King Saud University

Saudi Journal of Biological Sciences

ORIGINAL ARTICLE

Main vegetation types and plant species diversity along an altitudinal gradient of Al Baha region, Saudi Arabia

Abdullah Al-Aklabi [a,*], Abdul Wali Al-Khulaidi [b], Akram Hussain [c], Nageeb Al-Sagheer [d]

[a] Department of Biology, College of Science and Arts, Albaha University (BU), Baljurashi, Saudi Arabia
[b] Faculty of Applied Studies and Continuous Education, Saudi Arabia
[c] Al Baha University, Saudi Arabia
[d] Food and Agriculture Organization of the United Nation, Saudi Arabia

Abstract Plant species composition patterns and vegetation types were investigated along Elevational Gradients in Al Baha region, Saudi Arabia. Sandy plain, wadis, drainage lines, rocky outcrops, hills and fallow lands occur over a wide geographic range encompassing variation in plant species and communities among these different ecological sites. To provide a quantitatively based classification of the vegetation we used Multi Variant Statistical Package (MVSP) software, followed by the re-arrangement of a matrix of the similar plant species in rows and similar sample sites in columns. Plant density and environmental variables were measured and recorded in each quadrat. Two-way indicator species analysis and Canonical Correspondence Analysis (CCA) were used to analyze the relationships between vegetation and environmental variables, while Arc Map was used to analyze the pattern of plant species density. A total of 59 sample plots (25 × 25 m), stratified, randomly-placed relevés were collected in Al Baha region, along a cross section running from south-west to north-west. About 190 plant species belonging to 59 families were recognized. This study showed that these plant species formed 15 vegetation types that primarily correspond mainly to different combinations of elevation, and topography. The study concluded that this research has provided the first quantitative and systematic survey of the vegetation in Al Baha region.

© 2016 The Authors. Production and hosting by Elsevier B.V. on behalf of King Saud University. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

* Corresponding author.
 E-mail address: alaklabia@yahoo.com (A. Al-Aklabi).
Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

1. Introduction

The vegetation types of Al Baha region have not been studied in detail before, and this study is the first comprehensive one on the entire vegetation communities across altitudinal gradient in Al Baha region. A few studies have been carried out

on the vegetation of Al Baha and focused on the recording of few or individual plant species and vegetation (Alaklabi et al., 2014; Al-Zahrani and Elhag, 2005; Collenette, 1985; El-Karemy and Zayed, 1996; Hajar, 1993; Hassan and Al-Hemaid, 1995; Zayed and Fayed, 1987).

Al Baha region characterized by high diverse vegetation, *Juniperus procera* woodland and forest found there in abundance beside other communities. The high mountains of Al Baha are considered as one of most significant plant diversity zones in Saudi Arabia. Although Al-Baha is a small area in Kingdom of Saudi Arabia, recent studies estimated about 230 plant species (about 12% of the total plant species of the Kingdom). The flora of Al Baha is a mixture of the tropical African, Sudanian plant geographical region (Paleotropical origin) and the with very few of Saharo-Sindian or Saharo-Arabian region (Holarctic origin) and Mediterranean regions (Al-Khulaidi, 2013). Most of Al Baha's flora belongs to Sudanian region of Eritreo-Arabian province of Sudanian region (Zohary, 1973) or Somalia-Masai region center of endemism, (White, 1983). The Sudanian element dominates the western mountains and parts of the high land plains which are characterized by relatively high rain fall. The Mediterranean region element dominates the high mountain areas. The Saharo-Arabian element dominates the coastal plains, eastern mountain and the eastern and northern desert plains.

Much of the work on vegetation classification comes from European and North American ecologists (Van Der Maarel, 2004; Feldmeyer-Christie et al., 2005). They have fundamentally different approaches. In North America, vegetation types are based on a combination of the following criteria: climate pattern, plant habit, phenology and/or growth form, and dominant species. In the current US standard (adopted by the Federal Geographic Data Committee (FGDC), and originally developed by UNESCO and the Nature Conservancy, the classification is hierarchical and incorporates the non-floristic

criteria into the upper (most general) five levels and limited floristic criteria only into the lower (most specific) two levels (Van Der Maarel, 2004). In Europe, classification often relies much more heavily, sometimes entirely, on floristic (species) composition alone, without explicit reference to climate, phenology or growth forms (Feldmeyer-Christie et al., 2005). It often emphasizes indicator or diagnostic species which may distinguish one classification from another.

The aim of vegetation classification in this study is to group the plant species together on the basis of their floristic composition into vegetation types (communities) generally known as plant phytosociological units using MVSP software and following the method of Braun-Blanquet ordination methods.

2. Site description

Al Baha region (Fig. 1) is located in the south western part of Saudi Arabia. It is situated between longitude 41/42E and latitude 16/20N. The study area is located along environmental gradients with an elevation of 130–2450 m above sea level. It is a transition zone between dry coastal plain, Rocky mountains that face west and semi desert mountains that face east. It has a wide variety of woodland, shrubland, grassland, and forest habitats accompanied by many plant species.

2.1. Topography

Al Baha region composes of three main ecosystems as in Fig. 2. Tihama plain: it is a sandy flat to undulating plain, ranging from 50 to 150 (200 m) and narrowing toward northwest slopes and touching the foothills at 350 m. The plain is intersected by many valleys mainly wadi Nawan, wadi Al Hasaba, wadi Malal, wadi Nabira and wadi Uleib.
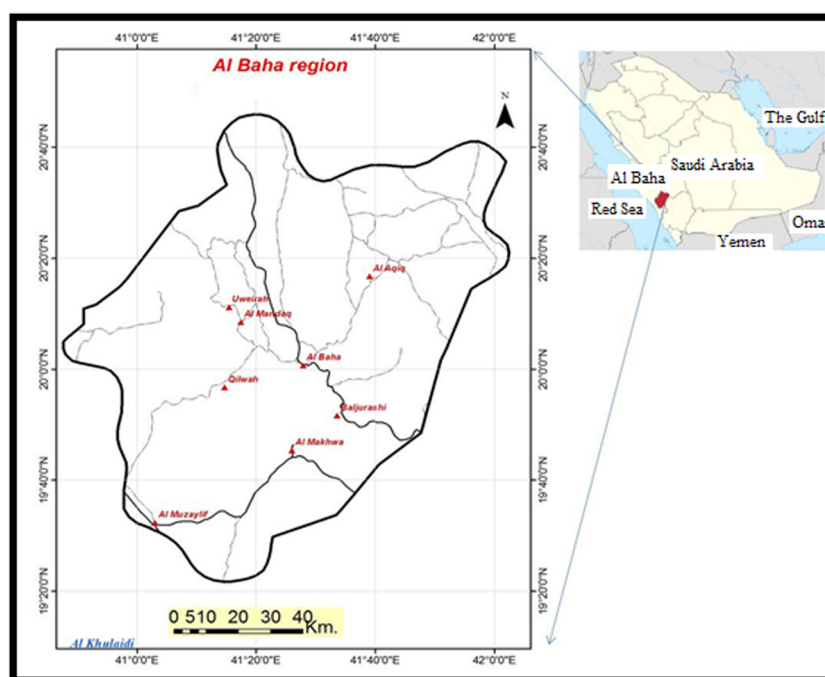

