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Geo-Environmental Study on Wadi Metaam in the Ibex Protectorate, Central Saudi Arabia

Haifaa A. Al-Olayan
Botany Department, College of Science, Princess Norah Bint Abdulrahman University,Riyadh, Saudi Arabia

Abstract
The present study is an attempt to demonstrate how geology, climate and plant cover interact in carving the environment. It is update knowledge and understanding of the plant diversity. It determines the impact of application of protection of wildlife on land cover, and illustrates how the laws of environmental protection help in preserving the natural and wildlife at Wadi Metaam and its tributaries in the Ibex Protectorate, Saudi Arabia.

The study demonstrates that Wadi Metaam was excavated at Tuwaiq Escarpment (Mountain) at the periphery of the Najd Plateau. It is made of limestone from the Middle-Upper Jurassic epoch; during that time, the climate was humid enough to allow for excavation of Wadi Metaam and its tributaries for more than 400 m through the escarpment.SPOT+5 images acquired for the years 2004, 2010, and 2013 and used to produce unsupervised and supervised classifications. The drainage of Wadi Metaam and its tributaries reflects a dendritic pattern. The drainage basin is at Al-Onouk, has an elevation of 1125 m, and slopes down along Abu Kaff toward three tributaries: Wadi Al-Ghaba (4^{th} order), Wadi Ghafar (4^{th} order), and Wadi Al-Agma (3^{rd} order). These are connected at Al-Molakatt to form the major Wadi Metaam. While the watershed area receives about 150 mm/yr of rainwater at Al-Ounouk, the situation is completely different at Wadi Metaam, where only 28 mm/yr of rainwater is received. These rains enrich Wadi Metaam with a wide diversity of shrubs and herbal perennial plants and sculpt its geomorphic features, which include karstfication and sinkholes. In Saudi Arabia's ambitious plan to secure water, the government has established a concrete dam 903 m long and 15 m high to store up to 10 million m^3 of rainwater. However, the dam has never been filled to more than half of its capacity. The collected plant samples represent four different sites; these are the open area at Wadi Metaam floor, the talus slopes, Tuwaiq Mountain, and the fenced area at Wadi Al-Ghaba. The density and plant cover in the fenced area are 53.80p/area and 43.22p/area, respectively, and decrease to 21.55p/area and 25.15p/area in the open area. The results reflect the impact of protection to increase plant species in general and plant species with nutritional value in particular.The most popular identified plants are 21 perennial plant species belonging to 15 families: *Acacia gerrardii, Acacia tortilis, and Acacia ehrenbergiana* (Mimosaceae), *Anvillea garcinii and Rhanterium epapposum* (Asteraceae), *Blepharis ciliaris* (Acanthaceae), *Calotropis Procera* (Asclepiadaceae), *Citrullus colocynhis,* and *Cucumis prophetarum* (Cucurbitaceae), *Haloxylon solicomicum* (Chenopodiaceae), *Lycium shawii* (Solanaceae), *Ziziphus nummularia* (Rhamnaceae), *Zygophyllum migahidi, and Fagonia bruguieri* (Zygophyllaceae), *Panicum turgidum* (Poaceae), *Zilla spinosa* (Brassicaceae), *Rhazya stricta* (Apocynaceae), *Cleome amblyocarpa, and Capparis sinaica* (Capparaceae), *Convolvulus oxyphyllus* (Convolvulaceae), and *Heliotrapium bacciferum* (Boraginacae).
Keywords: geomorphology, remote sensing, plant cover, Wadi Metaam, Ibex Protectorate, Saudi Arabia

1. Introduction
Saudi Arabia (16º 83'–32º 34' N and 34º 36'–56º 18' E) is a vast arid desert with total area of about 2.25 million km^2 that covers the major part of the Arabian Peninsula (Figure 1). Although the Kingdom of Saudi Arabia (KSA) lies within a typical arid to semi-arid region, it characterized by unique biological diversity and species that can acclimatize to live under adverse ecological circumstances including extreme weather and dry conditions. Thus, xerophytic vegetation makes up the prominent features of plant life in Saudi Arabia (Zahran 1982).

Several reports about the flora of Saudi Arabia have been previously published, the most comprehensive being Migahid & Hammuda (1974), and Chaudhary (2000). In addition, a number of ecological studies published on the vegetation in several regions of Saudi Arabia such as Al-Turki & Al-Olayan (2003), who published a synoptic analysis of the flora of the Hail region and recorded 338 wild plants representing 221 genera spread over 61 families. El-Ghanim & Haassan (2010) recorded 124 species representing 34 families in the same region. In addition, Al-Huquial & Al-Turki (2006) described a vegetation analysis of the Al-Aushazia Sabkha area at Al-Qassim. Floristic composition and vegetation analysis of other areas in Saudi Arabia reported for Makkah City (EL-Deen 2005) and Wadi El-Ghayl in Aseer Mountains (Fahmy & Hassan 2005).

Figure 1. Location map of the study area at Ibex Protectorate southwest of Riyadh, Saudi Arabia.

The Saudi Arabian economic capriole has resulted in lifestyle changes in agricultural, industrial, and urbanization practices; the increased resource demand due to increased human population as well as pollution and other constraints negatively affect its resources to an alarming extent (El-Bana & Al-Mathnani, 2009). Anthropogenic influences, including heavy grazing, wood fuel cutting, and termites have an additional impact on the biodiversity and vegetation distribution in Saudi Arabia (Fahmy & Hassan, 2005; Al-Huquial &Al-Turki, 2006). For this reason, the Saudi Arabian government established the National Commission for Wildlife Conservation and Development (NCWCD) in 1406 H (1985 m). The main goal of the NCWCD is to enact legislation to control grazing, wood gathering, and hunting in protected areas of Saudi Arabia. It has a mandate to prepare and implement plans to sustain terrestrial and marine wildlife and rehabilitate rare and threatened species and their habitats with the ultimate goal to return it to its natural environmental balance. At present, the commission manages 15 protected areas that have been ratified by its Board of Directors. One of these protected areas is Ibex Protectorate (Al-Khamis *et al.* 2012), which is the focus on the present study.

