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ORIGINAL ARTICLE

Vegetation analysis of Wadi Al-Jufair, a hyper-arid region in Najd, Saudi Arabia

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Abstract Wadi Al-Jufair, a tributary of Wadi [illegible]sah, is one of the important wadis of Najd region (Saudi Arabia) sheltering a rich diversity of higher plants. The study area is extended into approximately 15 km^2 encompassing the commonest geomorphological features encountered in desert wadis. The wadi supports several rare plants, including *Maerua crassifolia* Forssk., a regionally endangered tree, and *Acacia oerfota* (Forssk.) Schweinf., a rare shrub with restricted distribution. The present study aims to analyze the vegetation of wadi Al-Jufair and to propose its designation as an important [illegible]. The vegetation type is fundamentally of chamaephytic nature with some phanerophytes, and distinguished into associations where the dominant perennial species give the permanent character of plant cover in each habitat. Four vegetation groups were identified after the application of TWINSPAN, DCA and CCA programs and named after the characteristic species as follows: *Lycium shawii*; *Acacia oerfota*; *Acacia raddiana* – *Rhazya stricta* and *Artemisia monosperma*. These plant associations and speciation of Wadi Jufair demonstrate significant variation in soil texture, moisture, organic matter, pH, EC, and minerals.

1. Introduction

The wadi ecosystems in Najd Region are among the main plant diversity centers of central Saudi Arabia where biological research has been considerable but in-depth analysis on its floristic components are insubstantial (Vesey-Fitzgerald, 1957; Mandaville, 1990; Chaudhary, 1999). Moreover, the importance of wadi ecosystems for socioeconomic development is becoming increasingly recognized due to its ecological significance, physiographic variation and environmental gradients. The central Region of Saudi Arabia that belongs to Saharo-Arabian phytogeographical zone, consists of small mountains, hillocks, plateaus, desert plains, depressions "Raudhas" and wadis (Vesey-Fitzgerald, 1957; Shaltout and Mady, 1996, Sharaf El-Din et al., 1998; Alfarhan, 2001; Shaltout et al., 2010).

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Figure 1 (a) Location map of the study area and diagram of Wadi Al-Jufair. (b) Schematic representation of the spatial hierarchal organization of the vegetation along the profile transect at Wadi Aljufair. The vegetation groups are named as follows: VG I. *Lycium shawii*; VG II. *Acacia oerfota*; VG III. *Acacia raddiana-Rhazya stricta* and VG IV *Artemisia monosperma*.

Several studies were conducted in the past to evaluate the life in deserts (De Marco and Dinelli, 1974; Migahid, 1978), which, over the years, helped in strengthening the foundation of the desert studies in Saudi Arabia. Chaudhary (1983a), Mandaville (1986) and Al-Hemaid (1996) have demonstrated the vegetation of the sand dunes of Nafud, Dahna and Rub

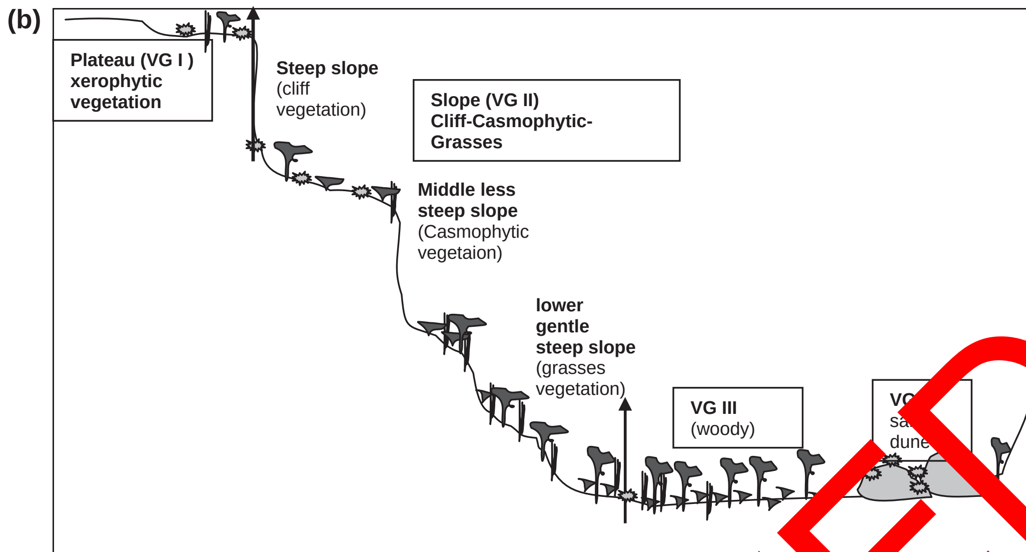

Figure. 1 (*continued*)

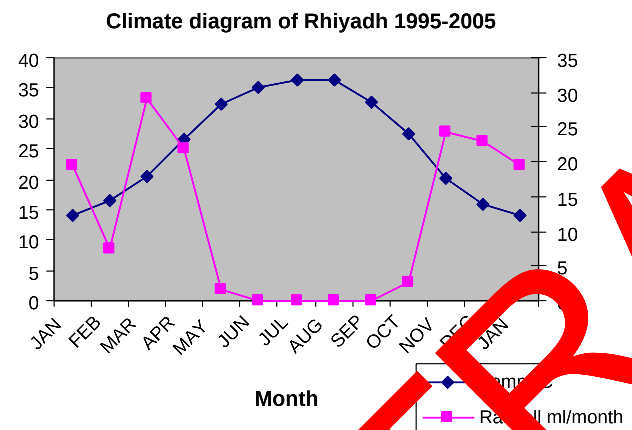

Figure 2 Climate dia[illegible]am of [illegible]yadh region.

al-Khali, while Al-Tu[illegible] (1997), [illegible]l-Sheikh and Yousef (1981), Schultz and Whitne[illegible] (1986) [illegible]ve studied the vegetation and floras of the sabkhas, [illegible]s and oth[illegible] prominent mountains of the Najd r[illegible] such a[illegible] Tuwaiq [illegible]ja and Salma. Considerable effort[illegible]ave als[illegible] been m[illegible]ward the elucidation of vegetation [illegible]vironme[illegible]al relationships in the ecosystems 'raudhas' [illegible]r de[illegible]ssio[illegible]altout and Mady, 1996, Sharaf El-Din et a[illegible] [illegible]998; Alfarhan, 2001) and plant communities of wadis, such [illegible] Wadi Al-Ammaria (Al-Yemeni, 2001) and Wadi Hanifa (Ta[illegible] and El-Ghanem, 2001; El Ghenem, 2006).