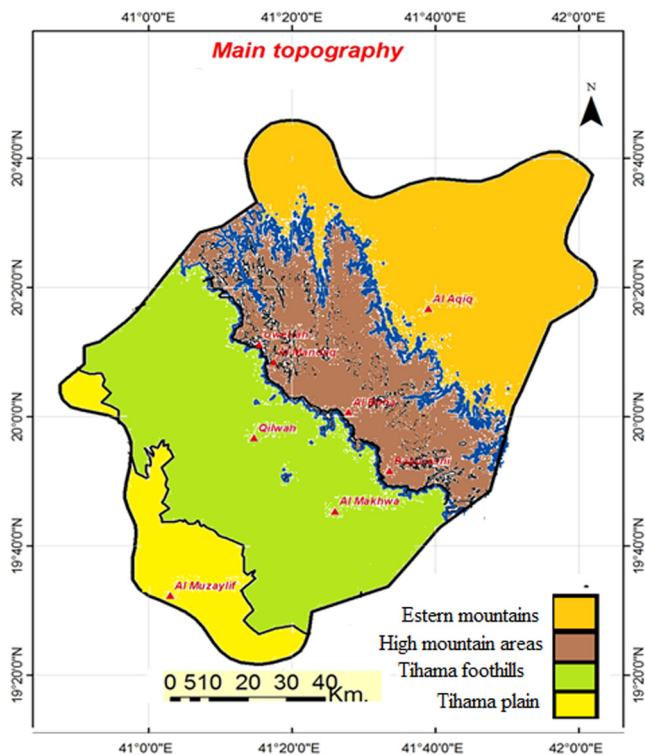**Figure 1** Location of the Al Baha region.

Figure 2 Topography of Al Baha region.

The foothills facing Tihama: it is a medium to steep slope intersected by valley gullies, descending gradually toward the west, the altitude ranges from 200 (400) to 2001 and 2200 west of Al Baha city and Uwera and between 2000 and 2100 m west of Baljurashi.

High-altitude mountains: in some parts with almost flat and undulating plateaus, the altitude ranges between 1700 to the east and from 2000 to 2500 m toward the west at Jabal Alzzrayeb, rising up to 2565 m at Al Hamd (north-east of Al Baha city).

The eastern mountains and plateaus: gradually descend toward the east and north-east, dissected by several valleys such as the wadi Jazab and wadi Ayna. The altitude ranges between 1300 and 1700 m.

2.2. Climate

The Orographic rise of air masses from the onshore wind provides an effective cooling mechanism, which causes rainfall. For example, areas exposed to the sea such as the southern slopes, receive more rainfall than the zones facing the interior plateau. Local topographic features cause similar effects, at correspondingly smaller scales. According to Koppen's climate classification system (1936), dry and semiarid climates (BWh) predominate in Arabian Peninsula. Almost the entire area of Al Baha belongs to the climate class BWh of tropical/subtropical desert (Ayele and Al Shadily, 2000).

The climate of Al Baha region is influenced by its varying topography. It is generally moderate in summer and cold in winter, with average temperature ranging between 12 and 23 °C. The climate is comparatively cold in winter (10–22 °C) and mild in summer (22–32 °C). Average rainfall in Al-Aqiq and Al-Mikhwah areas is 100–200 mm, temperature is 20–37 °C in winter and 36–51 °C in hot summer (Ibrahim, 2010;

Aref et al., 2011). Records from 7 stations show that annual average rainfall of the Al Baha area ranges from 142 mm to 316 mm. The annual rainfall reaches 142 mm at Al Aqiq (1650 m), 300 mm at Baljurashi (2062 m), 316 mm at Al Mandaq (1948 m), and 200 mm at Al Mikhwah (600 m) (Aboulabbes, 2013).

3. Materials and methods

After preliminary reconnaissance, transects were located along Elevational Gradients in Al Baha region, Saudi Arabia, consistently correlated mainly with elevation and topography. Transects were chosen to cross the region and identify major vegetation communities in the different landforms (Fig. 3). A total of 59 plant species which stratified, randomly-placed quadrats (25×25 m) were sampled along this transect. With the use of vegetation data sheet, the following variables were measured and recorded in the field: Terrain (land form by field observation according to the categories, slope direction; latitude and longitude using Geographical Positioning System (GPS) and vegetation cover, expressed as number of each species in the sample site.

The following methods were used to survey the plant cover based on the Zurich–Montpellier (Kent and Coker, 1992) or Braun-Blanquet school (Zonneveld, 1989):

(1) Plant species were identified and entered in rows and sample plots were entered in columns of an initial matrix.
(2) Number for each plant species and environmental data such as altitude, topography, exposure for each sample plot was added.
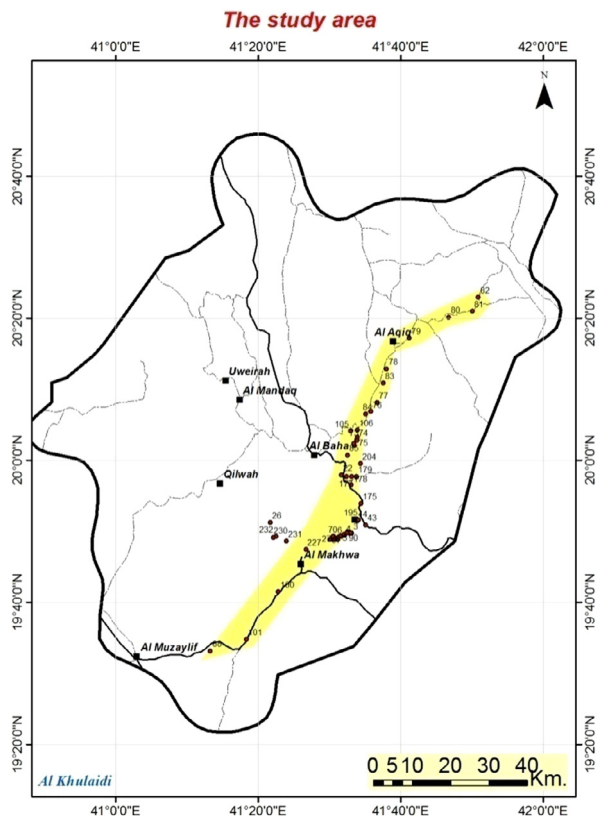

Figure 3 Cross section along the study area.

(3) Sample plots with a high similarity of plant species composition were placed side by side.

(4) Plant species with similar patterns in quadrat plots were aggregated.

Using MVSP Two-way indicator species analysis and Canonical Correspondence Analysis (CCA) were used to analyze the relationships between vegetation and environmental variables.

The number of plant species in each quadrat, as well as the number of individuals of each species was recorded to calculate plant density per hectare. ArcGis (Arc Map) was used to create a raster plant density map along the cross section (Silverman, 1986).

