*	Perennial	Chamaephyte	Sudano-Zambezian	66.67
44.	*Tephrosia nubica*	Perennial	Chamaephyte	Sudano-Zambezian	16.67
45.	*Tribulus macropterus*	Annual	Therophyte	Mediterranean + Irano-Turanian	83.33
46.	*Trichodesma africanum*	Annual	Therophyte	Saharo-Arabian + Sudano-Zambezian	83.33
47.	*Trichodesma ehrenbergii*	Annual	Therophyte	Saharo-Arabian + Sudano-Zambezian	33.33
48.	*Zygophyllum simplex*	Annual	Chamaephyte	Saharo-Arabian	100.00

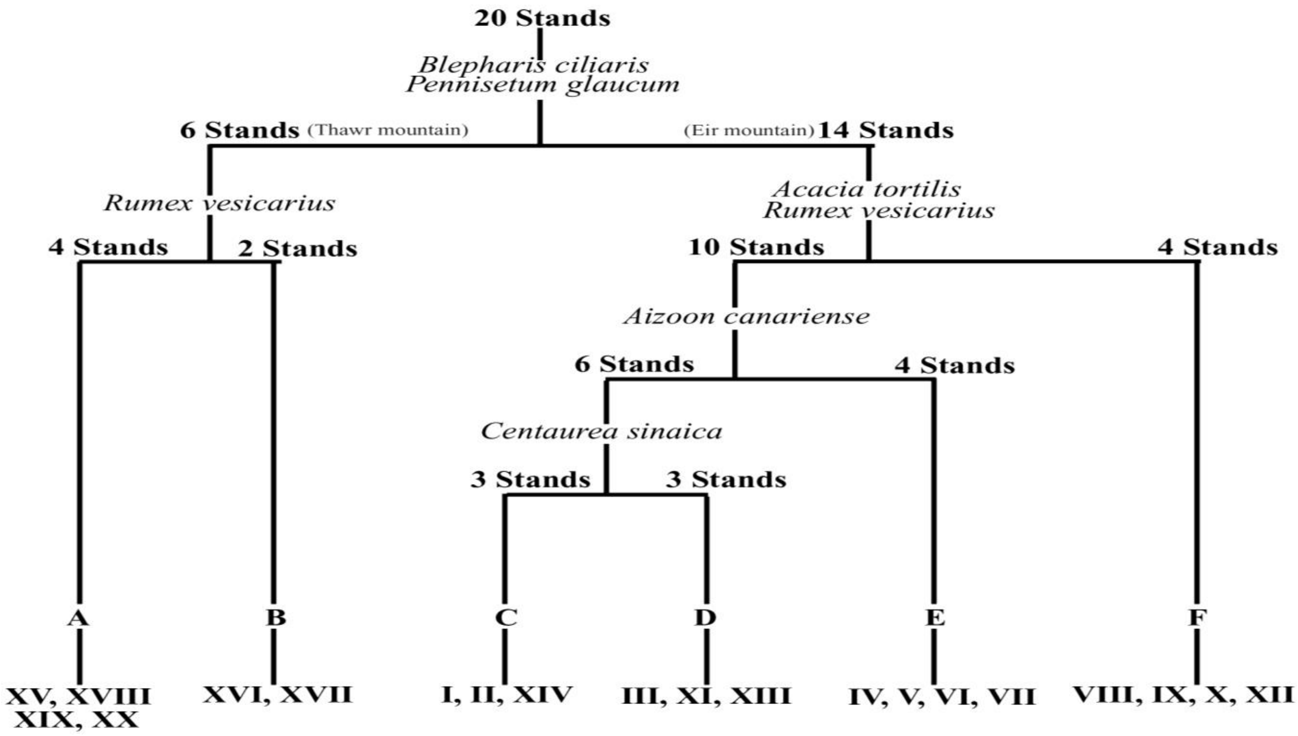

Fig. 2. TWINSPAN classification for the vegetation of the 20 investigated sites.

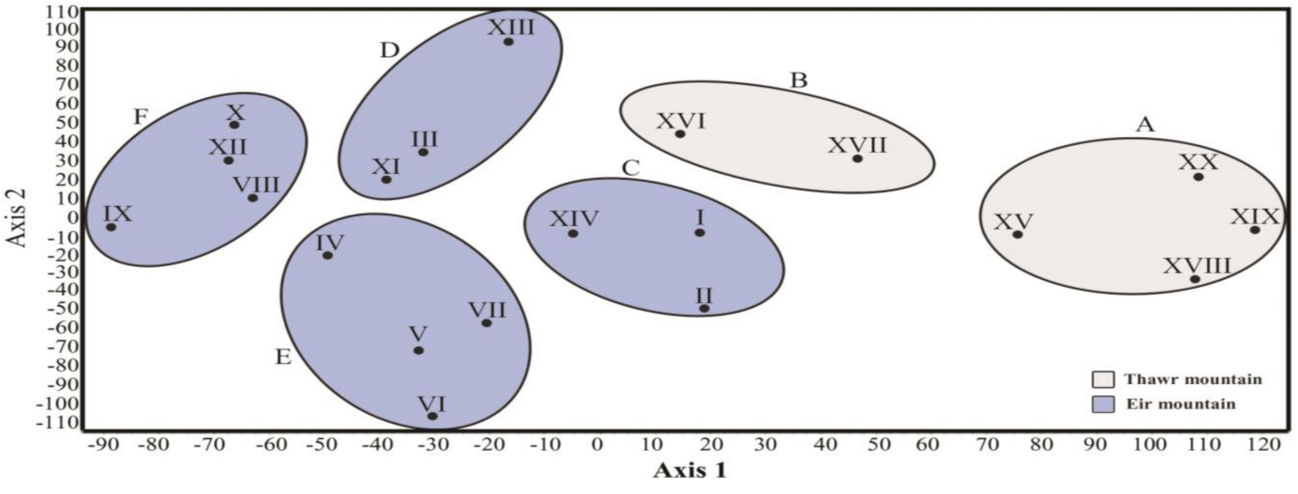

Fig. 3. DCA ordination diagram of the 20 sites on the first two axes with the TWINSPAN groups superimposed.

