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Floristic diversity and vegetation analysis of Wadi Al-Noman, Mecca, Saudi Arabia

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Abstract: Wadi Al-Noman in Mecca is one of the most important wadis. It was included among the most important water sources where the springs and wells of Zobida run and it provides drinking water for the holy places in Mecca and visitors to the Kaaba and Arafat regions. The present study provides an analysis of floristic composition, vegetation types, and structure and species distribution at 20 sites, emphasising the environmental factors that affect species distribution. A total of 126 species representing 39 families of vascular plants are recorded. Fabaceae, Poaceae, and Boraginaceae are the largest families, and therophytes and chamaephytes are the most frequent, indicating a typical desert life-form spectrum. The floristic composition of the different geomorphologic landscape units shows differences in species richness. The highest species richness value (23 species stand^{-1}) is recorded in the wadi bed. The lowest species richness value (18 species stand^{-1}) is recorded in the wadi plateau and fissures. Chorological analysis revealed that 52% of the studied species are bioregional, native to the Saharo-Arabian–Sudano-Zambezian region. After application of the TWINSPAN, DCA, and CCA programs 4 vegetation groups were identified, and they were named after the characteristic species as follows: (I) *Aristolochia bracteolata-Cucumis prophetarum*; (II) *Calotropis procera-Acacia hamulosa-Caralluma russeliana*; (III) *Acacia abyssinica-Acacia hamulosa-Tephrosia desertorum*; and (IV) *Argemone ochroleuca-Senna italica*. The associations and speciation of these Wadi Al-Noman plants demonstrate significant variation in pH, electrical conductivity, soil mineral contents, and human impact.

Key words: Floristic, canonical correspondence analysis, vegetation, multivariate analysis, wadi maturation, xerophytes

1. Introduction

Saudi Arabia is a huge arid desert with an area of about 2,250,000 km^2 and covers the majority of the Arabian Peninsula. Therefore, xerophytic vegetation is a prominent feature of the plant life in this country (Zahran, 1982). Wadis represent one of the most prominent desert landforms, exhibiting physiographic irregularities that lead to parallel variation in species distribution (Kassas & Girgis, 1964). Life-form distribution is closely related to topography and landform (Kassas & Girgis, 1965; Zohary, 1973; Orshan, 1986; Fakhireh et al., 2012). Life-form composition is typical of desert flora; the majority of species are therophytes and chamaephytes. Wadi vegetation in general is not constant. It varies from year to year depending upon moisture levels (Siddiqui & Al-Harbi, 1995). Establishment, growth, regeneration, and distribution of the plant communities in the wadis are controlled by many factors such as geographical position, physiographic features, and human impact (Shaltout & El-Sheikh, 2003; Kürschner & Neef, 2011; Alatar et al., 2012; Korkmaz & Özçelik, 2013).

It is to be noted that the human activities in the desert landscape have increased recently, due to rapid development in the study area. Human activities, through their effect on the physical components of the fragile desert ecosystem, contribute to disruption of the natural equilibrium among the components of the ecosystem. Usually, the main component subject to degradation is the soil, which is the basic resource of the ecosystem. This inevitably results in retrogressive changes in the vegetation (Shaltout & El-Sheikh, 2003; Guo, 2004).

A number of studies were conducted in the past to evaluate the life in deserts (Migahid, 1978; Chaudhary, 1999–2001) and they helped to strengthen the foundation of desert studies in Saudi Arabia. Al-Farraj et al. (1997) conducted vegetation studies in some raudhas in order to verify the abundance, frequency, and density of each species. A general description of the vegetation of western Saudi Arabia was given by Vasey-Fitzeraid (1957a, 1957b), and he recognised a number of vegetation and ecological types including littoral marshes, coastal desert plain, coastal

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foothills, mountain ranges, and wadis. Considerable efforts have been made to interpret vegetation–environmental relationships in wadi ecosystems (Kassas & Imam, 1954, 1959; Batanouny, 1979; El-Sharkawi et al., 1987; Shaltout & Mady, 1996; Al-Farhan, 2001; Alatar et al., 2012; Salama et al., 2013). Some other reports have dealt with the vegetation types in certain regions of the Saudi Kingdom, particularly in the Hijaz and Aseer regions (Zahran, 1982, 1983; Batanouny & Baeshain, 1983; Abulfatih, 1992; Abd El-Ghani, 1993; Fayed & Zayed, 1999; Al Wadie, 2002; Fahmy & Hassan, 2005). Abdel-Fattah and Ali (2005) indicated that soil water table and salinity cause discontinuities of vegetation in the Taif area (80–100 km south-east of Mecca). Moreover, Parker (1991) showed that water availability, including annual precipitation, soil properties, and topography, were biotic factors. In Mecca, a few studies have provided qualitative valuations of the distribution of plant species and associations in relation to physiographic factors (Abd El-Ghani, 1993, 1997).

Our aim is to analyse the vegetation of the Wadi Al-Noman in terms of species floristic composition, life-form, chorotype, diversity, and community structure in relation to edaphic variables. We also provide a general description of the floristic and ecological features of the different habitats in the study area, which is considered one of the most diverse sites in the Mecca strip, presumably due to the greater amounts of run-off water collecting there.

1.1. The study area

The city of Mecca lies in the western part of Saudi Arabia at 21°26′N and 39°46′E, about 80 km from Jeddah on the Red Sea coast. It is bordered by almost continuous granite and granite gneiss ridges (Brown et al., 1962). Wadi Al-Noman is also located in the western part of Saudi Arabia, between the El Hada mountains in the east and the Red Sea coast in the west, and it extends between 21°06′N and 21°32′N and 39°32′E and 40°20′E (Figure 1). It covers an area of 740.1 km^2 and extends about 25 km from Mecca. It is bordered to the north by Wadi El-Begaedy, to the west by Wadi Orna, to the south by mountains and Wadi Melcan, and to the east by the El Hada mountains. The vegetation in this arid area is of a restricted type (mode contracté, sensu Monod, 1954) and is found only in runnels, wadis, and depressions with deep, fine sediments that receive an adequate water supply and are mainly ground-water–dependent (Abd El-Ghani, 1992). According to Walter et al. (1975), the study area lies within the subtropical dry zone and it has very hot summers and mild winters. The average annual temperature is 30.7 °C; January is the coldest month with the lowest average temperature (23.9 °C), and the hottest month is July with the highest average temperature (35.8 °C) (Figure 2). Precipitation is scanty and unpredictable. The average annual precipitation is 9.2 mm, which usually falls during the winter months; however, the interannual variability of rain is high, and extreme rainfall can be more than 100 mm.

2. Materials and methods

2.1. Sample sites

A total of 20 sample plots were selected along the Wadi Al-Noman under study (upstream, midstream, and downstream parts, including the different wadi tributaries) in the period from January 2010 to January 2012. Locations and sample plots were selected to represent a wide range of physiographic and environmental variation in each tributary. In each location, sample plots were selected randomly using the relevé method described by Muller-Dombois and Ellenberg (1974). The sample plots were 50 m × 50 m, and the sampling process was carried out during the spring season when most species were expected to be growing (Figure 1). The vegetation sampling involved listing all plant species at the sample plots. The plant cover of each species was estimated according to the Zurich-Montpellier technique (Braun-Blanquet, 1965).