4. Results and discussion

4.1. Plant species density

The 190 plant species belonging to 59 families were recorded along the cross section. These plant species formed 15 vegetation types that primarily correspond mainly to different combinations of elevation, and topography. These types are representative of the vegetation in different ecosystems. Each type had a different vegetation structure, topography and environment (Table 1). The variation types were significantly related to elevation, topography, and aspect. The highest species diversity appeared in the fog affected mountain slopes facing Tihama coastal area under medium disturbance intensity. Factors such as fogs, elevation, slope, aspect, moisture, soil and topography were strongly correlated with species composition.

Plant species density is the number of plant species and abundance of each species that are found in the study area. ArcGis (Arc Map) was used to create a raster plant density map along the cross section. Plant density appears to peak at high altitude areas (around Aqabat Hizna and Baljurashi) and declines gradually toward south west (coastal plains) and north east (around Al Aqiq) as rainfall decreases and temperature increases (Fig. 4).

Using MVSP software and following the method of Braun-Blanquet ordination methods (Braun-Blanquet, 1932), the sample plots were arranged to similarities and then combined with 15 vegetation types (Fig. 6 and Table S1). A Number of each plant species were entered in the matrix. Species with similar distributions were grouped together in the table and association-analysis final groups were re-arranged to consolidate patterns in the table as much as possible. The matrix shows a diagonal clusters where the boundaries of vegetation types in rows and sociological species groups in columns can be detected visually through the absence or presence of different plant species. Vegetation types are labeled by the dominant species (the second name) and by the species almost exclusively occurring in the vegetation type (the first name) (see Figs. 5 and 7).

4.2. Description of main vegetation types

4.2.1. Tamarix aphylla – Salvadora persica type

This type forms woodland and is restricted to wadis. The vegetation cover ranges between 30% and 36%. The topography is composed of flat wadis. The altitude ranges from 150 to 160 m above sea level. The most common species are T. aphylla and S. persica.

4.2.2. Acacia ehrenbergiana – Acacia tortilis type

This type forms sparse woodland and is found on rocky slopes adjacent to wadis and fallow lands. The altitude ranges from 136 to 275 m above sea level.

The vegetation cover is very poor ranging between 2% and 9%. The average tree cover is 20%, the average shrub cover is 1%, and the average herbaceous cover is 1%. Association plant species are S. persica, Calotropis procera and Abutilon pannosum.

4.2.3. Commiphora myrrha – Maerua crassifolia – Acacia asak type

This type forms woodland to shrubland and grassland. The vegetation cover ranges between 8% and 110%. The average tree cover is 13%, the average shrub cover is 9%, and the average herbaceous cover is 25%.

The topography is composed of steep to moderate steep slope and rock outcrops. The altitude ranges from 700 to 990 m above sea level. The dominant species is A. asak. The most common species that always occur are A. asak, Anisotes trisulcus. The following species are rare and found only in this type: Barleria acanthoides, Barleria hochstetteri, Boscia angustifolia, Commelina forsskalaei, Commicarpus sp., Commiphora kua, Dobera glabra, Ecbolium viride, Euphorbia cuneata, Indigofera spiniflora, Portulaca oleracea, Pulicaria sp., Salsola sp., Sarcostemma viminale, Suaeda aegyptiaca.

4.2.4. Nicotiana glauca – A. asak type

This type represents the degraded sites of type 3 that occur in the same ecological zone and in the same type of land formation but at a higher altitude. The vegetation cover ranges between 5% and 24%. The average tree cover is 5%, the average shrub cover is 2%, and the average herbaceous cover is 4%. The most common species that always occur are A. asak and N. glauca. The following species are rare and found only in this type Forsskaolea tenacissima and Acacia hamulosa.

The topography is composed of a moderate steep slope. The altitude ranges from 1127 to 1756 m above sea level.

4.2.5. Flueggea virosa – A. asak type

This type forms woodland. The vegetation cover ranges between 70% and 80%. The topography is composed of a steep to moderate steep rocky drainage line. The altitude ranges from 1700 to 1750 m above sea level.

The most common plant species are: A. asak, Cissus rotundifolia, Crotalaria sp., Ficus cordata, Ficus ingens, F. virosa, Grewia trichocarpa, Grewia villosa, Lantana sp., Triumfetta flavescens.

4.2.6. Panicum turgidum – Acacia tortilis type

This type forms woodland and shrubland. The vegetation cover ranges between 18% and 65%. The average tree cover is 19%, the average shrub cover is 13%, and the average herbaceous cover is 9%. The topography is composed of wadis. The altitude ranges from 415 to 736 m above sea level.

The most common species and always occur are A. tortilis, Aerva javanica, Indigofera spinosa. The following species are

Table 1 Relationship between the vegetation types and different environmental factors.

Vegetation type	1	2	2	3	3	3	3	3	3	3	3	4	4	4	4	4	4	5	6	6	6	6	6	7	7	7	8	8	8
Way point (WP)	101	88	100	69	71	70	27	111	86	222	112	6	26	68	5	4	25	54	232	72	230	227	231	91	87	220	44	194	195
Plant density	42	3	17	128	72	14	11	103	71	292	138	11	9	40	21	24	13	54	155	31	126	223	147	101	54	68	147	107	282
Richness	3	3	4	23	13	8	8	16	12	20	23	5	7	6	6	4	4	11	18	13	17	19	21	14	9	18	8	7	20
Exposure	S	SW	SW	SE	SW	NW	W	W	SW	W	SW	W	NW	SW	W	SW	W	W	SW	W	SW	SW	SE	SW	W	W	S	S	S
land form	W	fa	s	RO	S	S	S	S	RS	RS	S	S	S	S	S	S	S	dr	W	W/P	W	W	W	S	RO	RS	Fa	Fa	Fa
Rainfall	90	90	90	250	250	250	250	250	250	250	250	250	250	250	250	250	250	250	150	200	150	150	150	250	250	250	300	300	300
Trees %	35	2	7	7	25	5	5	10	20	20	10	7	10	4	4	1	4	50	10	10	10	15	50	30	10	4	10	50	20
Shrub %	1	0	0	5	10	3	2	5	20	5	20	1	1	5	1	2	1	20	30	7	20	5	5	15	10	2	2	2	15
Herb %	0	0	2	40	5	0	0	50	10	15	80	0	0	15	5	5	0	10	20	1	5	10	10	10	15	20	80	80	50
Total	36	2	9	52	40	8	7	65	50	40	110	8	11	24	10	8	5	80	60	18	35	30	65	55	35	26	92	132	85
Altitude m	158	136	275	990	805	870	762	875	700	735	815	1167	1127	1287	1233	1426	1756	1720	440	736	472	440	417	1488	1463	1440	2025	2032	2040