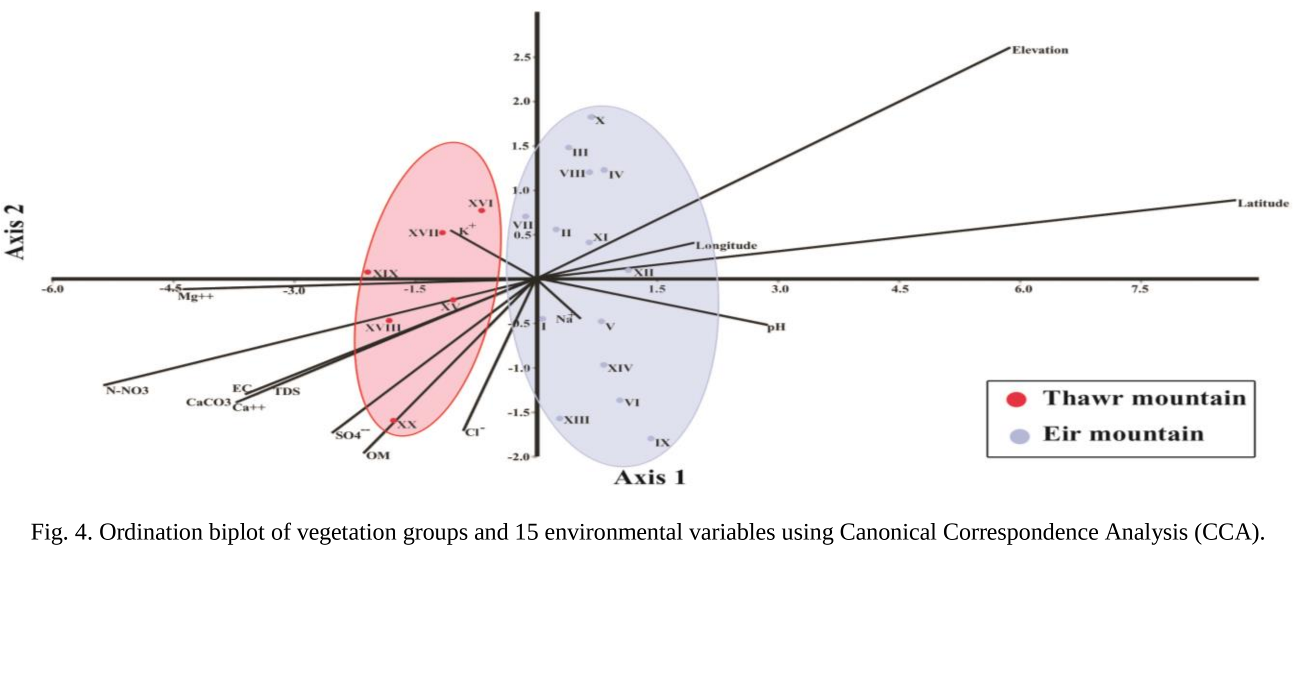

Fig. 4. Ordination biplot of vegetation groups and 15 environmental variables using Canonical Correspondence Analysis (CCA).

Table 4. Mean Values of different edaphic factors, number of taxa, number of individuals and 7 biodiversity indices for the six vegetation groups.

Edaphic variables \ Vegetation groups	A	B	C	D	E	F
TDS (ml/L)	1227.50	722.50	531.67	588.33	1241.25	700.00
pH (Unit)	7.04	7.22	7.30	7.27	7.15	7.13
N-NO_3 (ml/L)	36.03	24.18	9.55	12.45	25.59	6.42
K^+ (ml/L)	49.25	35.75	39.50	30.33	111.63	28.83
OM (%)	1.30	1.00	0.83	1.19	1.05	1.18
$CaCO_3$ (ml/L)	369.00	222.00	118.50	126.00	328.75	203.33
Mg^{++} (ml/L)	67.18	48.70	14.06	16.43	60.21	14.50
Cl^- (ml/L)	227.50	39.90	125.00	128.33	262.50	230.00
SO_4^{--} (ml/L)	282.50	158.00	114.33	100.67	320.88	170.67
Na^+ (ml/L)	123.20	54.60	74.17	244.00	162.00	106.00
Ca^{++} (ml/L)	147.60	88.80	47.40	50.40	131.50	81.33
EC (µs/cm)	2333.00	1388.50	957.00	1059.00	2234.25	1260.00
Taxa_S (Species richness)	67.00	24.00	67.00	45.00	60.00	39.00
Individuals	1169.00	588.00	860.00	885.00	1178.00	1177.00
Dominance_D	0.10	0.14	0.10	0.13	0.18	0.22
Simpson_1-D	0.90	0.86	0.90	0.87	0.82	0.78
Shannon_H	2.50	2.13	2.64	2.26	2.11	1.79
Evenness_e^H/S	0.73	0.71	0.63	0.65	0.55	0.62
Menhinick	0.97	0.69	1.29	0.86	0.86	0.56
Berger-Parker	0.19	0.23	0.19	0.21	0.32	0.36
Chao-1	16.75	12.00	22.33	15.00	15.00	9.75

Soil properties of the vegetation groups: The environmental properties of the six vegetation groups were summarized in Table 4. It can be noted that Total Dissolved Solids, Nitrates, Calcium Carbonates, Magnesium, Chlorine, Sulphates, Calcium and Electric Conductivity showed relatively high estimates on group (A), Sodium salts showed relatively high value on group (D), soil properties of group (E) were comparable to those of group (A), while group (F) had high value of Chlorine.