The collected plant specimens were identified and named according to Collenette (1999), Cope (1985), Mighaid (1996), and Chaudhary (1999–2001). Plant specimens were deposited in the Umm Al-Qura University Herbarium, Biology Department, Faculty of Science. Species life-forms were determined according to the location of regenerative buds and the parts shed during the unfavourable season (Raunkier, 1934). A chronological analysis of the floristic categories of species was made to assign the recorded species to world geographical groups, according to Wickens (1978) and Zohary (1973).

2.2. Soil analysis

Soil samples were collected at 3 random points from each site as a profile (composite samples) at a depth of 0–50 cm. The electrical conductivity (EC) and pH for each sample were determined as a 1:5 dilution in deionised water (Wilde et al., 1979). Soil analyses including total dissolved salts (TDS; g L^{-1}) and total carbonates (CO_3), bicarbonate (HCO_3), and chlorides (Cl; g 100 g^{-1} DW) were analysed by precipitation by AgCl and titration according to Jackson (1967); sulphates (SO_4; g 100 g^{-1} DW) were precipitated gravimetrically and estimated according to Wilde et al. (1979). Major cations such as sodium (Na), potassium (K), calcium (Ca), and magnesium (Mg; g 100 g^{-1} DW) were determined in the 1:5 soil extract by flame photometer (Jenway, PFP-7), according to the methods of Williams and Twine (1960). The minor cations iron (Fe), copper (Cu), and zinc (Zn) were determined using a GBC model 1100B atomic absorption spectrophotometer, and their concentrations were expressed in mg kg^{-1} dry soil.

2.3. Data analysis

Species cover-type data matrices were created as follows: (1) matrix of 20 sample plots × 100 common species cover values, and (2) matrix of 20 sample plots × 100 species cover values and soil variables. For classification and ordination of the wadi vegetation, multivariate analyses were applied to

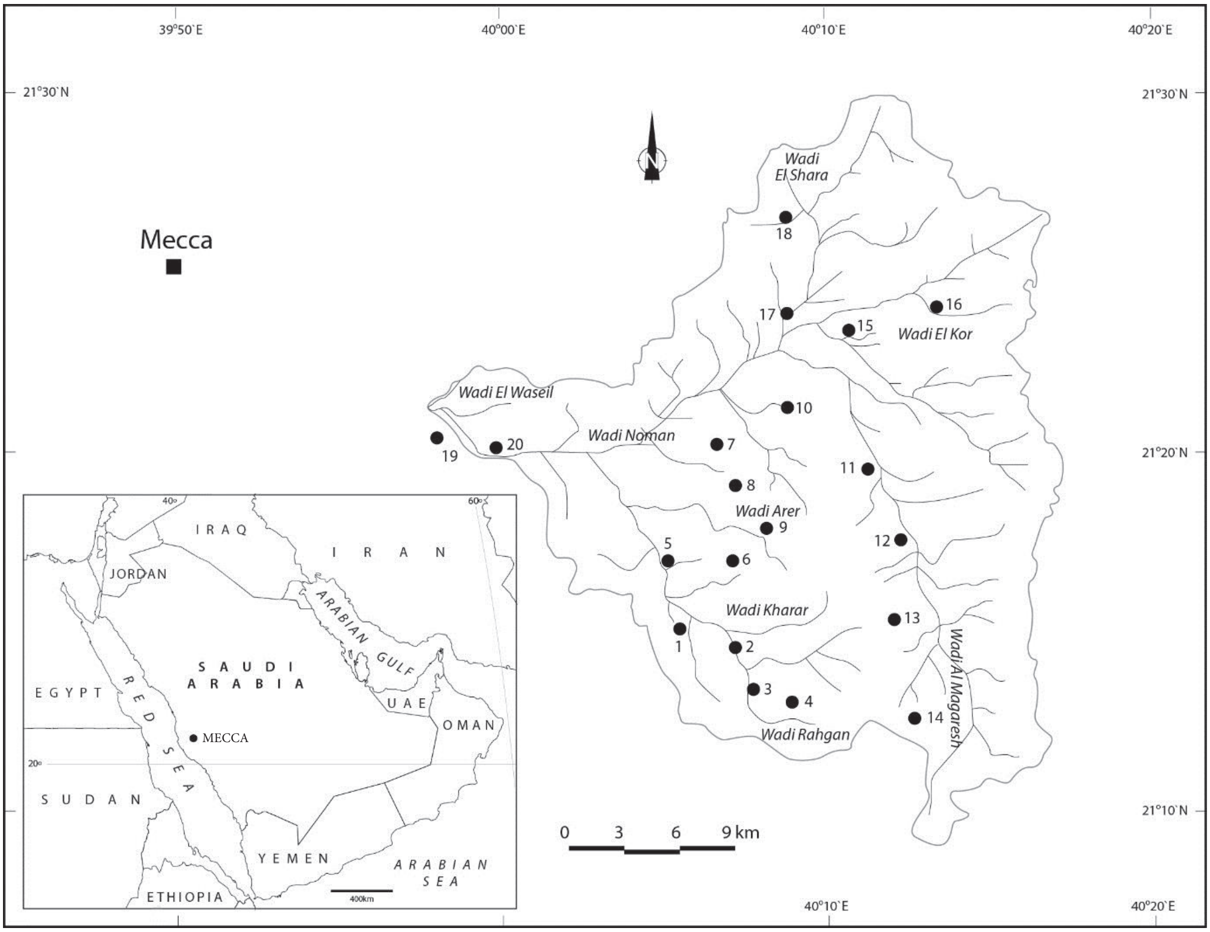

Figure 1. Map of study area Wadi Al-Noman showing sample plots 1–20.

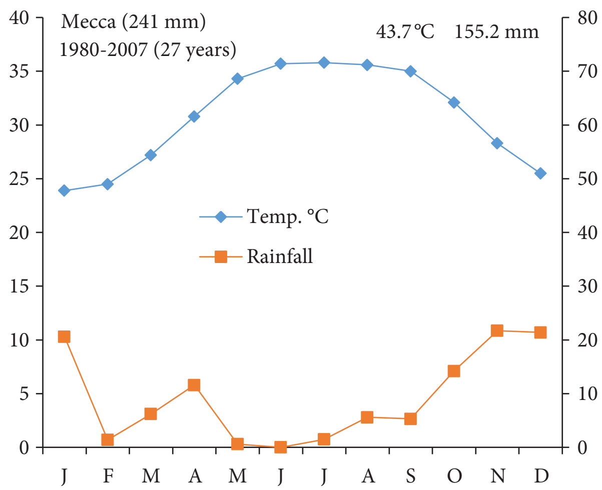

Figure 2. Climate diagram for Mecca, Saudi Arabia.