| Vegetation type	9	9	9	10	10	10	10	10	11	11	11	11	12	12	12	12	13	14	14	14	14	14	15
Way point (WP)	175	176	43	3	219	177	178	179	110	90	89	85	109	75	73	107	79	105	106	108	84	76	—
Plant density	123	136	591	14	174	306	149	209	107	52	67	131	111	91	58	29	20	123	95	94	112	82	198
Richness	17	16	13	3	10	17	16	23	21	12	16	16	15	11	9	5	7	15	13	19	14	14	14
Exposure	SW	S	NW	SW	S	N	E	S	SW	W	W	S	S	SE	SE	W	E	W	W	N	E	N	E
land form	RO	RO	W	s	RS	S	S	S	SS	S	S	W	W	S	S	S	h	W	W	S down	W	W	Riv
Rainfall	300	300	300	200	200	300	300	300	200	200	200	250	250	250	250	250	100	200	200	200	140	100	250
Trees %	7	3	60	7	1	30	15	10	15	8	5	10	15	60	2	4	7	5	20	7	7	15	5
Shrub %	25	5	40	0	8	2	2	5	2	10	40	60	30	2	40	2	2	25	3	2	20	5	1
Herb %	5	30	70	5	10	35	35	50	30	20	30	20	40	10	5	20	5	30	5	25	1	2	80
Total	37	38	170	12	19	67	52	65	47	38	75	90	85	72	47	26	14	60	28	34	28	22	86
Altitude m	2020	2084	2036	2031	1902	2260	2360	2383	1979	1718	1700	2085	1906	1835	1840	1865	1565	2020	1905	1921	1867	1805	1810
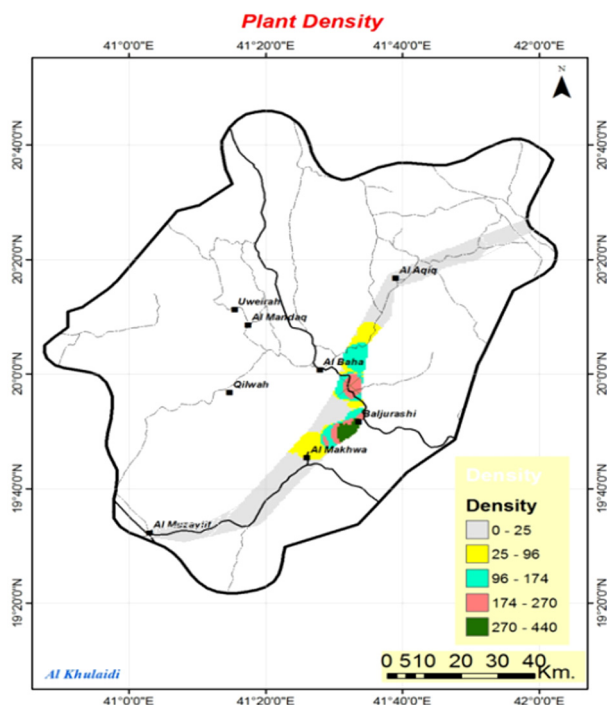
Figure 4   Plant density along the cross section.

found only in this type: *A. pannosum*, Aloe sp., *Boerhavia diffusa, Cissus quadrangular, Citrullus colocynthis, Cleome scaposa, Datura inoxia, Euphorbia inarticulata, Indigofera* sp., *Jatropha glauca, Jatropha pelargoniifolia, P. turgidum, Senna alexandrina, Senna italica, Tribulus terrestris*.

4.2.7. Combretum molle – Cyphostemma digitatum type

This type forms woodland to grassland. The vegetation cover ranges between 25% and 55%. The average tree cover is 15%, the average shrub cover is 2%, and the average herbaceous cover is 20%. The topography is composed of rocky slopes and rock outcrops. The altitude ranges from 1440 to 1490 m above sea level.

The most common species and always occur are *Abutilon fruticosum* and *C. molle*. The following species are rare and found only in this type: *C. molle, Coptosperma graveolens, C. digitatum, Psydrax schimperiana, Talinum portulacifolium, Ecbolium gymnostachyum, Ocimum filamentosum, Rhynchosia* sp., *Aerva lanata*.

4.2.8. Achillea biebersteinii – Acacia origena type

This type forms woodland to grassland. The vegetation cover ranges between 40% and 132%. The average tree cover is 33%, the average shrub cover is 5%, and the average herbaceous cover is 70%. The topography is composed of fallow lands and wadis. The altitude ranges from 2025 to 2177 m above sea level.

The most common plant species are of this type are: *A. origena, A. biebersteinii, Asphodelus fistulosus, Halothamnus bottae, Onopordum heteracanthum, Verbesina encelioides*. The following species are rare and found only in this type: *Chenopodium ambrosioides, Marrubium vulgare, Mirabilis jalapa, Phragmanthera austroarabica, Rumex steudelii, Ruta chalepensis, Xanthium spinosum*.

This type is found on fallow lands that been previously cultivated and severely in danger because of expanding the buildings.

4.2.9. Maytenus parviflora – Hyparrhenia hirta – J. procera type

This type forms forest, shrubland and grassland. The vegetation cover ranges between 12% and 170%. The average tree cover is 16%, the average shrub cover is 16%, and the average herbaceous cover is 24%. The topography is composed of rock outcrops, wadis and rocky slopes. The altitude ranges from 1900 to 2085 m above sea level.

The most common plant species of this type are: *J. procera, H. bottae, H. hirta, A. origena*. The following plant species are rare and only found in this type: *Periploca somalensis, Farsetia longisiliqua, Celtis africana, Phyllanthus* sp., *Astragalus atropilosulus* and *Centaurothamnus maximus*.

4.2.10. Lavandula dentata – Themeda triandra – J. procera type

This type forms forest, woodland and grassland. The vegetation cover ranges between 52% and 67%. The average tree cover is 18%, the average shrub cover is 3%, and the average herbaceous cover is 40%. The topography is composed of rocky slopes. The altitude ranges from 2015 to 2383 m above sea level.

The most common plant species of this type are: *J. procera, T. triandra, Micromeria imbricata, Sagoretia thea*. The following plant species are only found in this type: *Clutia lanceolata, Lavandula dentate* and rarely *Gomphocarpus fruticosus, Hypoestes forskalei, Meriandra bengalensis, Salvia aegyptiaca, Conyza pyrrhopappa, Cymbopogon* sp., *Ephedra aphylla*.

4.2.11. Barbeya oleoides – Olea europaea – J. procera type

This type forms shrubland and grassland. The vegetation cover ranges between 38% and 90%. The average tree cover is 10%, the average shrub cover is 28%, and the average herbaceous cover is 25%. The topography is composed of steep to moderate steep rocky slopes and rocky wadis. The altitude ranges from 1700 to 2065 m above sea level.

The most common plant species of this type are: *Jasminum grandiflorum, J. procera, Lavandula pubescens, O. europaea, Psiadia punctulata*. The following plant species are rare and only found in this type: *Opuntia ficus-indica, Pentas lanceolata*.

4.2.12. Ochradenus baccatus – Dodonaea viscosa type

This type forms forest, shrubland and grassland. The vegetation cover ranges between 38% and 90%. The average tree cover is 10%, the average shrub cover is 28%, and the average herbaceous cover is 25%. The topography is composed of steep to moderate steep rocky slopes and rocky wadis. The altitude ranges from 1700 to 2085 m above sea level.

The most common plant species of this type are: *Acacia etbaica, D. viscosa, O. europaea, P. punctulata*. The following plant species are rare and only found in this type: *Phoenix caespitosa, S. aegyptiaca*.