Ordination of stands: DCA application on the same data set produced aggregation of the 20 stands in six vegetational groups (Fig. 3) that resulted from TWINSPAN analysis, the stands were spread out 2.354 SD units along the first axis (eigenvalue = 0.3356047273), DCA axis 2 with an eigenvalue of 0.1944344938 and a gradient length of 2.045 SD units that was less important. It was observed that stands represented group (C) were occupied position among the other groups, Thawr mountain stands were positively delimited on DCA axis 1 while those of Eir mountain were negatively delimited.

Vegetation–Environmental relationships: CCA was conducted on the six TWINSPAN groups to explore the correlations between the different vegetation groups and the different environmental parameters. Data was plotted along the first two axes of CCA and the results showed good separation of the environmental groups into two main groups (Eir and Thawr) along CCA axis 1 (Fig. 4). CCA axis 1 showed correlation to elevation, longitude, latitude, pH, Mg^{++}, Ca^{++}, TDS, EC, Carbonate and Nitrate. Stands of Eir mountain were highly correlated with elevation, longitude, latitude and pH. Thawr mountain stands correlated with Ca^{++}, TDS, EC, Carbonate, Nitrate and Mg^{++}.

Biodiversity indices: The richness of species ranged from 10 to 22 species in each vegetation group, where groups (A and B) that located at Thawr mountain scored 29 species richness value, while vegetation groups that located at Eir mountain gained 62. Groups of Thawr mountain comprised the lower number of plant individuals at 586, while those of Eir mountain contained 1171 individual. The dominance reached its maximum value at group (F; 0.22). Using Simpson's formula to measure the evenness and relative abundance of the vegetation community, values ranged from 0.78 in group (F) to 0.90 in groups (A and C), while group (F) was less varied with a Shannon index 1.79, in the comparison with group (C; 2.64). The evenness reached its maximum value at group (A; 0.73) and its minimum value represented in group (E; 0.55). Menhenick values were ranged from 0.56 at group (F) to 1.29 at group (C). Berger-Parker values showed that species domination in group (F) had the maximum value (0.36), while groups (A and C) had the minimum value (0.19). The estimated richness of Chao was in the range of 9.75 for group (F) to 22.33 for group (C) (Table 4).

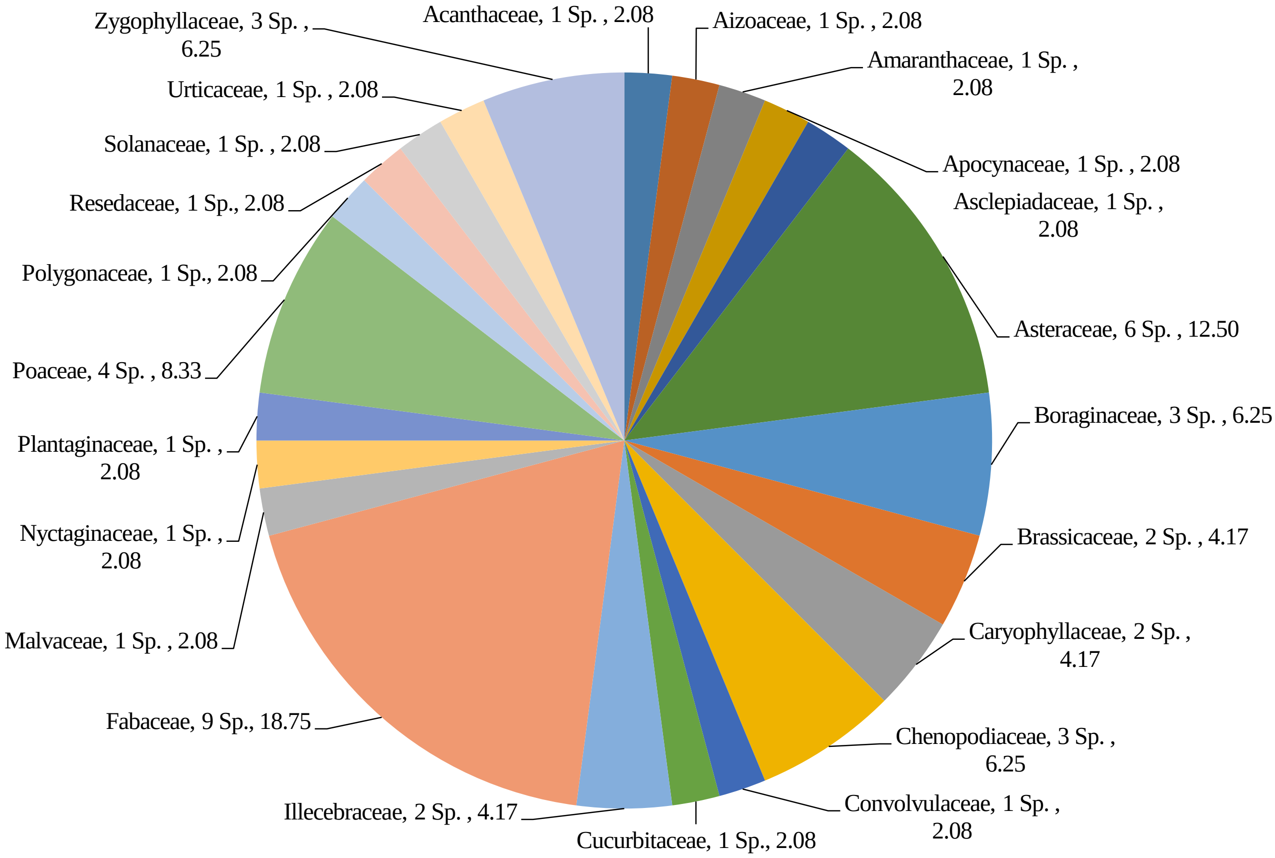

Fig. 5. Diagram of floristic composition with families represented in the study areas.