the 2 data sets. The first matrix was subjected to numerical classification using 2-way indicator species analysis (TWINSPAN) (Hill, 1979a). This procedure simultaneously classifies both stands and species directly, constructing an ordered 2-way table to exhibit the relationship between them as clearly as possible. TWINSPAN produces a hierarchical classification of vegetation groups (i.e. plant communities). Plant communities were named after their dominant species. Detrended correspondence analysis (DCA) (Hill, 1979b) was applied to the same first matrix data set in order to obtain an efficient graphical representation of the ecological structure of vegetation groups identified using TWINSPAN and to verify the identified vegetation units. In order to detect correlations between derived vegetation associations and environmental data, canonical correspondence analysis (CCA) according to Ter Braak and Smilauer (2002) was conducted with species cover, stands, and soil variables using the second matrix (El-Sheikh et al., 2010). Relationships between the ordination axes on one hand and community and soil variables on the other were tested using Pearson's simple linear correlation coefficient (r). Variation in species diversity, sample plot traits, and soil variables in relation to plant community were assessed using one-way analysis of variance (SAS, 1989–1996).

3. Results

3.1. Floristic diversity

A total of 126 species belonging to 90 genera and 39 families were recorded from various sample plots and attached areas. The most highly represented families were Poaceae (Gramineae) and Fabaceae (Leguminosae). Chamaephytes constituted 50 species, or 40% of the total species, followed by 40 species of therophytes (32%) and 16 species of phanerophytes (13%) (Table 1; Figure 3). Chronological analysis of the species in the study area revealed that biregional elements that belong to the Saharo-Arabian and the Sudano-Zambezian together have the highest share of species, representing 66 or

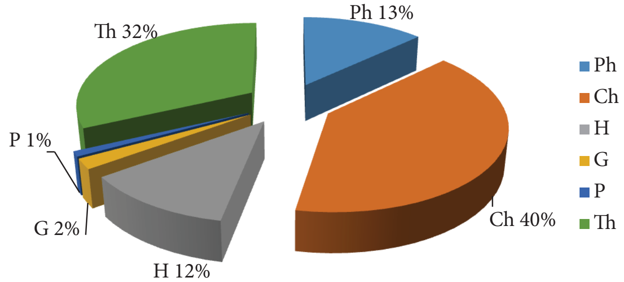

Figure 3. Life-form relative spectrum of Wadi Al-Noman vegetation. Ch = chamaephyte, Th = therophyte, Ph = phanerophyte, H = hemicryptophyte, P = parasite, and G = geophyte.

Table 1. Synoptic table of species composition of the 4 vegetation groups (I–IV) identified after the application of TWINSPAN to the vegetation data of the 20 sample plots of Wadi Al-Noman region. Cover levels: 1, <10%; 2, 10%–20%; 3, 20%–30%; 4, 30%–40%; and 5, >40%. Vegetation groups: (I) *Aristolochia bracteolata-Cucumis prophetarum*, (II) *Calotropis procera-Acacia hamulosa-Caralluma russeliana*, (III) *Acacia abyssinica-Acacia hamulosa-Tephrosia desertorum*, and (IV) *Argemone ochroleuca-Senna italica*. Life-forms: Th = therophyte, Ch = chamaephyte, Ph = phanerophyte, He = hemicryptophyte, Cr = cryptophyte. Chorotypes: COSM = Cosmopolitan, Pal = Palaeotropical, Pan = Pantropical, SA = Saharo-Arabian, SZ = Sudano-Zambezian, ME = Mediterranean, and IT = Irano-Turanian.

Taxa	Life-form	Chorotype	Vegetation groups I II III IV 11 1 111 2 1111 56233499456120780178	TWINSPAN levels
Ruellia patula Jacq.	Ch	ME + SA + SZ	--33----------------	00000
Achyranthes aspera L.	Th	IT + ME	--3-----------------	00000
Acacia seyal Del.	Ph	SA + SZ	--33----------------	00000
Commicarpus helenae (J.A.Schultes) Meikle	Ch	SA + IT	--34----------------	00000
Pupalia lappacea (L.) Juss.	Ch	PAL (weed)	--3------3----------	00001
Chenopodium murale L.	Th	COSM (weed)	--3------3----------	00001
Seddera virgata Hochst. & Steud.	Ch	SZ	---3--3-------------	00001
Solanum nigrum L.	Ch	COSM (weed)	--3---3-------------	00001
Glinus lotoides L.	Th	PAL (weed)	---------33---------	000101
Amaranthus graecizans L.	Th	PAL (weed)	----3----33---------	000101
Amaranthus hybridus L.	Th	PAL (weed)	---------43---------	000101
Trichodesma ehrenbergiana Schweinf.	Ch	SA + SZ	------3--3----------	000101
Senecio flavus (Decne.) Sch. Bip.	Th	SA + SZ	------3--33---------	000101
Pulicaria crispa (Forssk.)Benth. & Hook.	Ch	SA + SZ	------3---3---------	000101
Cuscuta hyalina Roth.	P	SA + SZ	------3-3-----------	000101
Phyllanthus maderaspatensis L.	Th	PAL (weed)	------3--33---------	000101
Lavandula pubescens Decne.	Ch	SA + SZ	---------33---------	000101
Ochradenus baccatus Delile	Ph	SA + SZ	---34-3--33------3--	00011
Cucumis prophetarum L.	H	SA + SZ	43-3--3-------------	001000
Phragmites australis (Cav.) Trin. ex Steud.	G	IT + ME + SA	4-------------------	001000
Aristolochia bracteolata Lam.	Ch	SA + SZ	43--33--------------	001001

Table 1. (Continued).