4.2.13. Rhazya stricta – Lycium shawii type

This type forms woodland and shrubland. The vegetation cover ranges between 6% and 66%. The average tree cover is 13%, the average shrub cover is 8%, and the average herbaceous cover is 6%. The topography is composed of steep to
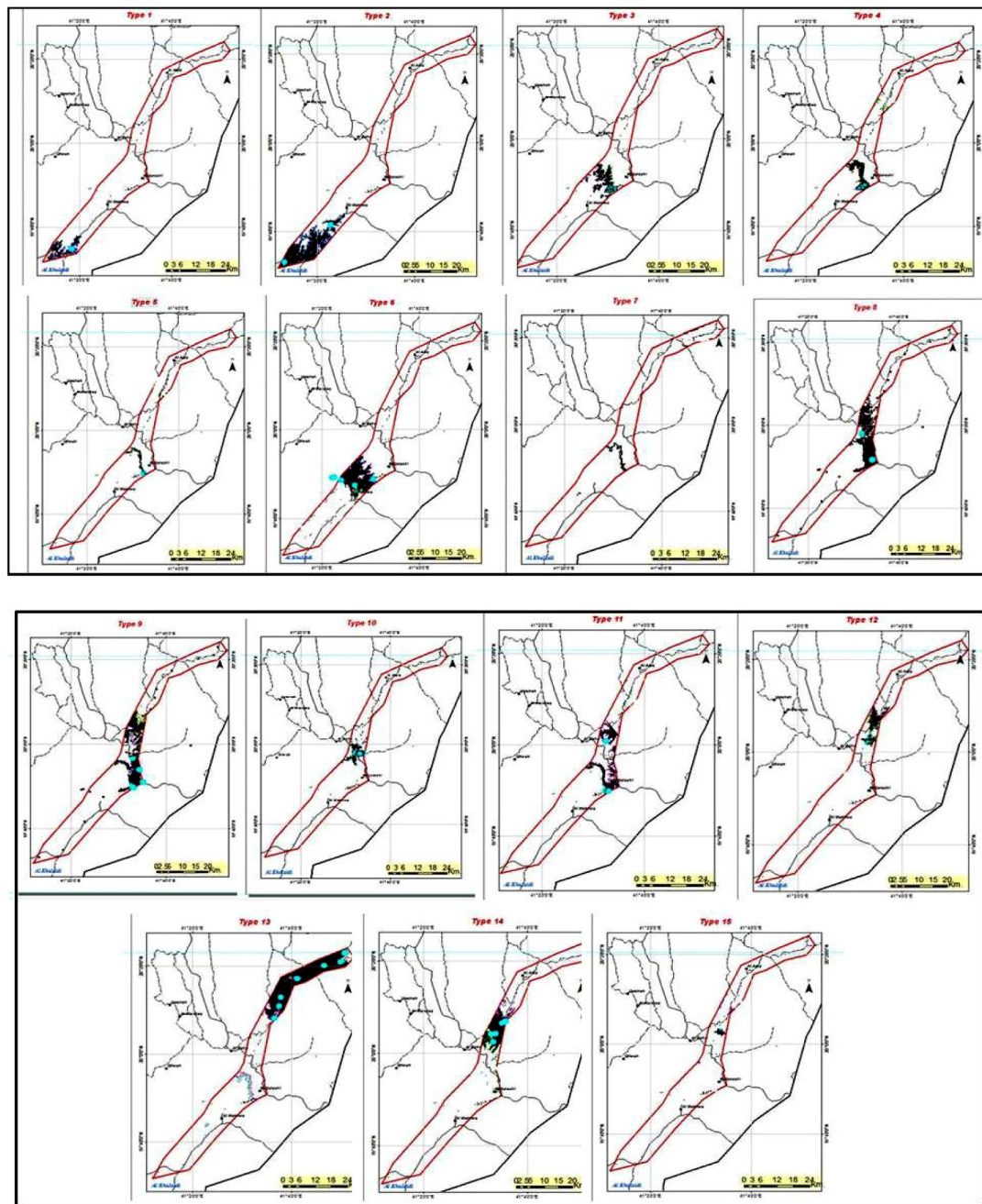
Figure 5 Maps showing the location of each vegetation type.

moderate steep rocky slopes plains, hills and wadis. The altitude ranges from 1378 to 1746 m above sea level.

The most common plant species of this type are: *A. ehrenbergiana*, *A. etbaica*, *A. tortilis*, *L. shawii*, *Ziziphus spina-christi*. The following plant species are rare and only found in this type: *Aizoon canariensis*, *Desmidorchis penicillata* (= *Caralluma penicillata*), *Caralluma quadrangula* (= *Monolluma quadrangular*), *Chrozophora oblongifolia*, *Euphorbia granulate*, *Hibiscus micranthus*.

4.2.14. Kleinia odora – Acacia etbaica type

This type forms woodland and shrubland. The vegetation cover ranges between 22% and 60%. The average tree cover

is 11%, the average shrub cover is 11%, and the average herbaceous cover is 13%. The topography is composed of wadis and foot slopes. The altitude ranges from 1805 to 2020 m above sea level.

The most common plant species of this type are: *A. etbaica*, *Acacia gerrardii*, *D. viscosa*, *Fagonia indica*, *Solanum incanum*, *Ziziphus spina-christi*. The following plant species are rare and only found in this type: *K. odora*, *Boerhavia elegans*, *Asparagus africanus*.

4.2.15. Kanahia laniflora – Bacopa monnieri type

This type forms grassland. The vegetation cover reaches 86%. The average tree cover is 5%, the average shrub cover is 1%,
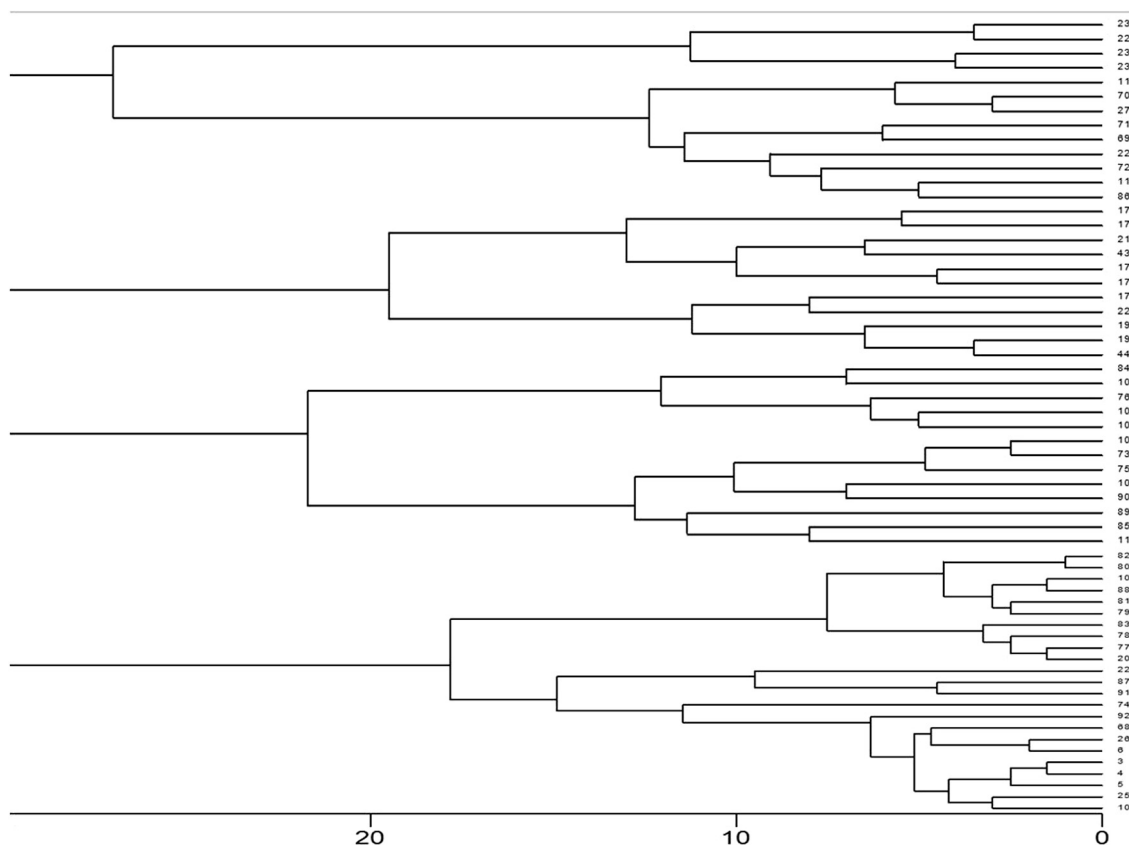
Figure 6   MVSP similarity result data.