Wild plants in the Najd region are very much associated with drought and aridity. Out of 2243 species of higher plants from the entire country (Chaudhary 1983a,b, 1999, 2000, 2001; Collenette, 1999), approximately 600 species are reported from the Central Region (Chaudhary, 1999, 2000, 2001; Zoghet and Alsheikh, 1999). Among these, many are either xerophytes or morphologically and physiologically adapted to cope with the harsh environment prevailing in the central region. Wild plants in the central region, though mostly annuals, have their own characteristics in combating desertification, improving the local climat[illegible] conse[illegible]ng soils, fixing sand dunes, preventing erosion and flooding [illegible]oghet and Alsheikh, 1999; Yousef and [illegible]kh, 1981a,b). [illegible]egetation of wadis in general is no[illegible] constant. It varies from year to year, depending upon th[illegible] moisture (Si[illegible]qui and Al-Harbi, 1995). Al-Farraj et al. (19[illegible]7) conducted [illegible]getation studies in some 'Raudhas' to verify t[illegible] abundanc[illegible] frequency and density of each species, while Al-Yem[illegible]Al-Farraj (1995) reported the characteristics of [illegible] bank and their relationship to the desert vegetation, a fun[illegible]part of understanding the ecological and physiological process of several plants.

Generally, the soil of the central region can be considered as "Aridisols", with no accumulation of clay or organic matter (Al-Nafie, 2004). Whereas the deposits in wadi-basin are deep and fine-textured with a firm, flat vegetation covered mud surface, supported by occasional rocky, sandy or phytogenic mounds (Batanouny, 1987). Since wadi Al-Jufair is vegetationally and floristically one of the richest wadis of the central region, the main objective of the present study is to analyze the vegetation of Wadi Al-Jufair and assess the role of edaphic factors and human impact that influences the vegetation and thereby proposes its designation as an important plant diversity center.

2. Study area

Wadi Al-Jufair (23° 50′ N, 46° 14′E and 24° 06′N, 46° 19′E), a tributary of Wadi Nisah, is located about 120 km south west of Riyadh City in Central Saudi Arabia (Fig. 1a). It is flanked by Tuwayq mountain range which has an altitude ranging from 600 to 1000 m a.s.l. The study area is about 20 km long and 500 m to several kilometers wide. Wadi Nisah and Tuwayq mountains are the main features of the central physiographic province of a large central plateau, "Najd", which is divided into "Higher Najd" in the western and "Lower Najd" in the eastern side. It is characterized by the dissection of its landscape into an extensive system of large wadis which flows eastwards, from the higher mountains in the west to the plains of Najd, responding to the general slope of the land. These wadis

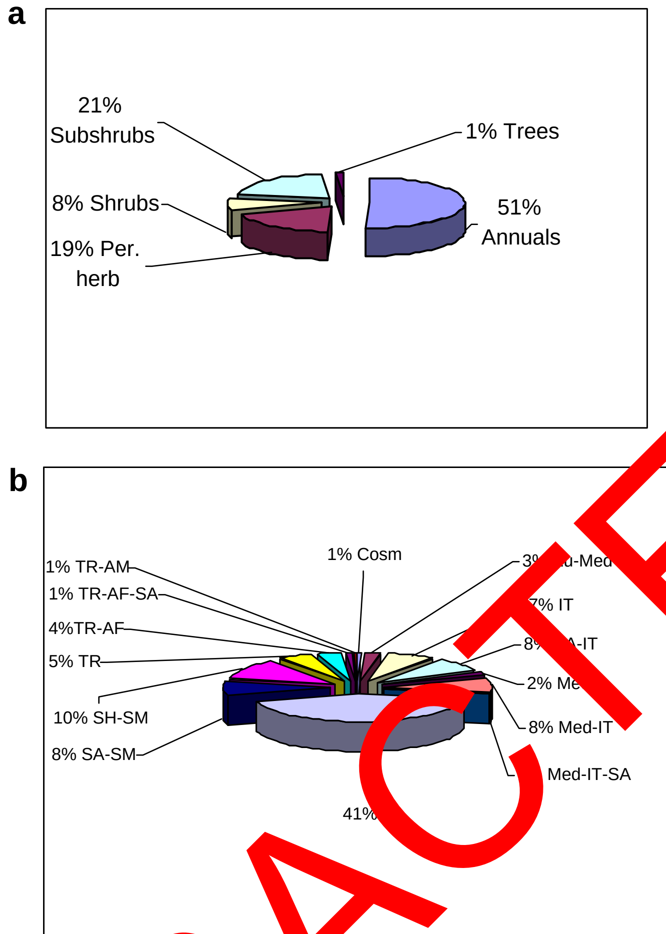

Figure 3 Life form (a) and Chorotype (b) relative spectra of the recorded species in Wadi Al-Jufair. (IT = Irano-Turanian; SA-IT = Saharo-Arabian-Irano-Turanian; SH-SM = Sahelian-Somali-Masai; TR = Tropical; SA = Saharo-Arabian; SA-SM = Saharo-Arabian-Somali-Masai; TR AF = Tropical African; TR AM = Torpical American; Med-IT = Mediterranean-Irano-Turanian; EU-Med-IT = Euro-Siberian-Mediterranean-Irano-Turanian; Med = Mediterranean; Med-IT-SA = Mediterranean-Irano-Turanian-Saharo-Arabian; Cosm = Cosmopolitan; TR AF-SA = Tropical Africa-Saharo-Arabian.

are not continuous, and at times covered and buried by the sand dunes of the Dahna desert. Seasonal springs originate in these wadis during rainy days and often create shallow pools along the banks and depressions. Remnants of dense vegetation can be found along the stretch reflecting a wetter climate of the past (Chapman, 1978; Al-Nafie, 2008). The dominant topography of the central province is made up of a nearly parallel sequence of several prominent crescent-shaped north-south escarpments, "Tuwayq Escarpment", which is mainly of hard marine limestone capped with upper Jurassic limestone, extending for about 1200 km, with elevations up to 850 m a.s.l. and 240 m above the nearby plains (Al-Nafie, 2008).