Calendula arvensis L.	Th	PAN (weed)	3--------33---------	001010
Cocculus pendulus (J.R.&G.Forst.) Diels	Ph	SA + SZ	33--3-333-3---3-----	001010
Leptadenia arborea (Forssk.) Schweinf.	Ph	SA + SZ	3---333-------------	001011
Euphorbia arabica T.Anderson	H	ME + SA + SZ	3-3-3-3--33---------	001011
Indigofera spinosa Boiss.	Ch	SA + SZ	3334333-333-----3---	001011
Portulaca oleracea L.	Th	COSM (weed)	3-3-333-------------	001011
Blepharis ciliaris (L.) B.L.Burtt.	Ch	SA + SZ	--3-3-3-33-3-----3--	0011
Rhazya stricta Decne.	Ch	SA + SZ	--3-3334-----4------	0011
Caralluma russeliana (Courb. ex Brongn.) Cufod.	Ch	SA + SZ	--4333-3333---33----	0011
Cleome paradoxa R.Br.	H	SZ	------3-3----3------	010
Cleome scaposa DC.	Th	SA + SZ	--33---------3------	010
Schouwia purpurea (Forssk.) Schweinf.	Ch	SZ	------33-----3------	010
Polypogon monspeliensis (L.) Desf.	Th	IT + ME + SA	---3---333----3---3-	010
Aerva javanica (Burm.F.) Juss. ex Schult.	Ch	SA + SZ	3-33----3333333-----	01100
Calotropis procera (Ait.) Ait.F.	Ch	SA + SZ	3-44434-444--4444---	01100
Heliotropium strigosum Willd.	Ch	SA + SZ	3---3---------3-----	01100
Trichodesma africana (L.) R.Br.	Ch	SA + SZ	33--3------3-3------	01100
Aizoon canariense L.	Th	SA + SZ	--3---3-33-433------	01101
Tephrosia desertorum L.	Ch	SA	----333-434433333---	01101
Acacia hamulosa Benth.	Ph	SA + SZ	----4334433333333---	01101
Acacia asak (Forssk.) Willd.	Ph	SA + SZ	--------343---44----	01101
Aristida adscensionis L.	Th	SA	--3-----3----3----3-	01110
Rumex vesicarius L.	Th	ME + SA + SZ	--3-3------------33	01110
Lycium shawii Roem. & Schult.	Ph	SA + SZ	3-33--3-------33--3-	01110
Setaria viridis (L.) P.Beauv.	Th	IT + ME + SA	3--3---333----3---33	01111
Lindenbergia indica (L.) Kountze	Th	PAL (weed)	3------3----------3-	01111
Cleome droserifolia (Forssk.) Delile	H	SA + SZ	3-33--3------33---33	1000
Gynandropsis gynandra (L.) Briq.	Th	PAL (weed)	3----------------3-	1000
Sisybrium erysimoides Desef.	Th	ME + SA + SZ	3-3---------------33	1000
Datura innoxia Mill.	Ch	SA	--33--3------33---3-	1000
Morettia parviflora Boiss.	Th	SZ	3-----333--333--4-33	10010
Abutilon pannosum (G.Forst.) Schltdl.	Ch	SA	---3----3--3--3----3	10010
Pistacia khinjuk Stocks	Ph	SA + SZ	4----------------4--	10011
Leptadenia pyrotechnica (Forssk.) Decne.	Ph	SA + SZ	33---------3----3---	10011
Avena fatua	Th	PAL (weed)	3-3--------3-3------	10011
Forsskaolea tenacissima L.	H	SA + SZ	3-------33-33----3--	10011
Nepeta deflersiana Schweinf. ex Hedge	Ch	SA	---------3------3---	101000
Chenopodium ambrosioides L.	Th	COSM (weed)	----3--------3------	101001
Chrozophora oblongifolia (Delile) Spreng.	Ch	IT + ME	------3--3---33-----	101001
Panicum turgidum Forssk.	G	SA + SZ	------3---------3---	101001
Corchorus antichorus (L.) Raeusch.	Ch	ME + SA + SZ	----3-3------33-----	101001
Heliotropium longiflorum Hochst. & Steud.	Ch	SA + SZ	----33--------3-3-3-	10101

Table 1. (Continued).

Fagonia paulayana Wagner & Vierh.	Ch	SA + IT	--1-3-3-------3--33-	10101
Stipagrostis ciliata (Desf.) de Winter	H	IT + ME + SA	------4----33-------	1011
Senna holosericea (Fresen.) Greuter	H	SA + SZ	-------4------3-3---	1011
Ziziphus spina-christi (L.) Willd.	Ph	SA + SZ	3-----3------333----	1011
Heliotropium arbainense Fresen.	CH	SA + SZ	----4---3-----333-33	1100
Abutilon fruticosum Guill. & Perr.	CH	SA + SZ	--3--------------33	1100
Abutilon muticum (Del.) Webb.	CH	SA	------3------3----3-	1100
Boerhavia repens L.	CH	SA + SZ	------3-----------33	1100
Capparis spinosa L.	Ch	IT + ME	------------------33	110100
Malva parviflora L.	Th	IT + ME	------------------33	110100
Ficus salicifolia Vahl	Ph	SA + SZ	------------------33	110100
Argemone ochroleuca Sweet	Th	SA + SZ	------------------44	110100
Senna alexandrina Mill.	H	SA + SZ	----------------3333	110101
Tribulus pentandrus Forssk	Th	SA + SZ	-----------------33-	110101
Cleome chrysantha Decne.	Ch	SA	-----------33-----33	11011
Senna italica Mill.	H	SA + SZ	------3-------433-34	11011
Commicarpus plumbagineus (Car.) Standley	Ch	SA + IT	-------------3----4-	11011
Farsetia longisiliqua Decne.	Ch	SA + SZ	------3----3-3------	11100
Solanum incanum L.	Ch	SA	------3------33-----	11100
Zygophyllum simplex L.	Th	SA + SZ	------3------3---3--	11100
Convolvulus hystrix Vahl.	H	SA + SZ	3----------33-------	11101
Cyperus rotundus L.	G	PAN (weed)	3-------------33----	11101
Imperata cylindrica (L.) Raeusch.	H	PAN (weed)	3----------3----3---	11101
Tribulus macropterus Boiss.	Th	SA + SZ	---3-------33-3-3--3	11101
Citrullus colocynthis (L.) Schrad.	H	Me + SA	-----------433333-34	11110
Schismus barbatus (L.) Thell.	Th	IT + ME + SA	--------------3-3-3-	11110
Aerva lanata (L.) Juss. ex J.A.Schultes	Ch	SA + SZ	----------------4---	111110
Pergularia tomentosa L.	Ch	SA + SZ	-----------4----3---	111110
Heliotropium pterocarpum Hochst. & Steud.	Ch	SA + SZ	-------------3--33--	111110
Dipterygium glaucum Decne.	Ch	SZ	-------------4--33--	111110
Cucumis dipsaceus Ehrenb. ex Spach	H	SA + SZ	-----------33-3-34--	111110
Otostegia fruticosa (Forssk.) Schweinf. ex Penzig	Ch	SA	----------------33--	111110
Tephrosia nubica (Boiss.) Baker	Ch	SA	-----------43-33----	111110
Acacia abyssinica Hochst.	Ph	SA + SZ	-----------4334433--	111110
Hyphaene thebaica (L.) Mart.	Ph	SA + SZ	-----------4--------	111110
Emex spinosus (L.) Campd.	Th	IT + ME + SA	--------------4-----	111110
Acacia elatior Brenan	Ph	SA + SZ	------3----4343-----	111111
			00000000000111111111 00111111111000000011 0011111110000001 0001111000111 **TWINSPAN level**	

52% of the total species, followed by the Saharo-Arabian region elements at 12 (10%) and Palaeotropic at 9 (7%). Pluriregional elements that belong to the Saharo-Arabian, Irano-Turanian, and Mediterranean regions and to the Saharo-Arabian, Sudano-Zambezian, and Mediterranean regions are represented by 8 and 7 species accounting for 12% of the total species, respectively. The floristic composition of the study area also included 6 species in the Sudano-Zambezian, 4 species in both the Irano-Turanian and Mediterranean, 4 in both the Saharo-Arabian and Irano-Turanian, 4 cosmopolitan species, 3 species in both the Saharo-Arabian and Mediterranean, and 3 Pantropic species (Table 1; Figure 4).