and the average herbaceous cover is 80%. The topography is composed of springs. The altitude ranges from 1800 to 1810 m above sea level.

The most common plant species of this type are: *Argemone ochroleuca, B. monnieri, K. laniflora, Pluchea* sp.

4.3. Environmental data analysis

4.3.1. The sampling plots

Altitude and rainfall are the most important environmental variables and increase along a gradient from the right to the left. There is a strong relationship between the distribution of sample plots of vegetation types 8–12 (left) with altitude and rainfall and between the sample plots of eastern mountain slopes, Tihama foothills and coastal plains (right) with land-form. The sample plots of wadis and fallow lands (types 1, 2 and 6) are negatively correlated with altitude and moisture, while the sample plots of vegetation types 8–10, are positively correlated with altitude and rainfall. Sample sites of vegetation type 13 with variable landforms are negatively correlated with rainfall Sample sites of wadis (type 6) are negatively correlated with rainfall and altitude.

4.3.2. Plant species

The CCA axis (Fig. 8) shows that altitude and rainfall increase along a gradient from the right to left and are strongly correlated with ordination axis 1. The CCA axis represents the following orders:

Species more commonly associated with high altitude areas and high rainfall (bottom left) and more commonly associated with fallow lands e.g. *A. origena, A. biebersteinii, A. fistulosus, Withania somnifera,* or commonly associated with rocky slopes e.g. *Echinops* sp., *Ficus palmata, H. bottae, M. parviflora, Nepeta deflersiana, O. heteracanthum, Osteospermum vaillantii, Polygala abyssinica, V. encelioides.*

Species more commonly associated with high altitude areas and relatively high rainfall and rocky areas (top left) e.g. *Anagyris foetida, Anarrhinum forsskaolii, Caylusea hexagyna, Centaurea pseudosinaica, H. hirta, J. procera, M. parviflora, M. imbricate, O. vaillantii, Periploca aphylla, P. abyssinica, Rumex nervosus, S. thea, T. triandra.*

Species negatively correlated with rainfall and altitude (bottom right) and more commonly associated with wadis e.g. *A. ehrenbergiana, C. colocynthis, P. turgidum, Desmidorchis retrospiciens, C. quadrangular, S. persica, E. inarticulata, J. glauca, T. aphylla* or more commonly associated with rocky slopes e.g. *Acacia johnwoodii, Adenium obesum, A. trisulcus, A. asak, M. crassifolia, Commiphora gileadensis, C. myrrha, Cadaba farinosa, Cadaba glandulosa, Grewia erythraea, Grewia tenax, I. spinosa, Premna resinosa, Pennisetum setaceum, Sarcostemma* sp.