As the study area is located in the middle of three separate habitats (sand dunes, rocky hills and depression), the vegetation of Wadi Jufair is influenced by the topography and soil type of these habitats. Wadi Jufair is somewhat an enclosed habitat protected by the Tuwayq Mountains and dissected into an extensive system of several small and big wadis. Despite the harsh environment, Wadi Al-Jufair ecosystem is diverse in habitats and accordingly the vegetation is different from one habitat to another. During winter, the vegetation of the main wadi and its tributaries is represented by different plant communities, each comprised of trees, shrubs, sub-shrubs and seasonal vegetation represented by mesophytic herbs and grasses.

The study area is physiographically distinguished into: plateau, slope and wadi bed. The major feature of the plateau is the flat rocky surface; its vegetation is restricted to notches and shallow drainage runnels where variable amounts of soil accumulate. The upper positions of slopes are steep and completely devoid of soil cover; and, therefore, support typical cliff vegetation. The middle slopes are less steep and covered by a shallow soil mixed with fragments of rocks of different sizes and support vegetation dominated by shrubby species of chasmophytic nature and grasses. The lower parts of slopes are gentle, where deep soil is accumulated by the run-off water and support dense vegetation. The fine soil has little chance to settle down due to the high velocity of flash floods during the rainy season. However, soil often filled up between large boulders where it supports the establishment of sparse vegetation. The wadi basin, which is opening into the main Wadi Nisah in the north, is characterized by sand dunes.

Table 1 Synoptic table of species composition of the four vegetation groups (I–VI) identified after the application of TWINSPAN to the vegetation data of the 22 stands of Wadi Al-Jufair region. The cover level are coded as follows: 1, ⩽10%; 2, 10–20%; 3, 20–30; 4, 30–40%; 5, ⩾40%. The vegetation groups are named as follows: I. *Lycium shawii*; II. *Acacia oerfota*; III. *Acacia raddiana-Rhazya stricta* and IV *Artemisia monosperma*. The life forms are: Th = Therophyte; Ch = Chamaephyte; Ph = Phanerophyte; He = Hemicryptophyte; Cr = Cryptophyte. The chorotypes are: IT = Irano-Turanian; SA-IT = Saharo-Arabian-Irano-Turanian; SH-SM = Sahelian-Somali-Masai; TR = Tropical; SA = Saharo-Arabian;SA-SM = Saharo-Arabian-Somali-Masai; TR AF = Tropical African; TR AM = Torpical American; Med-IT = Mediterranean-Irano-Turanian; EU-Med-IT = Euro-Siberian-Mediterranean-Irano-Turanian; Med = Mediterranean; Med-IT-SA = Mediterranean-Irano-Turanian-Saharo-Arabian; Cosm = Cosmopolitan; TR AF-SA = Tropical Africa-Saharo-Arabian.

Species	Life form	Chorotype	Vegetation group I II III IV 11 1 1111111222 1672053894241359678012	TWINSPAN DIVISION
Acacia ehrenbergiana Hayne	PH	SA	2-2-1-----14-52-------	00000[illegible]
Heliotropium bacciferum Forssk.	Ch	SA-SM	1-1---1-2-21211-2-----	000[illegible]
Tripleurospermum africanum (Boiss.) Rech. F.	Ch	SA	-----------2-21-------	00000[illegible]
Anvillea garcinii (Burm.f.) DC.	Ch	SA	-1-11-----23221-------	[illegible]0001
Fagonia bruguieri DC	Ch	SA	1-1--1----12-21-------	[illegible]00001
Abutilon fruticosum Guill. & Perr.	Ch	SH-SM	----1-----2-2---------	000100
Blepharis ciliaris (L.) B.L. Burtt	Th	SA-IT	-------1-13122--------	0001[illegible]
Chrysopogon plumosus Hochst.	He	Med-IT	-----1----4-4---------	00[illegible]0
Echinops erinaceus Kit Tan	Ch	IT	------1-1-3222--------	[illegible]100
Stipa capensis Thunb.	Th	SA-IT	----------232[illegible]-----	[illegible]00100
Tetrapogon villosus Desf.	He	SA-SM	----------1[illegible]1--------	[illegible]00100
Teucrium polium L.	Ch	SA	--------[illegible]2---------	[illegible]10[illegible]
Tribulus terrestris L.	Th	EU-Med-IT	------[illegible]-2[illegible]---------	00[illegible]
Acacia oerfota (Forssk.) Schweinf.	Ph	SH-SM	----22[illegible]12555[illegible]------	000[illegible]01
Dichanthium annulatum (Forssk.) Stapf.	He	TR	--------22212--[illegible]----	000101
Gymnocarpos decandrum Forssk.	Ch	SA	[illegible]11-1-1-2----[illegible]--	000110
Achillea fragrantissima (Forssk.) Sch. Bip.	He	SA-IT	[illegible]111-1----------	000111
Capparis sinaica Veill.	Ph	SH-SM	----1-1-1--2----------	000111
Helianthemum lippii (L.) Doum.-Cours.	Ch	SA-SM	----1-----[illegible]---------	000111
Maerua crassifolia Forssk.	Ph	SH-SM	-----2-2-2[illegible]---------	000111
Odontanthera radians (Forssk.) D.V.	Th	TR AF	----1-----[illegible]---------	000111
Salvia aegyptiaca L.	Ch	SA	[illegible]---1-----[illegible]---------	000111
Cenchrus ciliaris L.	Ch	SA	[illegible]11---112[illegible]-21-------	0010
Ephedra foliata Boiss.ex C.A. Mey	Ph	[illegible]-SM	1-[illegible]11----------	0010
Hyparrhenia hirta (L.) Stapf.	Ch	Med[illegible]SA	-1-11-2-2-------------	0010
Rhanterium epapposum Oliv.	Ch	[illegible]A	[illegible]-2-22-2--1----------	0010
Ochradenus baccatus Del.	Ph	[illegible] AF	1[illegible]--1-1------------	00110
Farsetia longisiliqua Decne	Ch	S[illegible]	2112------1111--------	001110
Helianthemum kahiricum Del.	[illegible]	SA[illegible]	-1-1------------------	001111
Malva parviflora L.	T[illegible]	Med[illegible]T	1-1-------------------	001111
Morettia parviflora Boiss	C[illegible]	SH-S[illegible]	-1-1------------------	001111
Pycnocyla nodiflora Decne.	[illegible]	SA	1213------------------	001111
Sclerocephalus arabicus Boiss.	[illegible]	[illegible]	1-1-------------------	001111
Unknown grass	Th	TR-AF	2-21------1-----------	001111
Lycium shawii Roem & Schult.	Ph	SA-SM	151524112113224-243---	01
Zilla spinosa (L.) Prantl.	Th	SA	-1-1------2-2-1-1-----	01
Acacia raddiana Savi	[illegible]	SH-SM	33331-----1---5442----	100
Euphorbia granulata Forssk.	C[illegible]	Sh-SM	----------1-111-----1	100
Senna italica Miller	Ch	SH-SM	-1-2------2-2-11143-1-	100
Haloxylon salicornicu[illegible]Moq.) Bunge.	Ch	SH-SM	----14----322252554-15	101
Tribulus terrestris [illegible]r. *inermis* Boiss.	Th	EU-Med-IT	----------1-2-112-3-1-	101
Gisekia pharnaceoi[illegible]*s* L.	Th	TR-AF	--------------1-141--	110000
Rhazya stricta D[illegible]e.	Ch	SA	--------------2-54521-	110000
Citrullus colocyn[illegible]*s* (L[illegible]Schrader	He	SA	--------------11353-2-	110001
Cynodon dactylon (L[illegible]s.	He	TR	-----------------45---	110001
Dipcadi ery[illegible]*um* We[illegible]& Berth	Cr	SA	----------------1-----	110001
Launanea [illegible]*dica*[illegible]*is* (L.[illegible]ook	Ch	SA	----------------1-----	110001
Ochthoch[illegible]*a comp*[illegible]*essa* (Fo[illegible]) Hilu	He	TR AF	----------------2-----	110001
Panic[illegible] *turgidu*[illegible] Forssk.	Ch	SA-SM	--------------1-25-1--	110001
Pergu[illegible]*ia to*[illegible]	Ch	SH-SM	--------------1---2---	110001
Tragus [illegible]*er*[illegible]*us* (L.) [illegible].	Th	Med	----------------1-----	110001