3.2. Multivariate analysis

The application of TWINSPAN to the cover and presence estimates of the 100 selected common species, recorded in the 20 Wadi Al-Noman sample plots, indicated 8 vegetation subgroups at level 5, summarised into 4 vegetation groups (VGs; i.e. plant communities) at level 2. These 4 major plant communities were characterised and named after the dominant and subdominant species as follows: (I) *Aristolochia bracteolata-Cucumis prophetarum*, (II) *Calotropis procera-Acacia hamulosa-Caralluma russeliana*, (III) *Acacia abyssinica-Acacia hamulosa-Tephrosia desertorum*, and (IV) *Argemone ochroleuca-Senna italic* (Table 1; Figure 5). The application of DCA confirmed the separation among these communities and indicated some relationships between environmental gradients and topographic aspects of Wadi Al-Noman (Figure 6).

CCA ordination was used to verify the correlation analysis between the dominant environmental factors and CCA axes. Correlation analysis indicated that the

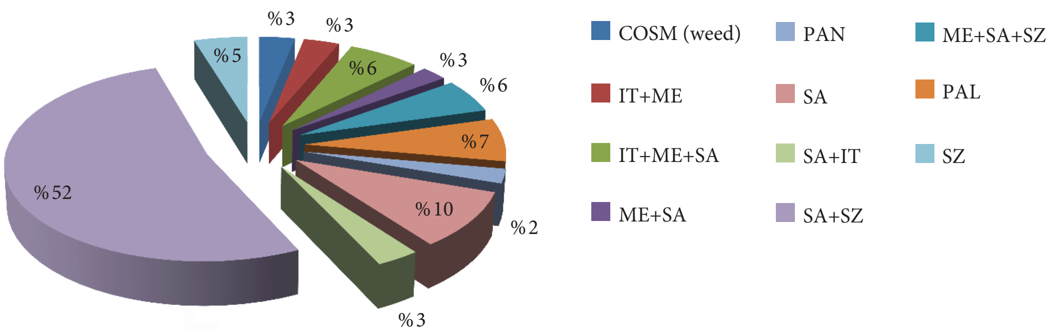

Figure 4. Floristic category spectrum of Wadi Al-Noman. COSM = Cosmopolitan, PAL = Palaeotropical, PAN = Pantropical, SA = Saharo-Arabian, SZ = Sudano-Zambezian, Me = Mediterranean, and IT = Irano-Turanian.

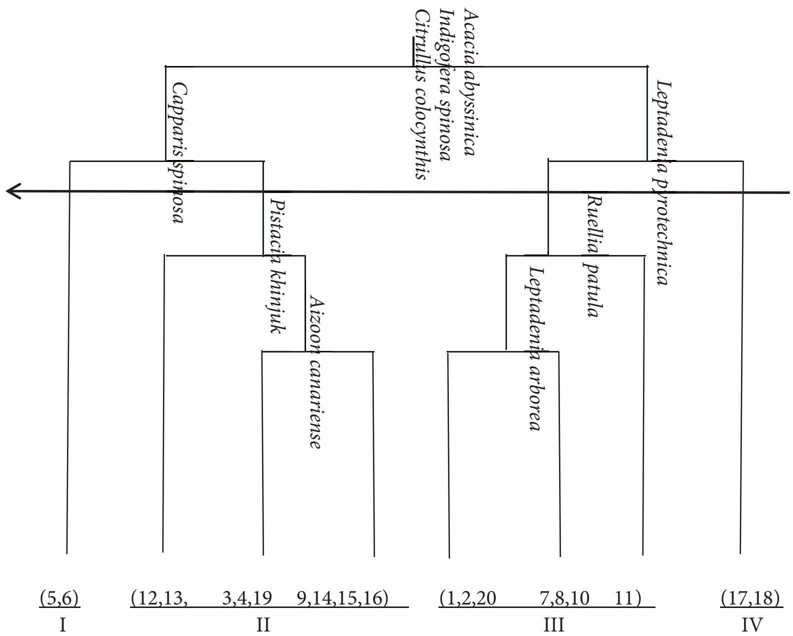

Figure 5. The dendrogram illustrating the presence of 4 vegetation groups using TWINSPAN analysis of 20 sample plots in the study area.

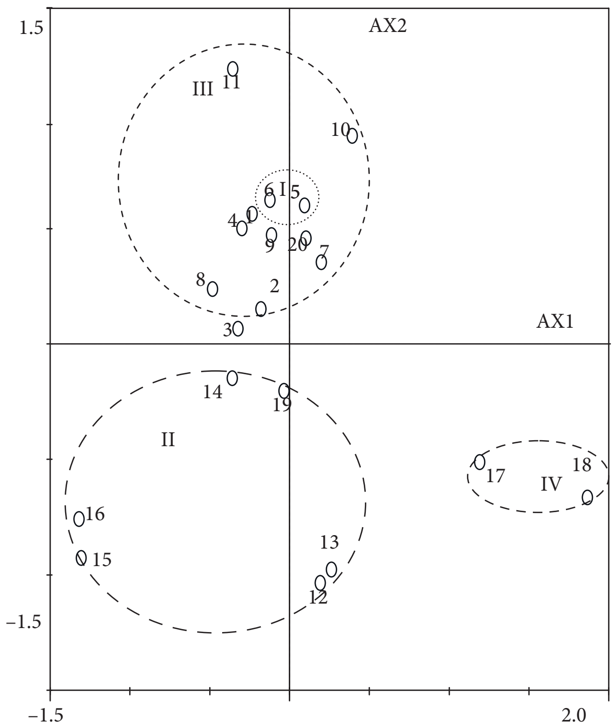

Figure 6. DCA ordination of the 4 vegetation groups identified using TWINSPAN analysis of the 20 sample plots in the study area.

separation of species along the first axis is affected negatively by K and species richness (–0.30) (Table 2). Therefore, *Aristolochia bracteolata-Cucumis prophetarum* (VG I), which occupies the wadi plateau and fissures, and *Calotropis procera-Acacia hamulosa-Caralluma russeliana* (VG II) and *Acacia abyssinica-Acacia hamulosa-Tephrosia desertorum* (VG III), which occupy the wadi slope and bed, were separated on the left of axis 1 from *Argemone ochroleuca-Senna italica* (VG IV) on the right, which inhabits the wadi bed (Figure 7).

Xerophytes occupied the wadi hills and fissures of the flat stony habitat of the *Aristolochia bracteolata-Cucumis prophetarum* VG I (e.g., *Pistacia khinjuk*, *Leptadenia pyrotechnica*, *Trichodesma africanum*, *Indigofera spinosa*, and *Cocculus pendulus*) on the upper, positive sector of axis 2, and they are correlated with low species diversity and soil mineral contents. The therophyte, chamaephyte, and shrubs species of the *Calotropis procera-Acacia hamulosa-Caralluma russeliana* VG II (e.g., *Blepharis ciliaris*, *Aizoon canariense*, *Aerva javanica*, *Rhazya stricta*, *Morettia parviflora*, *Euphorbia arabica*, *Phyllanthus maderaspatensis*, *Tephrosia desertorum*, *Cocculus pendulus*, *Ochradenus baccatus*, and *Lycium shawii*) on the centre and lower negative part of axis 1 are related to high altitude, salinity, and soil mineral contents. Ruderal and psammophytic species of the *Argemone ochroleuca-Senna italica* VG IV

Table 2. Interset correlations of environmental variables in Wadi Al-Noman with DCA axes. *: P ≤ 0.05.