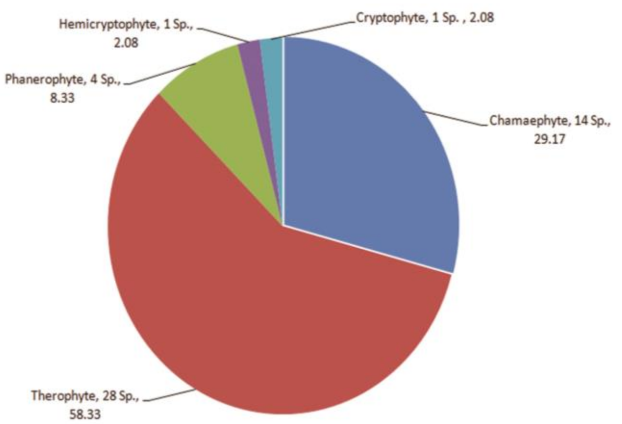

Fig. 6. Life form spectra of the recorded taxa.

Discussion

Floristic composition in the two investigated mountains showed that the highest species richness value recorded in Eir mountain (44 species), whereas Thawr mountain had the lowest value (28 species), indicating that Eir mountain was the most diversified mountain. This may be due to the distribution of many large depressions that noticed in Eir mountain where the plant growth is triggered mainly by rain. Vegetation develops in “contracted mode” (Monod, 1954) occur only in habitats receiving runoff water including depressions and channels (Shmida & Wilson, 1985).

The families that represented by more than one taxon constituted about 39% of the reported species (Fig. 5), while the rest families (fourteen) which constituting about 61% represented by only one species. Fabaceae and Asteraceae constitute the main bulk (65%) of the recorded families (Fakhry & Anazi, 2017). Fabaceae and Asteraceae are not only the largest families in the present study but also among the largest families of flowering plants in the world (Klopper *et al.*, 2007) and this can be due to their wide ecological tolerance in addition to their high capability of seed dispersal.

In the current study, the total number of recorded species was smaller than that of some studies performed in other locations of Saudi Arabia (Alharbi, 2010; Osman *et al.*, 2014), explaining the harsh condition of the scanned sites.

The spectrum of life-form was characterized as an arid desert environment. Therophytes and chamaephytes were found to be dominant, constituting the mean bulk (87.5%) of the reported taxa (Fig. 6). The high percentages of therophytes and chamaephytes indicate floristic characters of the floras of semiarid and arid regions (Pignatti & Pignatti, 1989). Therophytes constituted a higher ratio in Thawr mountain (64.2%) of its recorded species than that of Eir mountain (54.5%) of its recorded species and this ratio is comparable to that of Taif highlands (Alsherif & Fadl, 2016). The dominant dry climate permit the increase of therophytes percentage over the other life forms (Gomaa, 2012; Osman *et al.*, 2014). The high commitment of annuals (68.75%) might be identified with their short life cycles that empower them to oppose the unsteadiness of the parched desert biological system of the investigated zone and they additionally can produce seeds without the requirement for a meeting pollinator (Baker, 1974), and this encourages a progression of their life cycles.

Chorological investigation uncovered the prevalence of bi-regional species (52.1%) over all other phytogeographical components, trailed by mono-regional species (35.42%) (Fig. 7). The most elevated proportion of mono-regional components was native to Saharo-Arabian phytochorion (22.92%), while that of bi-regional components was native to Saharo-Arabian and Sudano-Zambezian phytochoria (27%). According to (Abd El-Ghani & Amer, 2003) Saharo-Arabian species are appropriate indicators of desert environmental conditions. This result can be upheld by an examination conducted on Asir highlands (Hegazy *et al.*, 1998) and Taif highlands (Alsherif & Fadl, 2016), and this might be attributed to the dependence of these components on parched climatic conditions (AlNafie, 2008).