Table 1 (*continued*)

Calotropis procera (Ait.) Ait.f.	Ph	SH-SM	-----------------554--	11001
Polycarpae repens (Forssk.) **Asch. & Scheweinf.**	He	SH-SM	----------------2----1	11001
Bassia muricata (L.) Asch.	Th	SA-IT	--------------1-------	11010
Corchorus depressus L.	Ch	SA	--------------1-------	11010
Dactyloctenium aegyptiacum	He	TR	--------------2-------	11010
Fagonia glutinosa Del.	Ch	SA	--------------1-------	11010
Paronychia arabica (L.) DC.	Th	SA	--------------1-------	11010
Portulaca oleracea L.	Th	Cosm	--------------1-------	11010
Reseda muricata C. Presl	Th	SA	--------------1-------	11010
Chrozophora oblongifolia (Del.) A. Juss.	Ph	IT	---------------1----1-	11011
Cleome amblyocarpa Barr. & Murb.	Th	SA-SM	---------------1----12	1110
Cyperus conglomeratus Rottb.	He	SA	--------------1---213-	1110
Haplophyllum tuberculatum (Forssk.) A. Juss.	Ch	SA	---------------1----12	1110
Artemesia monosperma Del.	Ch	SA	-------------------555	11110
Astenatherum forsskalei (Vahl) Nevski	Ch	SA	-------------------132	11110
Dipterygium glaucum Decne.	Ch	SA	---------------------4	11110
Heliotropium digynum (Forssk.) Asch.	Ch	SA	-------------------453	1111[illegible]
Kickxia aegyptiaca (L.) Nab.	Ch	SA	--------------------1-	111[illegible]
Kohautia caespitosa Schinzl.	Ch	TR AF-SA	-------------------1--	111[illegible]
Lasiurus scindicus Henr.	He	SA-SM	-------------------1--	11110
Leptadenia pyrotechnica (Forssk.) Decne.	Ph	SA-SM	--------------------3[illegible]	11110
Moltkiopsis ciliata (Forssk.) I. M. Johnston	Ch	SA	[illegible]	11110
Neurada procumbens L.	Th	SA	[illegible]2	111[illegible]
Pennisetum divisum (Gmel.) Henr.	Ch	SA	[illegible]-2-	11[illegible]0
Stipagrostis ciliata (Desf.) de Wint.	He	SA	----------1-1--1-[illegible]51	[illegible]111

Meterological data of the central region is characterized by mean air temperature ranging from 10 °C in January to 42 °C in July and an annual rainfall from 12 to 36 mm (Fig. 2). The mean relative humidity ranges between 10% and 50%, while the mean evaporation value is 10.35 mm/day (Al-Nafie, 2008).

3. Material and methods

3.1. Sampled stands

A total of 22 sites were selected. The stan[illegible] were [illegible]tributed along transect on the wadi that covered [illegible]rious la[illegible]forms (6 on the wadi plateau, 6 on the wadi slope [illegible]d 10 [illegible] the [illegible] bed and delta). The sampling pro[illegible]s was ca[illegible]ed out during spring season when most specie[illegible]re expected [illegible] be growing (Fig. 1a and b). The vegetati[illegible] par[illegible]eters include[illegible] listing of all species, life forms and chorotypes. Species nomenclature followed Chaudhary [illegible]999, 2000, 20[illegible]) and Collenette (1999). Plant cover [illegible]s estimated by using the line intercept method (Canfield[illegible]941).

3.2. Soil an[illegible]

Thre[illegible]oil sampl[illegible], down to [illegible]0 cm depth, were collected from each s[illegible]d a[illegible]ne composite sample for each site. Soil textu[illegible]as determined by the hydrometer method (Allen et al., 1974). Total organic matter was determined based on loss-on-ignition [illegible]t 450 °C. Soil water extract was prepared (1:5), by dissolving 100 g air dried soil in 500 ml distilled water for estimation of pH and electrical conductivity (EC) as mS cm $^{-1}$. Soil nutrient elements (Ca, K, Na, Mg, Fe, N and P) were determined using Spectrophotometer (model ICP MSEOS 6000 Series). All procedures are outlined by Allen et al. (1974).