Species commonly associated with middle to low altitude, relatively low rainfall and rocky areas or wadis and drainage lines (middle right) e.g. *C. molle, C. graveolens, C. digitatum, Ehretia obtusifolia, F. ingens, F. virosa, Grewia tembensis, G. trichocarpa, G. villosa, Hibiscus deflersii, P. schimperiana.* The species *A. etbaica, Acacia gerrardii, B. oleoides,*
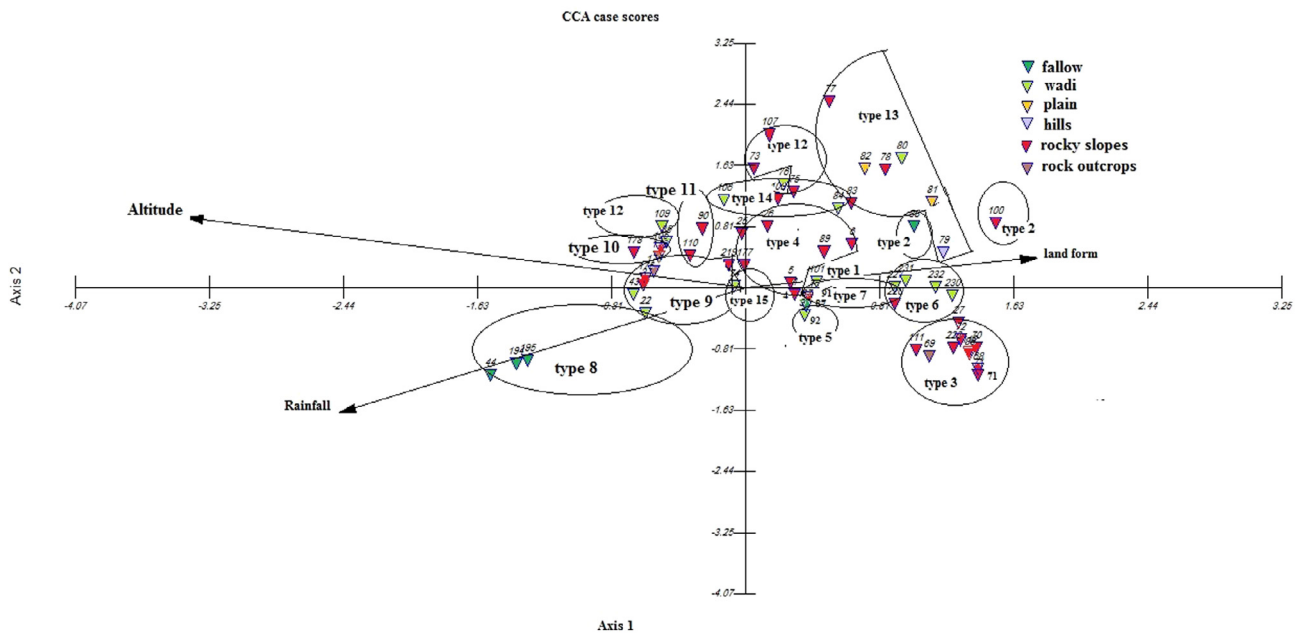
Figure 7 Canonical Correspondence Analysis (CCA) ordination biplot of sampling points on main landforms and environmental variables (altitude, rainfall and land form). Arrows represent the environmental data and point in the direction of maximum change of the environmental variable across the diagram. Altitude and rainfall are the most important environmental variables. Altitude and landform are strongly correlated with ordination axis 2. There is a very clear segregation between vegetation types 8 to 12 (left) and of the other vegetation types (right). The first group is strongly correlated with altitude and rainfall, and the second group is strongly correlated with the landforms.
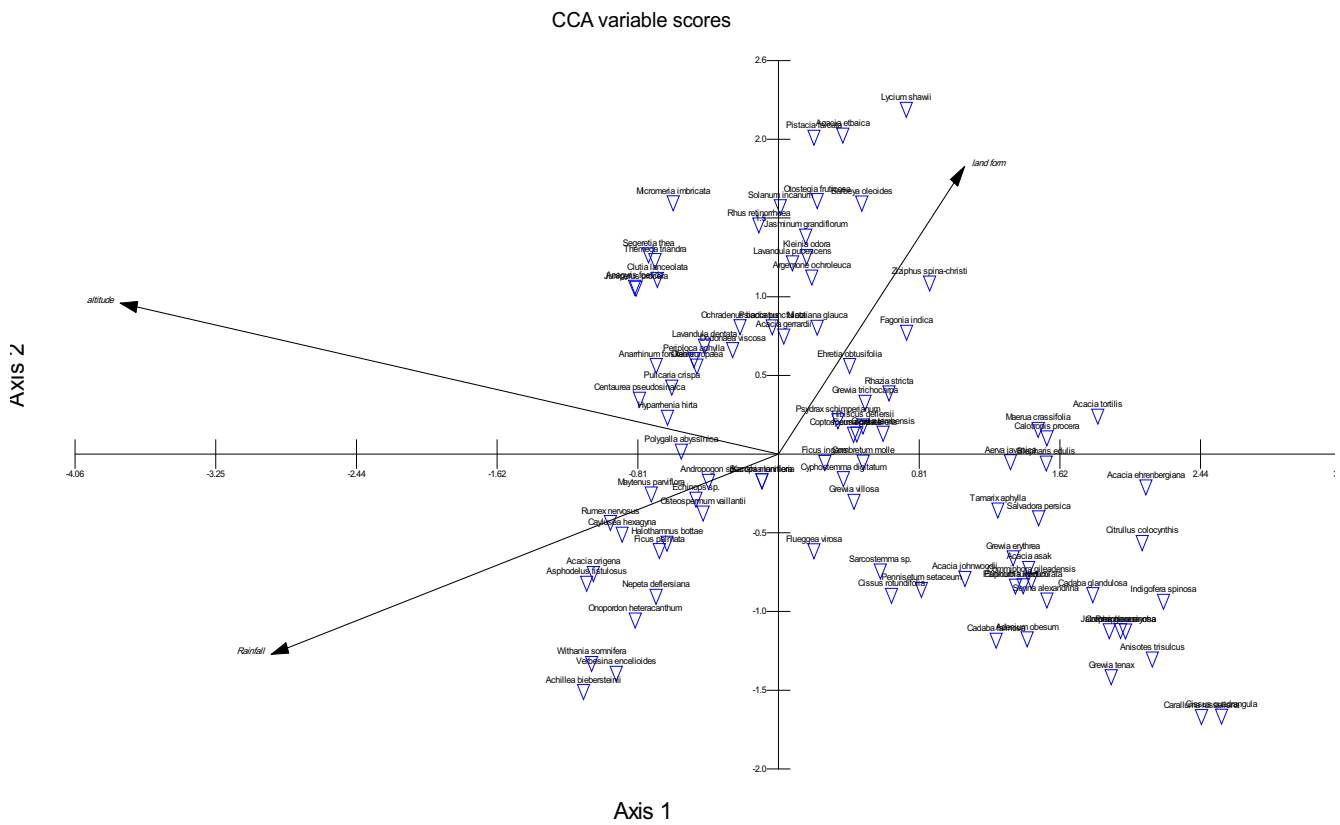
Figure 8 Canonical Correspondence Analysis (CCA) ordination biplot of plant species and 3 environmental variables. Altitude and moisture (rainfall) are the most important environmental variables.

J. grandiflorum, *K. odora*, *L. pubescens*, *L. shawii*, *Otostegia fruticosa*, *Pistacia falcata* (top right) are associated with rocky areas, relatively low altitude and low rainfall.

The life form spectrum in Tihama and eastern part of the study area reflects a typical desert flora, the majority of species being therophytes and Chamaephytes. These results agree with the spectra of vegetation in desert habitats in other parts of Saudi Arabia (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). It may also be stated that the Saharo Arabian species which are restricted in their distribution to the south western 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; El-Ghanem et al., 2010).

The present study is the first systematic survey of the vegetation of the region. Previous studies concentrated on compiling floristic checklists or on general descriptions of the vegetation communities found in selected habitats without following any consistent scientific methodology. It is intended that the present research should form the basis for any future management plants for the region.

Human activities and climate change have changed the natural environment over time; in particular they have tipped the ecological balance resulting in a fragmentation of habitats. For example, the increases of invasive *N. glauca*, rapidly can result in detrimental effect on indigenous species. Infrastructure around the main cities has resulted in damaging the vegetation communities, in particular *A. origena* and *J. procera* communities.

The study evaluated the vegetation types, the structure of plant communities and their distribution, the plant species composition, plant biodiversity and areas with the greatest plant diversity.

Fog-affected seaward-facing mountain slopes occur in the mountains above Aqabat Hizna and around Baljurashi, these landscapes support dense deciduous woodland dominated by the tree *J. procera*, together with *A. origena*. As the influence of fog decreases further north-east or south-west, forest and woodland is replaced by sparse woodland or shrubland dominated by *A. asak*, *A. tortilis* and *A. ehrenbergiana*. Beyond this, the vegetation becomes sparser and finally gives way to open semi-desert.

The main threats to the vegetation in Al Baha are from the direct and indirect impacts of human activities. In general, these relate to changes in the traditional land management practices which in the past have protected the vegetation. In particular the vegetation in the region has been directly and indirectly changed by the recent rapid economic growth. Direct threats of development include the taking of land for building; this is widespread on the high altitude areas such as around Baljurashi where it will potentially affect important *J. procera* and *A. origena* communities.

The building of new roads affects the vegetation in various ways: by changing watersheds and creating micro-niches along the roadsides. Human activities in the study area, have allowed invasive species, such as *N. glauca*, to rapidly spread with a resultant detrimental effect on the abundance of native species. This plant becomes the dominant species in many parts of the study area forming a pure stand of open woodland. Pure stands of *N. glauca* trees are common now in the river beds of the main Wadi, road sides and neglected agricultural land.