N	Variable	AX1	AX2
1	Alt (m)	–0.2130	0.2282
2	pH	0.1169	–0.1696
3	EC (µS cm^{-1})	–0.1224	–0.0016
4	TDS (ppm)	–0.1205	–0.0369
5	CO_3 (ppm	–0.0792	–0.0632
6	HCO_3 (ppm	–0.0817	–0.0572
7	SO_4 (ppm	–0.0864	0.1580
8	Ca (ppm	–0.0816	–0.0498
9	Na (ppm	–0.1119	0.0733
10	K (ppm	–0.30*	0.1669
11	Cl (ppm	–0.1025	0.1502
12	Fe (ppm	–0.1390	0.1216
13	Mg (ppm	–0.1647	–0.0113
14	Total species (no.)	0.0178	–0.0391
15	Total cover (m 100 m^{-1})	0.0333	–0.1011
16	Simpson (C)	–0.30*	–0.0360
17	Shannon Ĥ	0.1060	–0.1846

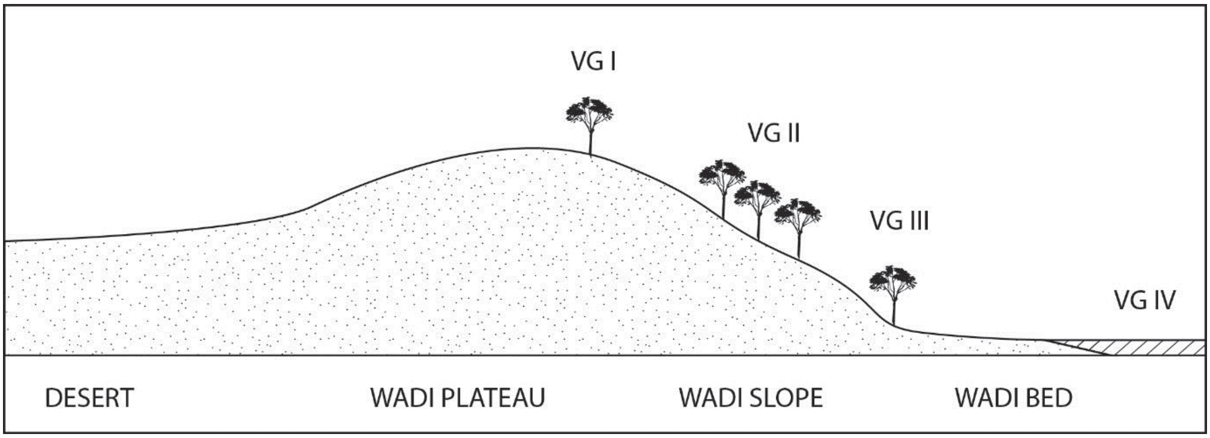

Figure 7. Transect diagram showing the topographic situation of the vegetation groups in the section part of Wadi Al-Noman. The vegetation groups are named as follows: (I) *Aristolochia bracteolata-Cucumis prophetarum*, (II) *Calotropis procera-Acacia hamulosa-Caralluma russeliana*, (III) *Acacia abyssinica-Acacia hamulosa-Tephrosia desertorum*, and (IV) *Argemone ochroleuca-Senna italica*.

inhabit disturbed sample plots of the wadi bed (e.g., *Citrullus colocynthis*, *Heliotropium arbainense*, *Cleome chrysantha*, *Cleome droserifolia*, *Morettia parviflora*, *Stipagrostis ciliate*, *Senna alexandrina*, *Abutilon fruticosum*, *Malva parviflora*, *Ficus salicifolia*, and *Boerhavia repens*) on the positive part of axis 1 and are related with high species diversity and plant cover values (Figure 8).

Species richness was negatively correlated with Fe (–0.50) and altitude (–0.33) (Table 3). Species cover was positively correlated with pH (0.30) and species richness (0.98) and negatively with altitude (–0.31) and Fe (–0.54). Species evenness was positively correlated with species richness, total plant cover, and pH (0.85, 0.87, and 0.41, respectively) and negatively with Fe (–0.40).

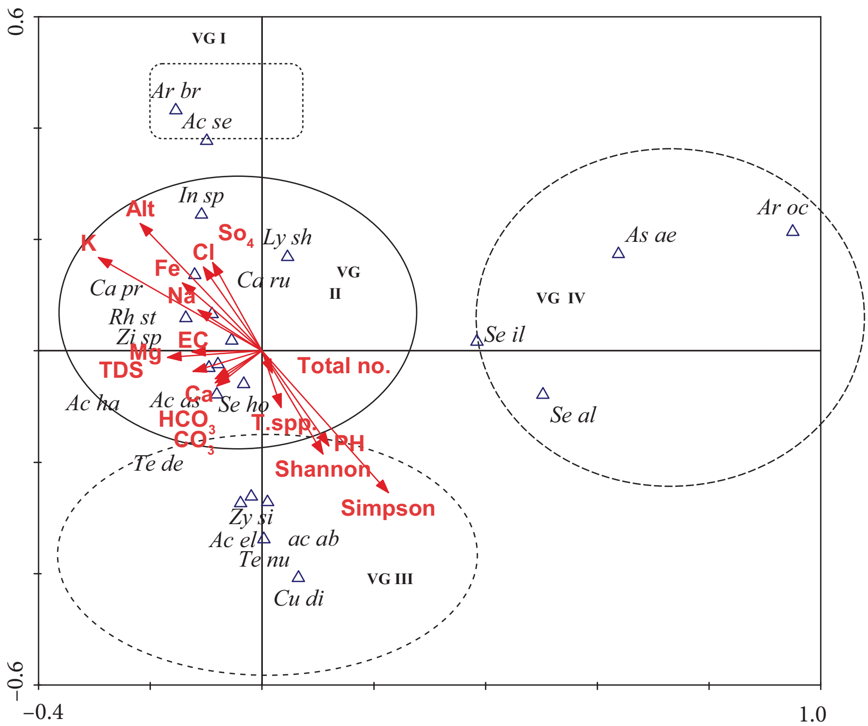

Figure 8. CCA biplot with environmental variables (arrows), the sample, and the abundant species represented by the first 2 letters of the genus and a specific epithet. For complete names of species, see Table 1.

Table 3. Correlation analysis (Pearson's correlation coefficient = r) of species diversity and environmental variables. *: P ≤ 0.05, **: P ≤ 0.01, and ***: P ≤ 0.001.