3.3. Data analysis

The cover estimates of 77 plant species recorded in 22 stands were subjected to multivariate analysis; using TWINSPAN, DCA an[illegible] CCA [illegible]Hill, 1979a,b; Ter Braak and Smilauer, 2002). Species richn[illegible] (α-diversity) of the vegetation cluster wa[illegible]ated as the [illegible]rage number of species per stand. S[illegible]annon-Wiener index $H = -\sum_{i=1}^{s} p_i \log p_i$ for the relative [illegible]enness, and S[illegible]pson index $C = \sum_{i=1}^{s} p_i^2$ for the relative concentration of do[illegible]inance were calculated for each stand on the ba[illegible] of the rel[illegible]ive cover p_i of the *i*th species (Pielou, 1975; Mag[illegible]88). Relationships between the ordination axes [illegible] one hand, and community and soil variables on the other [illegible]ere tested using Pearson's simple linear correlation coefficient (*r*). The variation in the species diversity, stand traits and soil variables in relation to plant community were assessed using one way analysis of variance (SAS, 1989–1996).

4. Results

4.1. Floristic diversity

One hundred and fifty seven species, belonging to 133 genera and 40 families were recorded from various stands and adjoining areas, of which the most represented families are Poaceae and Asteraceae. Therophytes constituted 81 species (51%) of the total species) followed by Chamaephytes of 33 species (21%) and perennial herbs 31 species (18%) (Fig. 3a). Regarding the chorotype (Fig. 3b), the Saharo-Arabian region (auct, Zohary, 1973) has the highest share of species (41%), followed by the bi-regional and pleuri-regional elements that belong to the Sahelien-Somali Masai (10%), Saharo-Arabian-Somali Masai (8%), Saharo-Arabian-Irano Turanian (8%), and Mediterranean-Irano Turanian (8%).

4.2. Multivariate analysis

TWINSPAN dendrogram divided the data set (22 stands × 72 species) into 8 vegetation subgroups at level 5 and four vegetation groups (i.e., plant communities) at level 2. These four major plant communities were characterized and named after the dominant and subdominant species as follows: (I) *Lycium shawii*; (II) *Acacia oerfota*; (III) *Acacia raddiana* – *Rhazya*

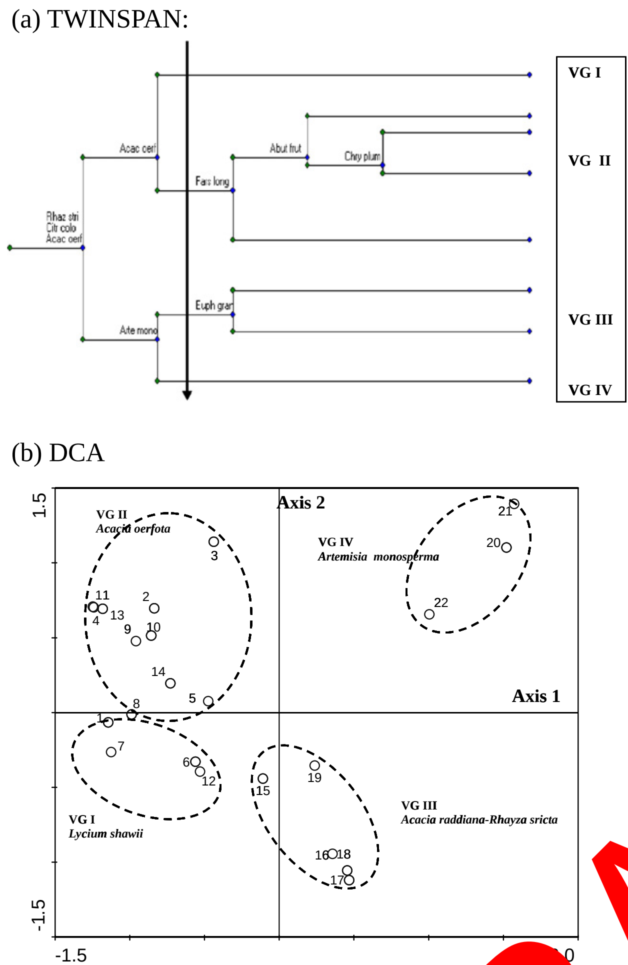

Figure 4 Relationship between the four plant communities after application of TWINSPAN (a) and DCA (b).

stricta and (IV) *Artemisia monosperma*. The application of DCA and CCA confirmed the separation between these communities and indicated relationships between environmental gradients and topographic aspects of wadi Al-Jufair (Table 1, Fig. 4a and b).

CCA ordination was used to verify the correlation analysis between the dominant environmental factors and CCA axes (Fig. 5a and b and Table [illegible]). Correlation analysis indicated that the separation of the species along the first axis is strongly affected positively by EC, sand, nitrogen content and species dominance (r = 0.310–0.851) and negatively by organic matter, clay, silt, Ca, Fe, K, Mg and P contents (r = −0.337 to −0.896). On the other hand, species richness (0.369) and clay content (0.310) were correlated positively with the second axis and negatively with pH, Fe and plant cover (r = −0.306 to −0.554). Therefore, the *Lycium shawii* (VG I) that occupies the wadi plateau and *Acacia oerfota* (VG II) that occupies the wadi slope were separated on the left hand of axis 1 from the *Acacia raddiana-Rhazya stricta* (VG III) and *Artemisia monosperma* (VG IV) which inhabited the wadi bed and on the right hand of axis 2 (Fig. 5a).