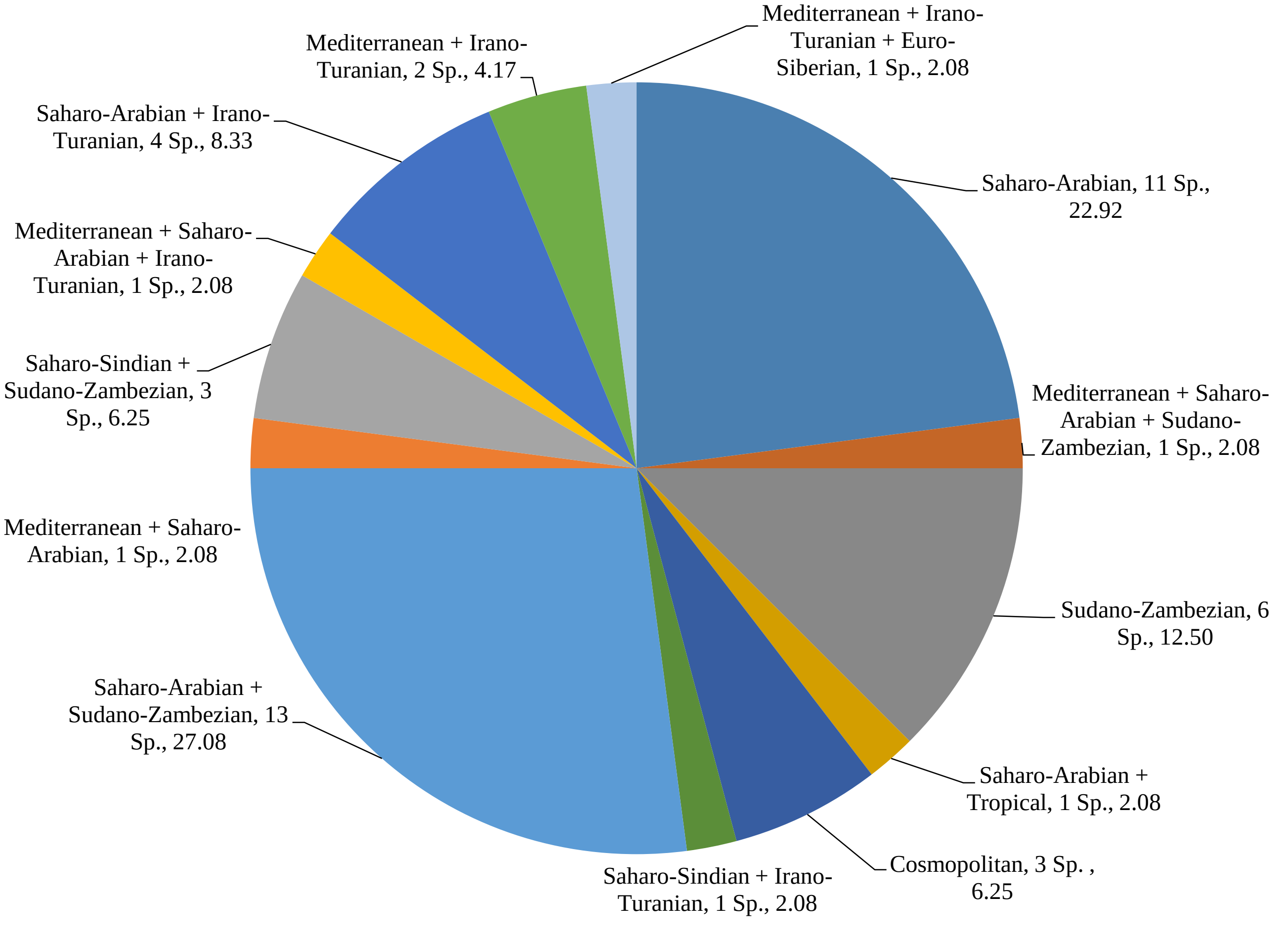

Fig. 7. Distribution of the Chorotypes for the recorded taxa

Phytosociological investigations indicated that six of the recorded species, i.e., *F. bruguieri*, *F. tenacissima*, *M. parviflora*, *P. incisa*, *S. hirtigluma* and *Z. simplex* were ubiquitous. These species covered a wide board of ecological distribution that have the highest presence values (P=100%) and represented in all the six vegetation groups. About 55% of the recorded species showed a certain degree of consistency, where they exclusively confined to a certain vegetation group and do not penetrate elsewhere (Abd El-Ghani *et al.*, 2017).

TWINSPAN application revealed the separation of two main distinct plant communities one consisting of six vegetation groups that characterized Thawr mountain and the other that consisting of 14 stands and distinguished Eir mountain. DCA application on the same data supports the delimitation between both plant communities of the two mountains. Noticeably, some of the vegetation types recognized in this study have a remarkable similarity with that reported in Ohud mountain (Obaid *et al.*, 2020).

Spatial distribution of plant taxa and communities in a small geographic area in desert ecosystems is attributed to landform pattern and heterogeneous topography (Kassas & Batanouny, 1984). Edaphic factors and microclimatic conditions leads to variation in the behavior of plant associations distribution of the study area. The soil components of Thawr mountain is rich in Nitrate, Organic matter, Calcium carbonate, Magnesium, Calcium and electric connectivity as compared with that of Eir mountain. It is noted that four species *viz*., *C. dactylon*, *M. parviflora*, *S. diandra* and *S. vermiculata* exerted a local presence in the flora of Thawr mountain rather than Eir mountain, leading to the assumption of a clear relationship between vegetation and the considered edaphic parameters (Jongman & Ter Braak, 1987). On the other hand, 19 species exerted a local existence in Eir mountain plant community where its soil is rich in total dissolved solids, Potassium, Chlorine, Sulphates and Sodium. The distribution of taxa and the differences between communities are determined with the concentration of different ions (El-Ghareeb & Hassan, 1989). Soil–vegetation relationships that were assessed with CCA clarified the relative positions of both mountains along with the most substantial ecological gradients. The edaphic factors play an important role in delimiting plant communities (Sasaki *et al.*, 2008). The vegetation structure of both mountains is relatively simple, in which the species are withstand the harsh environmental conditions. This is not only reflected by the dominance of annuals but also by the presence of several highly adapted and drought-resistant species (Abdel-Razik *et al.*, 1984).

Diversity indices are scientific functions that combine richness and evenness in a single measure and serve as valuable tools enabling biologists to quantify diversity in a community and describe its numerical structure. The value of Simpson's Index of Diversity **1-**D ranges between 0 and 1, indicating that greater the value for the greater the site diversity (Simpson, 1949). In the present study, the results indicates that the Simpson's Index of Diversity **1-**D in Thawr mountain is greater than that of Eir mountain where it reached 0.88 and 0.84 respectively, despite of species richness in Eir mountain is greater than that of Thawr mountain. The Shannon-Weiner index (Murray & Barnes, 1998) is based on measuring uncertainty. The degree of uncertainty of predicting the species of a random sample is dependent on the diversity of a community. Therefore, community with low diversity (dominated by one species) has low uncertainty of prediction and, conversely, if diversity is high the uncertainty is high. The present results also indicates that the diversity of Thawr mountain is greater than that of Eir mountain where it reached 2.32 and 2.20, respectively. Evenness is a measure of the relative abundance of different species reflecting the richness of an area. Consequently, having more evenness value leads to the varied diversity in the community (Hillebrand *et al.*, 2008). This study shows that the evenness value of Thawr mountain (0.72) is greater than that of Eir mountain (0.61), indicating that the diversity of Thawr mountain is greater than that of Eir mountain.

Conclusion

Eir mountain is surrounded with populated areas unlike Thawr mountain that bordered with only one populated area at the east side and protected with Ohud mountain at west side. It is concluded that human availability around Eir mountain may have negative effects on species abundance, evenness and diversity compared to those of Thawr mountain. Consequently, it is recommend to plan ecological restoration strategy to maintain the diversity level at Eir mountain.

References

Abd El-Ghani, M. 1993. Habitat features and plant communities of the Holy Places, Makkah, Saudi Arabia. *Fedd. Rep.,* 104: 417-425.