Variable	Species richness (species stand^{-1})	Plant cover (m 100 m^{-1})	Conc. of dominance (C)	Relative evenness (Ĥ)
Altitude (m)	–0.33*	–0.31*	0.24	–0.23
pH	0.22	0.30*	–0.11	0.41**
EC (μS cm^{-1})	0.11	0.11	–0.03	0.21
TDS (ppm)	0.10	0.13	0.01	0.22
CO_3 (ppm)	0.12	0.18	–0.05	0.25
HCO_3 (ppm)	0.12	0.18	–0.06	0.26
SO_4 (ppm)	0.01	–0.02	–0.09	0.07
Ca (ppm)	0.19	0.20	–0.07	0.27
Na (ppm)	–0.09	–0.06	0.06	–0.01
K (ppm)	–0.07	–0.05	–0.01	0.03
Cl (ppm)	–0.07	–0.08	0.03	–0.06
Fe (ppm)	–0.50**	–0.54**	–0.21	–0.40**
Mg (ppm)	0.17	0.17	–0.07	0.25
Species richness (species stand^{-1})	1.00	0.98***	–0.26	0.85***
Plant cover (m 100 m^{-1})		1.00	–0.15	0.87***
Conc. of dominance (C)			1.00	–0.12
Relative evenness (Ĥ)				1.00

3.3. Plant community–soil relationship

The *Aristolochia bracteolata-Cucumis prophetarum* community (VG I) had the lowest species richness, plant cover, relative species evenness, EC, TDS, CO_3, HCO_3, Ca, Na, and Cl values (18, 20, 1.12, 305, 199.7, 107.7, 109.5, 32.4, 15.1, and 2.5, respectively), whereas it had the highest Fe content (3.5) (Table 4). The *Calotropis procera-Acacia hamulosa-Caralluma russeliana* community (VG II) achieved the highest altitude, EC, TDS, CO_3, HCO_3, SO_4, Ca, Na, K, Cl, and Mg values (649 m, 553, 288.7, 134, 137, 55, 61, 28.7, 12.7, 21, and 4.2, respectively) and had the lowest pH (7.24). On the other hand, the *Argemone ochroleuca-Senna italica* community (VG IV) demonstrated the highest levels of species richness (23), species cover (27 m 100 m^{-1}), species dominance (0.14), relative evenness (1.33), and pH (7.37), whereas it had the lowest altitude, K, Fe, and Mg levels (495 m, 6.7, 1.5, and 1.9, respectively).

4. Discussion

In terms of floristic and vegetation composition in the studied area, Poaceae (Gramineae) and Fabaceae (Leguminosae) are represented by the highest number of species (10 and 11, respectively). A floristic analysis shows that the majority of plants in the study area are annuals, and the minority group occupies a tree habit. The dominance of members of Poaceae and Fabaceae coincides with the findings reported by Al-Turki and Al-Qlayan (2003), El-Ghanem et al. (2010), and Alatar et al. (2012). The life-form distribution of plants growing in arid regions is closely related to topography and landform (Kassas & Girgis, 1964; Zohary, 1973; Orshan, 1986; Shaltout et al., 2010). According to Walter et al. (1975), the study area lies within the subtropical dry zone, which has very hot summers and mild winters. The dominant perennial species provide the permanent character of the plant cover in each habitat. This may be credited to the rather short rainfall, which is not adequate for the appearance of many annuals. On the other hand, the rainy season provides a better opportunity for the appearance of a considerable number of annuals, which then provide a characteristic physiognomy to the vegetation (Hosni & Hegazy, 1996; Shaltout & Mady, 1996; Shaltout et al., 2010; Alatar et al., 2012).

The biological spectrum of the study area indicates the dominance of chamaephytes (40%) and therophytes

Table 4. Mean ± standard error of soil variable and diversity indices of 4 vegetation groups after TWINSPAN as follows: (I) *Aristolochia bracteolata-Cucumis prophetarum*, (II) *Calotropis procera-Acacia hamulosa-Caralluma russeliana*, (III) *Acacia abyssinica-Acacia hamulosa-Tephrosia desertorum*, and (IV) *Argemone ochroleuca-Senna italica*. Maximum and minimum values in bold.

Variable	VG I	VG II	VG III	VG IV	Mean	F-value
Species richness (species stand^{-1})	**18.0 ± 12.0**	22.4 ± 3.7	22.1 ± 3.4	**23.0 ± 5.0**	21.9	0.11
Total cover (m 100 m^{-1})	**20.0 ± 14.0**	25.3 ± 3.6	26.1 ± 4.1	**27.0 ± 5.0**	25.3	0.17
Conc. of dominance (C)	**0.05 ± 0.04**	0.07 ± 0.02	0.12 ± 0.03	**0.14 ± 0.1**	0.09	0.96
Relative evenness (Ĥ)	**1.12 ± 0.34**	1.24 ± 0.07	1.3 ± 0.05	**1.33 ± 0.11**	1.26	0.41
Altitude (m)	522.0 ± 2.0	**648.78 ± 64.9**	510.0 ± 17.9	**495.0 ± 11.0**	57.2	1.62
pH	7.30 ± 0.0	**7.24 ± 0.12**	7.29 ± 0.1	**7.37 ± 0.1**	7.28	0.13
EC (µS cm^{-1})	**305.5 ± 7.5**	**552.8 ± 158.7**	383.2 ± 46.4	352.6 ± 22.6	448.7	0.52
TDS (ppm)	**199.7 ± 5.3**	**288.7 ± 70.2**	248.7 ± 30.2	229.0 ± 14.7	233.0	0.60
CO_3 (ppm)	**107.7 ± 4.3**	**134.2 ± 26.9**	118.0 ± 12.8	111.9 ± 3.8	123.7	0.18
HCO_3 (ppm)	**109.5 ± 4.5**	**137.4 ± 27.7**	119.9 ± 13.1	114.0 ± 4.0	126.2	0.19
SO_4 (ppm)	35.3 ± 3.7	**55.0 ± 16.7**	**31.0 ± 2.1**	40.5 ± 0.5	43.17	0.64
Ca (ppm)	**32.4 ± 1.6**	**61.1 ± 25.1**	45.4 ± 8.4	38.3 ± 6.0	50.5	0.24
Na (ppm)	**15.1 ± 0.2**	**28.7 ± 10.6**	16.2 ± 1.8	18.5 ± 0.5	21.9	0.50
K (ppm)	7.4 ± 0.3	**12.7 ± 2.1**	8.1 ± 0.8	**6.7 ± 3.1**	9.9	1.75
Cl (ppm)	**2.5 ± 0.0**	**21.2 ± 5.8**	10.4 ± 2.1	3.5 ± 2.1	14.8	1.6
Fe (ppm)	**3.5 ± 0.8**	2.4 ± 1.2	1.8 ± 0.8	**1.5 ± 0.8**	2.2	0.23
Mg (ppm)	2.6 ± 0.0	**4.2 ± 1.5**	3.0 ± 0.3	**1.9 ± 0.1**	3.4	0.38

(32%). The domination of chamaephytes and therophytes over other life-forms seems to be a response to the hot dry climate and human and animal interference. Therophytes are adapted to the dryness of the region and shortage of rainfall, because they spend their vegetative period in seed form (Asri, 2003). These results are congruent with the spectra of vegetation in the desert habitats in other parts of Saudi Arabia (El-Demerdash et al., 1995; Chaudhary, 1999–2001; Collenette, 1999; Al-Turki & Al-Qlayan, 2003; Fahmy & Hassan, 2005; El-Ghanem et al., 2010; Alatar et al., 2012), and this picture also reflects the vegetation spectra in other parts of the Middle East (Danin & Orchan, 1990; Zahran & Willis, 1992; Abd El-Ghani, 2000; El-Bana & Al-Mathnani, 2009).