Xerophytes occupied the fissures of flat stony habitat of Lycium shawii community (e.g., *Bassia muricata, Corchorus depressus, Dactyloctenium aegyptium, Fagonia glutinosa, Helianthemum kahiricum, Paronychia arabica, Portulaca oleracea, Pycnocycla nodiflora, Reseda muricata* and *Sclerocephalus arabicus)* on the lower negative part of axis 1 are correlated with P, Ca, Mg, pH and Fe content. The cliff, chasmophytic and grasses species of the Acacia oerfota community (e.g., *Acacia ehrenbergiana, Anvillea garcinii, Capparis sinaica, Dichanthium annulatum, Gymnocarpos decandrum, Hyparrhenia hirta, Lasiurus scindicus, Ochradenus baccatus, Rhanterium epapposum, Stipa capensis, Tripleurospermum auriculatum* and *Zilla spinosa)* on the upper negative part of axis 1 are correlated with organic matter, silt, clay, K, species number and relative evenness. On the other hand, the grasses, shrubs and sub-shrubs inhabit the wadi bed of the Acacia raddiana-Rhazya stricta community (e.g. *Calotropis procera, Citrullus colocynthis, Cynodon dactylon, Halocnemum strobilaceum, Ochthochloa compressa, Panicum turgidum, Pergularia tomentosa, Polycarpaea repens* and *Senna italica)* on the lower positive part of the axis 1 are correlated with EC, nitrogen, sand and species cover. The psammophytic community inhabits the sand dunes of Artemisia monosperma (e.g., *Cyperus conglomeratus, Haloxylon salicornicum, Haplophyllum tuberculatum, Lasiurus scindicus, Leptadenia pyrotechnica, Moltkiopsis ciliata, Neurada procumbens,* and *Pennisetum divisum)* on the upper positive part of axis 1 are correlated with species concentration of dominance. These combinations are typical of grass communities inhabiting the wadi bed and sand dunes (Fig. 5b).

The species richness was positively correlated with organic matter (0.405) and clay (0.673), and negatively with total cover, EC and sand ([illegible], −0.322 and −0.389, respectively) (Table 3). The species cover was positively correlated with pH (0.352) and sand ([illegible]), and negatively with organic matter, clay, silt and K contents (−0.454, −0.422, −0.526 and −0.410, respectively). The species concentration of dominance was positively correlated with Mg (0.394) and Na (0.548), and negatively with the species relative evenness (−0.522) and clay (−0.323). The species evenness was positively correlated with pH, EC and clay (0.468, 0.311 and 0.447, respectively) and negatively with Mg, Na and N (−0.559, −0.465 and −0.355, respectively).

4.3. Plant community–soil relationship

The *Acacia raddiana-Rhazya stricta* community (VG III) demonstrated the highest levels of species richness (14.4) and species cover (110.1 m 100 m^{-1}). The *Acacia oerfota* (VG II) attained the highest relative evenness (0.92) and the lowest species cover (43.72 m–100 m^{-1}) and dominance (0.13). *Artemisia monosperma* (VG IV) showed the highest concentration of species dominance (0.48), while *Lycium shawii* (VG I) attained the lowest levels of species richness (12.75) and relative species evenness (0.69). The habitats of *Lycium shawii* community (VG I) are characterized by the highest contents of O.M., silt, Ca, Fe, Mg, P and the lowest of pH and sand. On the other hand, the *Acacia oerfota* (VG II) characterized the sites of the highest pH, EC, clay and K. *Artemisia monosperma* community (VG IV) occupied sites with the highest values of sand and the lowest of most soil variables (Table 4).

5. Discussion and conclusion

The life form distribution of plants growing in arid regions is closely related with topography and landform (Kassas and Girgis, 1964; Zohary, 1973; Orshan, 1986; Shaltout et al., 2010).

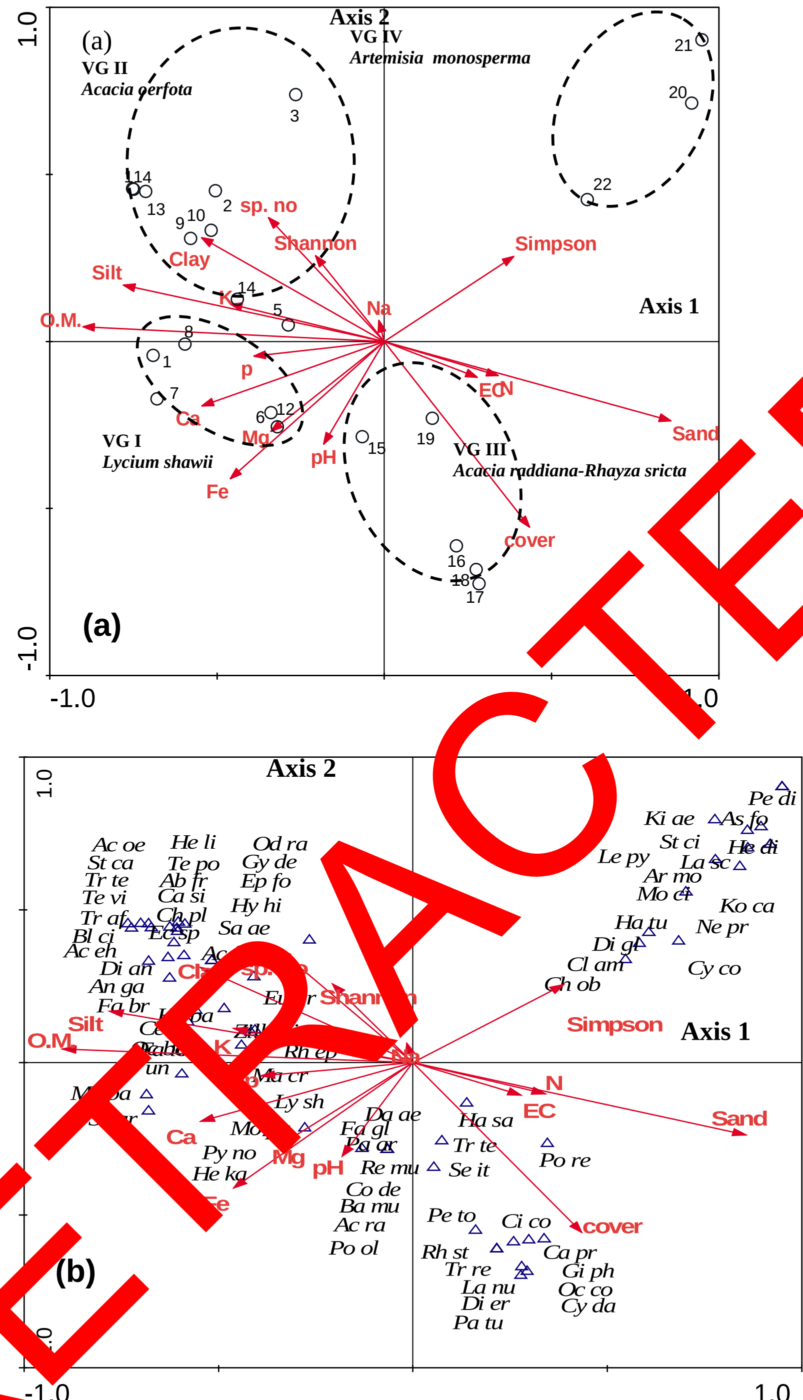

Figure 5 A biplot with environmental variables (arrows), the stands (a) and the abundant species represented by the first 4 letters of genus and spe[illegible] name (b). (For complete names of species, see Table 1.)