Abd El-Ghani, M., F. Salama, B. Salem, A. El-Hadidy and M. Abdel-Aleem. 2017. Phytogeography of the Eastern Desert flora of Egypt. *Wulfenia*, 24: 97-120.

Abd El-Ghani, M.M. and W.M. Amer. 2003. Soil-vegetation relationships in a coastal desert plain of southern Sinai, Egypt. *J. Arid Environ.,* 55: 607-628.

Abdel-Razik, M., M. Abdel-Aziz and M. Ayyad. 1984. Environmental gradients and species distribution in a transect at Omayed (Egypt). *J. Arid Environ.,* 7: 337-352.

Al-Robai, S.A., H.A. Mohamed, A.A. Ahmed and A.W.A. Al-Khulaidi. 2019. Effects of elevation gradients and soil components on the vegetation density and species diversity of Alabna escarpment, southwestern Saudi Arabia. *Acta Ecol. Sin.,* 39: 202-211.

Alharbi, F.K. 2010. Plant Diversity of Al-Lawz Mountains, Tabouk Region, Saudi Arabia. PhD thesis, King Saud University, Riaydh, Saudi Arabia.

Allen, S.E., H.M. Grimshaw and A.P. Rowland. 1986. Chemical analysis: In: (Eds.): Moore, P.D., S.B. Chapman. Methods in Plant Ecology, Blackwell, Oxford, pp. 285-344.

Almazroui, M. 2011. Calibration of TRMM rainfall climatology over Saudi Arabia during 1998-2009. *Atmos. Res*., 99: 400-414.

AlNafie, A.H. 2008. Phytogeography of Saudi Arabia. *Saudi J. Biol. Sci*., 15: 159-176.

Alsherif, E.A. and M.A. Fadl. 2016. Floristic study of the Al-Shafa Highlands in Taif, Western Saudi Arabia. *Flora - Morphol. Distrib. Funct. Ecol. Plants*, 225: 20-29.

Baierle, H.U., A.M. El-Sheikh and W. Frey. 1985. *Vegetation und Flora im mittleren Saudi-Arabien (aṭ-Ṭāʾif--ar-Riyāḍ)* (No. 22). Reichert Verlag.

Baker, H.G. 1974. The evolution of weeds. *Ann. Rev. Ecol. Syst*., 5: 1-24.

Barth, H.J. 1999. Desertification in the Eastern Province of Saudi Arabia. *J. Arid Environ.*, 43: 399-410.

Barthlott, W., W. Lauer and A. Placke. 1996. Global distribution of species diversity in vascular plants: Towards a world map of phytodiversity (Globale Verteilung der Artenvielfalt Höherer Pflanzen: Vorarbeiten zu einer Weltkarte der Phytodiversität). *Erdkunde,* 317-327.

Batanouny, K.H. and N.A. Baeshin. 1983. Plant communities along the Medina-Badr road across the Hejaz mountains, Saudi Arabia. *Vegetatio,* 53: 33-43.

Berger, W.H. and F.L. Parker. 1970. Diversity of Planktonic Foraminifera in Deep-Sea Sediments. *Science,* 168: 1345-1347.

Boulos, L. 1985. The middle east. *Plant Resour. Arid semiarid lands a Glob. Perspect*, 187-232.

Bradley, A.V., A.E. Haughan, A. Al-Dughairi and S.J. McLaren. 2019. Spatial variability in shrub vegetation across dune forms in central Saudi Arabia. *J. Arid Environ.,* 161: 72-84.

Canfield, R.H. 1941. Application of the line interception method in sampling range vegetation. *J. For.,* 39: 388-394.

Chao, A. 1984. Nonparametric estimation of the number of classes in a population. *Scand. J. Stat.,* 265-270.

Chau, N.L. and L.M. Chu. 2017. Fern cover and the importance of plant traits in reducing erosion on steep soil slopes. *Catena,* 151: 98-106.

Chaudhary, S.A. 2001. Flora of the Kingdom of Saudi Arabia. Ministry of Agriculture and Water. *Riyadh,* 2: 342-354.

Collenette, S. 1985. *Illustrated guide to the flowers of Saudi Arabia*. Scorpion.

Collenette, S. 1999. Wildflowers of Saudi Arabia, National Commission for wildlife conservation and development (NCWCD), Riyadh, Saudi Arabia.

Deichmann, J.L., O. Acevedo-Charry, L. Barclay, Z. Burivalova, M. Campos-Cerqueira, F. d'Horta, E.T. Game, B.L. Gottesman, P.J. Hart and A.K. Kalan. 2018. It's time to listen: there is much to be learned from the sounds of tropical ecosystems. *Biotropica*, 50: 713-718.

El-Demerdash, M.A., A.K. Hegazy and A.M. Zilay. 1995. Vegetation-soil relationships in Tihamah coastal plains of Jazan region, Saudi Arabia. *J. Arid Environ.,* 30: 161-174.

El-Ghareeb, R. and I.A. Hassan. 1989. A phytosociological study on the inland desert plateau of the Western Mediterranean Desert of Egypt at El-Hammam. *J. Arid Environ.,* 17: 13-21.

El-Keblawy, A., M.A. Abdelfattah and A.H.A. Khedr. 2015. Relationships between landforms, soil characteristics and dominant xerophytes in the hyper-arid northern United Arab Emirates. *J. Arid Environ.,* 117: 28-36.

Ellenberg, D. and D. Mueller-Dombois. 1974. *Aims and methods of vegetation ecology*. Wiley New York.

Fakhry, A.M. and H.K. Anazi. 2017. Floristic diversity and vegetation structure of Al-Dissah area northwestern Saudi Arabia. *Egypt. J. Exp. Biol.,* 13: 447-457.

Fayed, A.A. and K. Zayed. 1989. Vegetation along Makkah-Taif road (Saudi Arabia). *Arab Gulf J. Sci. Res.,* 7: 97-119.

Feldman, Y. 2006. Country Profile: Saudi Arabia.