5. Summary

Primarily, this study will improve the understanding of the distribution and ecology of plant taxa in the region. However, it also emphasizes that vast areas in this remarkable region are still botanically un-explored very well. The research is the first detailed vegetation survey to be completed in Al Baha region and provides data which can be used as a baseline for monitoring change. The methods and protocols developed during the study can be used as a basis for carrying out similar studies in other parts of Saudi Arabia and for helping to devise management and conservation programs. In the study area, the major vegetation types, their composition and biodiversity were identified and vegetation maps generated.

The result of Braun-Blanquet and MVSP analyses revealed 15 vegetation types and demonstrated several distinct patterns of species distribution such as:

1. Species found over wide range of ecological sites.
2. Species distributed mainly on wadi beds.
3. Species only found on rocky slopes facing the Red sea.
4. Species only seen on high altitude mountains.
5. Species only seen on coastal plain and semi-desert areas.

Due to the varied topography over the study area, several important microhabitats were identified, including runnels, west facing mountains, wet sites, coastal plains, and semi desert areas. Each of these microhabitats supports special types of vegetation, each with a characteristic floristic composition and distinct physiognomy.

Human activity has exploited the plant resources of the entire area but has preferentially targeted particular types of vegetation. There is a clear evidence of overgrazing in the wadis, the collection of firewood from certain trees (e.g. *J. procera*, *A. tortilis*). There has been obvious direct targeting of the natural resources, for instance, the clearing of the forest and woodland in high altitude areas for infrastructure.

Further study on the factors that influence the distribution of plant species of Al Baha region and the possible effects of climate change on the distribution patterns is needed. It would be helpful if vegetation surveys could be combined with data or Abiotic factors such as altitude, aspect, soil, moisture and other environmental factors and biotic factors such as human and other living organisms to get a better and clear idea on the distribution, abundance and composition of plants in particular rare, endemic and near-endemic species. Detailed vegetation as well as topography and land use mapping of the whole region of the Al Baha using the modern softwares such as ArcGIS and ERDAS is recommended.

University of Al Baha for their great help and assistance to fulfill this study.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.sjbs.2016.02.007.

References

Aboulabbes, O., 2013. Overall status of watershed and watershed management in the Al Baha region. Watershed consultant report. Sustainable Management of Natural Forests and Rangelands in The Kingdom Of Saudi Arabia (UTF/SAU/039/SAU).

Alaklabi, A., Arif, Ibrahim A., Bafeel, S.O., Alfarhan, A.H., Ahamed, A., Thomas, J., Bakir, M.A., 2014. Nucleotide based validation of the endangered plant *Diospyros mespiliformis* (Ebenaceae) by evaluating short sequence region of plastid rbcL gene. POJ 7 (2), 102–107 (102).

Al-Khulaidi, A.A., 2013. Flora of Yemen. The Sustainable Natural Resource Management Project (SNRMP II). EPA and UNDP, Republic of Yemen.

Al-Turki, T.A., Al-Qlayan, H.A., 2003. Contribution to the Flora of Saudi Arabia: Hail region. Saudi J. Biol. Sci. 10, 190–222.

Al-Zahrani, K.H., Elhag, E.A., 2005. Environmental pollution and its effect on the sustainable development of tourism and vegetation in Al-Baha Area, Kingdom of Saudi Arabia. Res. Bull. 139, 5–35 (Food Sci. Agric. Res. Center, King Saud Univ.).

Aref, I.M., El-Atta, H.A., AL-Ghamde, A.M., 2011. Effect of forest fires on tree diversity and some soil properties. Int. J. Agric. Biol. 13, 659–664.

Ayele, T., Al Shadily, S.A., 2000. Some of the engineering geological and hydrogeological problems and conditions of Ethiopia and Yemen. Acta Geol. Univ. Comenianae 55, 51–62.

Chaudhary, S.A., 1999. In: Flora of the Kingdom of Saudi Arabia, vol. I. Ministry of Agriculture and Water, Riyadh.

Chaudhary, S.A., 2000. Flora of the Kingdom of Saudi Arabia, vol. II, Parts 1–3. Ministry of Agriculture and Water, Riyadh.

Chaudhary, S.A., 2001. In: Flora of the Kingdom of Saudi Arabia, vol. III. Ministry of Agriculture and Water, Riyadh.

Collenette, 1985. An Illustrated Guide to the Flowers of Saudi Arabia. Scorpion Publishing Ltd., London, p. 26.

Collenette, I.S., 1999. Wildflowers of Saudi Arabia. National Commission for Wildlife Conservation and Development, Riyadh.

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

El-Ghanem, W.A., Hassan, L.M., Galal, T.M., Badr, A., 2010. Floristic composition and vegetation analysis in Hail region north of south western Saudi Arabia. Saudi J. Biol. Sci. 17, 119–128.

El-Karemy, Z.A.R., Zayed, K.M., 1996. A contribution to the vegetation and habitat types of Baha plateau (Saudi Arabia). Feddes Repertorium 107 (1–2), 135–144.

Fahmy, A.G., Hassan, L.M., 2005. Plant diversity of wadi el Ghayl, Aseer Mountains, Saudi Arabia. Egypt. J. Desert Res. 55, 39–52.

Feldmeyer-Christie, E., Zimmerman, N.E., Ghosh, S., 2005. Modern Approaches in Vegetation Monitoring. Akademiai Kiado, Budapest.

Ghazanfar, S.A., Fisher, M., 1998. Vegetation of the Arabian Peninsula. Kluwer, London.

Hajar, A.S.M., 1993. A comparative ecological study on the vegetation of the protected grazed parts of Hema Sabihah, in Al-Bahah region, south western Saudi Arabia. Arab Gulf J. Sci. Res. 11, 259–280.

Hassan, H.M., Al-Hemaid, F.M., 1995. Road-side trees shrubs in Saudi Arabia alongside Al-Qunfuda-Al-Baha, motor way (Aqabat el-Baha). J. King Saud Univ. Sci. 7 (2), 61–171.

Ibrahim, M.M., 2010. Study of cystic echinococcosis in slaughtered animals in Al Baha region, Saudi Arabia: interaction between some biotic and abiotic factors. Acta Trop. 113, 26–33.

Kent, M.P., Coker, 1992. Vegetation Description and Analysis. A Practical Approach. John Wiley and Sons, New York, p. 384.

Koppen, W., 1936. Das geographische System der Klimate. In: Koppen, W., Geiger, R. (Eds.), Handbuch der Klimatologle, Band 1 (Teil V. Berlin).

Silverman, B.W., 1986. Density Estimation for Statistics and Data Analysis. Chapman and Hall, New York.

Van Der Maarel, E., 2004. Vegetation Ecology. Blackwell Publishers, Oxford, UK.

White, F., 1983. The Vegetation of Africa. A Descriptive Memoir to Accompany the Unesco/Aetfat/UNSO Vegetation Map of Africa. UNESCO, Paris.

Zayed, K.M., Fayed, A.A., 1987. Vegetation of area between Taif and Baha, SW Saudi Arabia. Taeckholmia 10, 77–105.

Zohary, M., 1973. Geobotanical Foundations of the Middle East, vols. 1 and 2. Gustav Fischer Verlag, Stuttgart, W. Germany.

Zonneveld, I.S., 1989. The land unit – a fundamental concept in landscape ecology, and its applications. Landscape Ecol. 3 (2), 67–86.