The Najd plateau in the rain-shadow of the Tuwayq Escarpment in central Saudi Arabia has different wadis (Mandaville, 1986). Wadi Al-Jufair is a mature wadi characterized by its wide, deep valley-fill deposits, and well defined channels cutting older rocky limestone formations. Therefore, the wadi ecosystem divided into a number of habitats is discernible on the ground of the soil thickness and plant cover. The vegetation is featured into associations where the dominant perennial species give the permanent character of plant cover in each habitat. This may be attributed to the rather scanty rainfall which is not adequate for the appearance of many annuals. On the other hand, the rainy season provides better chance for the appearance of a considerable number of annuals, which give a characteristic physiognomy to their vegetation (Shaltout and Mady, 1996; Schultz and Whitney, 1986; Hosni and Hegazy, 1996; Shaltout et al., 2010).

Floristic analysis indicated that the synanthropic species (e.g., *Bassia eriophora*, *Cynodon dactylon*, *Prosopis juliflora*,

Table 2 Inter-set correlations of environmental variables with CCA axes. Significant values in bold.

N	Name	AX1	AX2
1	pH	−0.18	**−0.31***
2	EC mS/cm	**0.31***	−0.11
Bulk soil (%)			
3	Organic matter	**−0.90*****	0.04
4	Sand	**0.85*****	**−0.24***
5	Clay	**−0.54***	**0.31***
6	Silt	**−0.78*****	0.17
Minerals (ppm)			
7	Ca	**−0.54****	−0.19
8	Fe	**−0.46****	**−0.41****
9	K	**−0.50****	0.11
10	Mg	**−0.34***	**−0.27***
11	Na	−0.02	0.06
12	P	**−0.39****	−0.04
13	N	**0.39***	−0.12
Diversity indices			
14	Species richness spp.stand^{-1}	**−0.34***	**0.37***
15	Species cover m−100 m^{-1}	**0.43****	**−0.56*****
16	Conc. of Dominance (C)	**0.39****	**0.25***
17	Relative evenness (Ĥ)	−0.21	**0.26***

* $p \leqslant 0.05$.
** $p \leqslant 0.01$.
*** $p \leqslant 0.001$.

Salsola imbricata and *Tamarix nilotica*) are rare or completely absent in Wadi Al-Jufair, indicating low human impact. However, these species have been recorded as common in a few other wadis and depressions (e.g., Raudhas) in the Najd region (Shaltout and Mady, 1996; Al-Farraj et al., 1997; Alfarhan, 2001; Taia and El-Ghanem, 2001; EL Ghenem, 2006; El-Ghanem et al., 2010). The presence of *Acacia oerfota*, a rare shrub with restricted distribution and *Maerua crassifolia*, an endangered tree (Mandaville, 1986) in the study area, can be considered as a positive sign that Wadi Al-Jufair is one of the few areas in the Najd region with less human impact.

The life form spectrum reflects a typical desert flora, the majority of species being therophytes and Chamaephytes (about 72%). These results agree with the spectra of vegetation in desert habitats in other parts of Saudi Arabia (e.g., El-Demerdash et al., 1995; Collenette, 1999; Chaudhary, 1999, 2000, 2001; Al-Turki and Al-Qlayan, 2003; Fahmy and Hassan, 2005; El-Ghanem et al., 2010). Life forms of desert plants are also closely related with topography (Kassas and Girgis, 1964; Zohary, 1973; Migahid, 1978; Orshan, 19[illegible]; Hosni and Hegazy, 1996; Hegazy et al., 1998; Shaltout et al., 2010). It may also be stated that the Saharo Arabian species which are restricted in their distribution to the central strip of Saudi Arabia are more abundant in habitats of more favorable micro-environmental conditions and those providing better protection (Zohary, 1973; Ghazanfar and Fisher, 1998; Hegazy et al., 1998; El-Ghanem et al., 2010). Besides the high percentage of Saharo Arabian species in the study area, there are several other chorotypes attaining considerable values. This is due to the fact that the central region contains most of the rocky habitat types of the Peninsula and covers a wide range of bioclimatic zones. The central region falls within the transition zone from the Somalia-Masai regional center of endemism at low and medium altitudes to the Afromontane archipelago-like center of endemism at high altitudes, and above the tree line between those of the Mediterranean region and Irano-Turanian phytochorion are present (Zohary, 1973; Mandaville, 1990;

Table 3 Correlation between species diversity and edaphic variables. Significant values in bold.

Variable	Species richness	Species cover m 100 m^{-1}	Conc. of dominance (C)	Relative evenness (Ĥ)
Diversity indices				
Species richness spp/stand	1.00			
Species. cover m/100 m	**−0.27***	1.00		
Conc. of dominance (C)	−0.02	−0.02	1.00	
Relative evenness (Ĥ)	**0.40****	−0.03	**−0.52****	1.00
Soil				
pH	0.15	**0.35***	−0.27	**0.47****
EC mS/cm	**−0.32***	−0.01	−0.14	**0.31***
Bulk soil (%)				
Org. matter	**0.41****	**−0.45****	−0.22	0.16
Sand	**−0.39****	**0.59*****	0.04	0.04
Clay	**0.67*****	**−0.42****	**−0.32***	**0.45****
Silt	0.23	**−0.52****	0.05	−0.18
Mineral soil (ppm)				
Ca	0.08	0.14	−0.07	0.13
Fe	**0.28***	0.07	0.08	−0.13
K	0.10	**−0.41****	−0.09	0.13
Mg	−0.20	−0.25	**0.39****	**−0.56*****
Na	0.18	**−0.30***	**0.55****	**−0.47****
P	0.15	−0.22	**0.29***	−0.27
N	−0.10	0.07	0.17	**−0.35***

* $p \leqslant 0.05$.
** $p \leqslant 0.01$.
*** $p \leqslant 0.001$.

Table 4 The mean ± Standard deviation of soil variable and diversity indices. Significant values in bold.