Franklin, J., D.R. Drake, L.A. Bolick, D.S. Smith and T.J. Motley. 1999. Rain forest composition and patterns of secondary succession in the Vava'u Island Group, Tonga. *J. Veg. Sci.,* 10: 51-64.

Gentry, A.H. 1988. Changes in plant community diversity and floristic composition on environmental and geographical gradients. *Ann. Missouri Bot. Gard.,* 1-34.

Gibb, R., E. Browning, P. Glover-Kapfer and K.E. Jones. 2019. Emerging opportunities and challenges for passive acoustics in ecological assessment and monitoring. *Methods Ecol. Evol.,* 10: 169-185.

Gomaa, N.H. 2012. Composition and diversity of weed communities in Al-Jouf province, northern Saudi Arabia. *Saudi J. Biol. Sci.*, 19: 369-376.

Greig-Smith, P. 1983. *Quantitative plant ecology*. Second edition. Butterworths, London, England.

Hammer, Ø., D.A.T. Harper and P.D. Ryan. 2001. PAST: Paleontological statistics software package for education and data analysis. *Palaeontol. Electron.,* 4: 9.

Hayashi, K., V.D. Lelyana and K. Yamamura. 2020. Acoustic dissimilarities between an oil palm plantation and surrounding forests: Analysis of index time series for beta-diversity in South Sumatra, Indonesia. *Ecol. Indic.,* 112: 106086.

Hegazy, A.K., M.A. El-Demerdash and H.A. Hosni. 1998. Vegetation, species diversity and floristic relations along an altitudinal gradient in south-west Saudi Arabia. *J. Arid Environ.,* 38: 3-13.

Henderson, P.A. and R.M.H. Seaby. 1999. Community Analysis Package (CAP) version 1.2. *Pisces Conserv. Ltd. IRC House, UK*.

Hill, M.O. 1979. TWINSPAN: a FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. Cornell University, Section of Ecology and Systematics, Ithaca, New York, USA. Huntly, N. 1991. Herbivores and the. *Ann. Rev. Ecol. Syst.,* 22: 477-503.

Hill, M.O. and H.G. Gauch. 1980. Detrended correspondence analysis: An improved ordination technique. In *Classification and ordination* (pp. 47-58). Springer, Dordrecht.

Hillebrand, H., D.M. Bennett and M.W. Cadotte. 2008. Consequences of dominance: a review of evenness effects on local and regional ecosystem processes. *Ecology,* 89: 1510-1520.

Jackson, M.L. 1969. Soil Chemical Analysis-Advanced Course. *Soil Chem. Anal. Course.,* (Edition 2).

Jongman, R.H.G., C.J.F. Ter Braak and O.F.R. Van Tongeren. 1987. Data analysis in community and landscape, ecology. Pudoc, Wageningen

Kassas, M. and K.H. Batanouny. 1984. Department of Botany, Faculty of Science, University of Cairo, Giza, Egypt. *Sahara Desert,* (2). p77.

Kharkwal, G., P. Mehrotra, Y.S. Rawat and Y.P.S. Pangtey. 2005. Phytodiversity and growth form in relation to altitudinal gradient in the Central Himalayan (Kumaun) region of India. *Curr. Sci.,* 873-878.

Klopper, R.R., L. Gautier, C. Chatelain, G.F. Smith and R. Spichiger. 2007. Floristics of the angiosperm flora of Sub-Saharan Africa: An analysis of the African Plant Checklist and Database. *Taxon,* 56: 201-208.

Korner, C. 2000. Why are there global gradients in species richness? Mountains might hold the answer. *Trends Ecol. Evol.,* 15: 513-514.

Körner, C. 2007. The use of altitude in ecological research. *Trends Ecol. Evol.,* 22: 569-574.

Liu, L., M. Han, Y.B. Liu and B. Pan. 2017. Spatial distribution of wetland vegetation biomass and its influencing factors in the Yellow River Delta Nature Reserve. *Acta Ecol. Sin.,* 37: 4346-4355.

Lozano-García, B., L. Parras-Alcántara and E.C. Brevik. 2016. Impact of topographic aspect and vegetation (native and reforested areas) on soil organic carbon and nitrogen budgets in Mediterranean natural areas. *Sci. Total Environ.,* 544: 963-970.

Ludwig, J.A., L. Quartet, J.F. Reynolds and J.F. Reynolds. 1988. *Statistical Ecology: a primer in methods and computing*. John Wiley & Sons.

Ludwig, J.A., D.J. Tongway, G.N. Bastin and C.D. James. 2004. Monitoring ecological indicators of rangeland functional integrity and their relation to biodiversity at local to regional scales. *Austral Ecol*., 29(1): 108-120.

Mandaville, J.P. 1965. Notes on the vegetation of Wadi As Sahba, Eastern Arabia. *J. Bombay Nat. Hist. Soc.,* 62: 330-332.

McAuliffe, J.R. 1994. Landscape evolution, soil formation, and ecological patterns and processes in Sonoran Desert Bajadas. *Ecol. Monogr.,* 64: 111-148.

Menhinick, E.F. 1964. A comparison of some species-individuals diversity indices applied to samples of field insects. *Ecology*, 45: 859-861.

Migahid, A.M. 1996. Flora of Saudi Arabia, vol. (1). Riyadh University Publications. *Riyadh, Saudi Arabia*.

Monod, T. 1954. Modes contracté et diffus de la végétation saharienne. *Biol. Deserts, Cloudsley-Thompson JL (ed.). Inst. Biol. London,* 35-44.

Mori, A.S., F. Isbell and R. Seidl. 2018. $β$-diversity, community assembly, and ecosystem functioning. *Trends Ecol. Evol.,* 33: 549-564.

Mota, G.S., G.R. Luz, N.M. Mota, E.S. Coutinho, M. das Dores Magalhães Veloso, G.W. Fernandes and Y.R.F. Nunes. 2018. Changes in species composition, vegetation structure, and life forms along an altitudinal gradient of rupestrian grasslands in south-eastern Brazil. *Flora,* 238: 32-42.