The importance of the study area from a phytogeographical point of view may be due to the position of Mecca (Asir Mountains). Chorological analysis of the floristic data revealed that the Saharo-Arabian–Sudano-Zambezian chorotype (52%) forms the major component of the floristic structure in Wadi Al-Noman. The presence of the biregional Saharo-Arabian–Sudano-Zambezian chorotype in a higher percentage than the interregional chorotype (mono- and pluriregionals) is not in accordance with Zohary (1973). The Saharo-Arabian–Sudano-Zambezian chorotypes decrease moving north and are replaced by Mediterranean and Irano-Turanian chorotypes (Danin & Plitman, 1987; Abd El-Ghani & Amer, 2003). This may be due to the fact that Saharo-Arabian–Sudano-Zambezian and Saharo-Arabian plant species are good indicators of a desert environment, while Mediterranean species point to a more mesic environment. The low percentage of endemic species is remarkable. Wickens (1977) and Boulos (1997) mentioned that the Saharo-Arabian region is characterised by the presence of few endemic species and genera. The Saharo-Arabian species that are restricted in their distribution to the central strip of Saudi Arabia are more abundant in habitats with more favourable microenvironmental conditions and those providing better protection (Ghazanfar & Fisher, 1998; Hegazy et al., 1998; El-Ghanem et al., 2010).

Due to the sharp topography of the study area and the importance of this wadi, several microhabitats were recognised, namely wadi beds, slopes, and cliffs. Each of these habitats supports a special type of vegetation with a characteristic floristic composition and plant cover. Wadi Al-Noman in Mecca is one of the most important wadis. It is a mature wadi characterised by its wide, deep valley fill deposits and well-defined canals cutting into older, rocky limestone formations. Therefore, the wadi ecosystem can be divided into a distinct number of habitats according to soil thickness and plant cover. Spatial distribution of plant species and communities over a small geographic area in desert ecosystems is related to heterogeneous topography and landform patterns (Kassas & Batanouny, 1984; Alatar et al., 2012). The heterogeneity of local topography, edaphic factors, and microclimatic conditions leads to variation in the distributional behaviour of the plant associations of the study area. In terms of classification, the vegetation that characterises the study area can be divided into 4 vegetation groups. Most of the identified vegetation groups are more or less comparable with those recorded in some other wadis of Saudi Arabia (Abd El-Ghani, 1997; Al Wadie, 2002; Alatar et al., 2012) and the Taif region (Abdel Fattah & Ali, 2005; Mosallam, 2007).

Among these groups in the Wadi Al-Noman ecosystem, VG IV, characterised by the *Argemone ochroleuca-Senna italica* community, has a clear difference from other groups; this community was recognised as pure vegetation in the Sudera-Taif region by Mosallam (2007). This group has the highest number of ruderals, weeds, and invasive plant species (the plants that usually invade disturbed sites). This could be an effect of severe human impact, as the wadi bed habitat has been subjected to intensive human practices such as cutting, over-grazing, and construction activities, especially roads. This is consistent with studies indicating that the vegetation of intensively disturbed sites is dominated by nonnative alien species and many annuals and, therefore, has high species richness and plant cover (Shaltout & El-Sheikh, 2003; Kürschner & Neef, 2011; Alatar et al., 2012). On the other hand, VG II and VG III are less distinct because they are characterised by mixed communities of native trees, shrubs, and grasses. In Saudi Arabia, Shaltout and Mady (1996), Abd El-Ghani (1997), Al-Yemeni and Zayed (1999), Al-Yemeni (2001), Al-Wadie (2002), El-Ghanem (2006), and Alatar et al. (2012) recognised several plant associations, some of which are comparable to those of the present study (e.g., *Acacia* taxa, *Rhazya stricta*), which are comparable to those identified in neighbouring countries (Batanouny, 1987; El-Bana & Al-Mathnani, 2009; Shaltout et al., 2010). Communities on stony plateaus and rocky outcrop slopes in Wadi Talha at Asir (Al-Wadie, 2002) and vegetation in Taif (Abdel Fattah and Ali, 2005) are, however, comparable to Wadi Al-Noman, which may be due to the similarities in climate and topography. VG I includes *Aristolochia bracteolata-Cucumis prophetarum* and inhabits rocky outcrop slopes, which consist of notches and shallow drainage runnels and have low species diversity and plant cover (Kürschner & Neef, 2011; Alatar et al., 2012).

The *Acacia abyssinica-Acacia hamulosa-Tephrosia desertorum* community of cliff, chasmophytic, shrubby, and grassy species inhabits the outcrops of the rocky slopes. Then comes the community of *Calotropis procera-Acacia hamulosa-Caralluma russeliana*, composed of dense, woody, and sparse short-lived annual species that inhabit the main wide channel of the wadi bed. The most diverse groups, VG II and VG III, inhabiting the wadi slope outcrops and beds and characterised by *Acacia hamulosa* and *Acacia abyssinica-Calotropis procera*, could be related to higher concentration of salinity and soil mineral contents, perhaps due to animal grazing, rainfall, and floods and their effects on the parent rocks (Pulford et al., 1992). The soil, accumulated by runoff water, supported dense woody vegetation and grasses with dense cover during the rainy season. Similar conclusions were made by other authors (Chaudhary, 1983; El-Demerdash et al., 1995; Shaltout & Madi, 1996; Al-Yemeni, 2001; Abbadi & El-Sheikh, 2002; Al Wadie, 2002; Springuel et al., 2006; Alatar et al., 2012).

A correlation analysis in the present study indicates that the species diversity (richness and evenness) is positively correlated with increasing cover and pH. These factors may reflect the human impact degree in some disturbed sites of the wadi bed in the study area (e.g., VG IV, *Argemone ochroleuca*). In such cases, most of the total cover is accounted for by 1 or 2 species that can make the best use of available resources as a result of their high competitive capacities under environmental stress. Similar correlations were reported by El-Demerdash et al. (1995), Abbadi and El-Sheikh (2002), El-Sheikh et al. (2006, 2010), and Alatar et al. (2012). Concerning the socioeconomic changes of the wadi bed area, increasing human activities could be observed. Such activities greatly change the community structure, species diversity, and plant cover (Batanouny, 1987; Shaltout & El-Sheikh, 2003).

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