Variable	VGI	VGII	VGIII	VGIV	Total mean	*F*-value
Diversity indices						
Species richness	12.75 ± 9.8	13.70 ± 44.8	**14.40 ± 43.2**	13.66 ± 21.1	13.68	0.07
Species cover	54.27 ± 76.5	43.72 ± 81.3	**110.1 ± 58.2**	97.70 ± 6.0	68.08	**3.29***
Conc. of dominance (C)	0.35 ± 78.6	0.13 ± 65.1	0.25 ± 30.9	**0.48 ± 64.2**	0.24	**4.15***
Relative evenness ($\hat{H}$)	0.69 ± 36.	**0.92 ± 17.9**	0.75 ± 12.7	0.76 ± 20.9	0.82	2.24
Soil						
pH	7.9 ± 0.0	**8.12 ± 1.8**	8.06 ± 5.3	7.93 ± 6.9	8.04	0.70
EC mS/cm	0.44 ± 65.0	**0.52 ± 66.6**	0.34 ± 65.0	0.43 ± 62.7	0.46	0.39
Bulk soil (%)						
O.M.	**1.66 ± 16.6**	1.57 ± 23.9	0.76 ± 58.6	0.32 ± 53.7	[illegible]	**13.9*****
Sand	60.3 ± 1.64	65.2 ± 7.7	83.00 ± 11.8	**86.69 ± 1.2**	71.30	**21.7*****
Clay	12.16 ± 18.9	**13.66 ± 45.8**	10.56 ± 25.5	9.49 ± 6.0	12.11	0.85
Silt	**27.54 ± 4.9**	21.12 ± 40.9	6.43 ± 3.3	3.81 ± 39.3	[illegible]	**11.3*****
Mineral soil (ppm)						
Ca	**57.93 ± 23.8**	31.73 ± 51.6	20.87 ± 84.4	8.26 ± 13.9	30.83	6.62***
Fe	**2.24 ± 1.4**	1.40 ± 31.6	1.53 ± 31.1	1.05 ± 22.1	1.53	**6.2*****
K	0.36 ± 11.9	**0.41 ± 1.2**	0.14 ± 35.6	[illegible]	[illegible]	0.93
Mg	**1.46 ± 2.7**	0.54 ± 56.4	0.45 ± 26.4	[illegible]	[illegible]	**21.5*****
Na	0.01 ± 7.9	0.01 ± 23.2	0.009 ± 15.1	0.01 ± 34.3	0.0098	**3.91***
P	**3.52 ± 4.1**	0.64 ± 16.5	[illegible]	[illegible]	1.11	**16.36*****
N	0.01 ± 7.0	0.01 ± 3.2	0.008 ± 15.1	[illegible]	0.008	**3.91***

* $p \leqslant 0.05$.
*** $p \leqslant 0.001$.

White and Leonard, 1991; Hegazy et al., 1998; Ghazanfar and Fisher, 1998; Alfarhan, 1999).

Among the four vegetation groups in Wadi Al-Jufair ecosystem, vegetation group III, characterized by *Acacia raddiana-Rhazya stricta* has clear separation with group IV dominated by *Artemisia monosperma*. On the other hand, the groups I and II are less separated because they are characterized by mixed communities of shrubs, chasmophytes and grasses. In Saudi Arabia, Shaltout and Mady (1996), Al-Yemeni and Zayed (1999), Al-Yemeni (2001), Al-Wadie (2002) and EL Ghenem (2006) recognized several plant associations, some of which are comparable to those of the present study (e.g., *Acacia raddiana-Rhazya stricta* which is comparable to that identified in neighboring countries: Batanouny, 1987; El-Bana and Al-Mathnani, 2009; Shaltout et al., 2010). The sand dune group *Artemisia monosperma* is analogous with association and is recognized by Al-Yemeni and Zayed (1999) at Al-Thumamah sandy habitats. Communities in stony plateau and rocky outcrop slopes of Wadi Talha at Asir, as recognized by Al-Wadie (2002), are, however, less comparable in Wadi Al-Jufair, which may be due to the variations in climate and topography.

Lycium shawii community inhabits the flat stony wadi plateau which consists of notches and shallow drainage runnels. *Acacia oerfota* community of cliff, chasmophytic shrubby and grassy species inhabits the outcrops of the rocky slopes. Then comes the community of *Acacia raddiana-Rhazya stricta* composed of dense woody and sparse short lived perennial species that inhabits the main wide channel of the wadi bed. On the other hand, in the wadi delta, the sand dunes are inhabited by adapted psammophytic *Artemisia monosperma* community. The most diverse groups II and III, inhabiting the wadi slope outcrop and bed and characterized by *Acacia oerfota* and *Acacia raddiana-Rhazya stricta* could be related to high soil pH, high clay content in its soil and/ or heterogeneity of substrate in shallow soil mixed with fragments and deep valley-fill soil deposits (Fig. 1b). The soil, accumulated by run-off water, supported dense woody and grasses vegetation with high cover during the rainy season. Similar conclusions were made by (Chaudhary, 1983a,b; Siddiqui and Al-Harbi, 1995; El-Demerdash et al., 1995, Shaltout and Madi, 1996; Al-Yemeni, 2001, Al Wadie, 2002, Abbadi and El-Sheikh, 2002; Springuel et al., 2006). *Artemisia monosperma* group (IV), inhabiting the sand dunes at wadi delta, had low species diversity. This could be due to the increase in aridity at its loose and unstable soil surface, high salinity due to excessive evaporation at its surface and high content of sand (mostly red sand derived from bed rock) with poor fertility. This adverse habitat supported a few adapted psammophytic phytogenic populations of sand binding plants with highest concentration of their dominance and plays a major role in decreasing species diversity of central Saudi Arabia as a whole (Chaudhary, 1983a; Al-Hemaid, 1996; Shaltout and Mady, 1996; Al-Yemeni, 2000; Al-Wadie, 2002; Shaltout et al., 2010).

Correlation analysis in the present study indicates that the species diversity (richness and evenness) is positively correlated with increasing organic matter, clay pH and EC. These factors may reflect the degree of wadi bed maturation in the study area (Kassas and Imam, 1954). On the other hand, species diversity decreased with increasing Mg, Na, N, EC, sand and species cover (which correlates positively with pH and sand). In such cases, most of the total cover is accounted by one or two species (e.g., the community of *Artemisia monosperma*) that can apparently 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) and El-Sheikh et al. (2010).

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