Muik, A., C. Dold, Y. Geiß, A. Volk, M. Werbizki, U. Dietrich and D. von Laer. 2012. Semireplication-competent vesicular stomatitis virus as a novel platform for oncolytic virotherapy. *J. Mol. Med.,* 90: 959-970.

Murray, L. and A. Barnes. 1998. Beyond the wow factor evaluating multimedia language learning software from a pedagogical viewpoint. *System,* 26: 249-259.

Obaid, W.A., T. Boutraa and U.K. Abdel-Hameed. 2020. Floristics and soil characteristics of Ohud mountain, Al-Madinah Al-Munawarah, Western Saudi Arabia. *J. Mt. Sci.,* 17: 2405-2417.

Osman, A.K., F. Al-Ghamdi and A. Bawadekji. 2014. Floristic diversity and vegetation analysis of Wadi Arar: A typical desert Wadi of the Northern Border region of Saudi Arabia. *Saudi J. Biol. Sci.,* 21: 554-565.

Pignatti, E. and S. Pignatti. 1989. Life forms distribution and phytogeographical affinities of the Canarian flora. *Flora,* 183: 87-95.

Piper, C.S. 1950. Soil and plant analysis. Interscience Pub. *Inc., New York.*

Rahman, M.A., J.S. Mossa, M.S. Al-Said and M.A. Al-Yahya. 2004. Medicinal plant diversity in the flora of Saudi Arabia 1: A report on seven plant families. *Fitoterapia,* 75: 149-161.

Ramsay, P.M. and E.R.B. Oxley. 1997. The growth form composition of plant communities in the Ecuadorian páramos. *Plant Ecol.,* 131: 173-192.

Raunkiaer, C. 1934. The life forms of plants and statistical plant geography; being the collected papers of C. Raunkiaer. *Life forms plants Stat. plant Geogr. being Collect. Pap. C. Raunkiaer.*

Rothfritz, H., I. Jüttner, A.M. Suren and S.J. Ormerod. 1997. Epiphytic and epilithic diatom communities along environmental gradients in the Nepalese Himalaya: implications for the assessment of biodiversity and water quality. *Arch. Für Hydrobiol.,* 138: 465-482.

Sasaki, T., T. Okayasu, Y. Shirato, U. Jamsran, S. Okubo and K. Takeuchi. 2008. Can edaphic factors demonstrate landscape-scale differences in vegetation responses to grazing. *Plant Ecol.,* 194: 51-66.

Shaheen, H., Z.U.R. Mashwani and M.E.U.I. Dar. 2015. Spatial patterns and diversity of alpine vegetation across Langer-Shandur Valley, Hindukush Himalayas. *Curr. Sci.,* 1534-1539.

Shannon, C.E. and W. Weiner. 1963. The mathematical theory of communication Urban University Illinois Press. 125pp.

Shmida, A.V.I. and M.V. Wilson. 1985. Biological determinants of species diversity. *J. Biogeogr.,* 1-20.

Simpson, E.H. 1949. Measurement of diversity. *Nature*, 163: 688.

Socolar, J.B., J.J. Gilroy, W.E. Kunin and D.P. Edwards. 2016. How should beta-diversity inform biodiversity conservation? *Trends Ecol. Evol.,* 31: 67-80.

Sueur, J., A. Farina, A. Gasc, N. Pieretti and S. Pavoine. 2014. Acoustic indices for biodiversity assessment and landscape investigation. *Acta Acust.,* 100: 772-781.

Ter Braak, C.J.F. and P. Smilauer. 2002. *CANOCO reference manual and CanoDraw for Windows user's guide: software for canonical community ordination (version 4.5)*.

Ulrich, W., S. Soliveres, F.T. Maestre, N.J. Gotelli, J.L. Quero, M. Delgado-Baquerizo, M.A. Bowker, D.J. Eldridge, V. Ochoa, B. Gozalo, E. Valencia, M. Berdugo, C. Escolar, M. García-Gómez, A. Escudero, A. Prina, G. Alfonso, T. Arredondo, D. Bran, O. Cabrera, A.P. Cea, M. Chaieb, J. Contreras, M. Derak, C.I. Espinosa, A. Florentino, J. Gaitán, V.G. Muro, W. Ghiloufi, S. Gómez-González, J.R. Gutiérrez, R.M. Hernández, E. Huber-Sannwald, M. Jankju, R.L. Mau, F.M. Hughes, M. Miriti, J. Monerris, M. Muchane, K. Naseri, E. Pucheta, D.A. Ramírez-Collantes, E. Raveh, R.L. Romão, C. Torres-Díaz, J. Val, J.P. Veiga, D. Wang, X. Yuan and E. Zaady. 2014. Climate and soil attributes determine plant species turnover in global drylands. *J. Biogeogr*., 41(12): 2307-2319.

Verboom, W.H., J.S. Pate, M.A. Abdelfattah and S.A. Shahid. 2013. Effects of Plants on Soil-Forming Processes: Case Studies from Arid Environments. *Developments in Soil Classification, Land Use Planning and Policy Implications*. Springer. pp. 329-344.

Verheye, W.H. 2009. *Land use, land cover and soil sciences-volume IV: Land use management and case studies*. EOLSS Publications.

Vermeersch, S., W. De Genst, F. Vermoesen and L. Triest. 2003. The influence of transformations of an ordinal scale of a floristic gradient, applied on a TWINSPAN classification. *Flora-Morphology, Distrib. Funct. Ecol. Plants,* 198: 389-403.

Zahran, M. 1982. Vegetation types of Saudi Arabia. *King Abdel Aziz Univ. Press. Jeddah, Saudi Arab.*

Zohary, M. 1973. Geobotanical foundations of the Middle East. Stuttgart, Germany: Gustav Fischer.

(Received for publication 24 December 2021)