Ibex Protectorate is located in the central western part of Saudi Arabia between 23°12′ and 23° 35′ N and 46° 15′ and 46°50′ E, at Hotat Bani Tamim province, which is south of Al-Harik province and about 180 km from the city of Riyadh. It is located within the Riyadh administrative area (Figure 1). It has an area of approximately 2369 km^2 and is nearly 212 km in diameter. Ibex Protectorate established in 1408 H (1988 m). It was named as such because it is one of the most important natural sites for the survival of the *Nubian Ibex capra*. The estimated ibex number at the beginning of the formation of the region was 50–100 ibex, and according to the annual report of the King Khalid Wildlife Research Centre, that number reached 317 in 2003 (KKWRC 2003). The Ibex protectorate is the first protectorate used for the resettlement of *Gazella gazella* in Saudi Arabia.

1.1 Climate

The climate of the Ibex Protectorate is mostly arid desert. The climatic records for the years from 2003–2004 were recorded in Al-Motairi (2004) (Figure 2) and from 2005–2006 in Al-Khamis *et al.* (2012) (Table 1). The climate characterized by hot, dry summer and cold winter with little rain. The average temperature ranges from 16–37°C, the average relative humidity changes from 11–46%, and the average annual rainfall ranging from 3–30 mm/yr (Al-Motairi 2004; Al-Khamis *et al.* 2012).

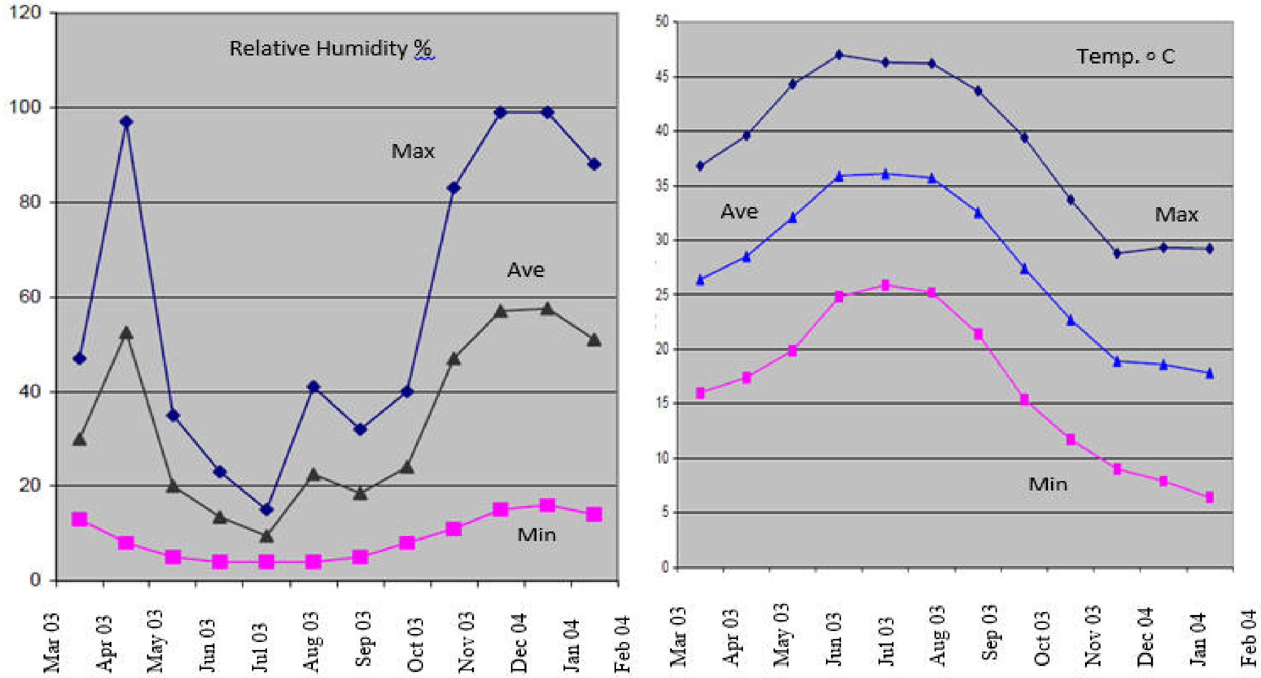


Figure 2. Climatic records of relative humidity and temperature in the study region from 2003–2004 (modified after Al-Motairi 2004).

1.2 Geologic setting and stratigraphy

The Jurassic outcrops in central Saudi Arabia are arranged in a convex arc that hinges in the Al-Riyadh region with horns oriented to the northwest and to the south (Figure 3). Jurassic succession in Saudi Arabia is represented by the Shaqra Group, which is subdivided into seven formations. From oldest to newest, these are the Marrat, Dhruma, Tuwaiq Mountain Limestone, Hanifa, Jubaila, Arab, and Hith formations (Carrigan et al. 1995; Figure 4). The total outcrop length is above 1000 km, and its width does not exceed 85 km in any location. The greatest outcrop width and thickness (1100 m thick) are in the Al-Riyadh region, which is area closest to the open sea domain of the Tethys, located to the north-east of Riyadh, and underlays most of the present-day Arabian Gulf (El-Asa'ad 2004).

Tuwiaq is one of the largest worldwide sedimentary plateaus; it is located within the Arabian shelf and parallel to the Arabian shield that lines eastern Saudi Arabia. This is one of the physiographic elements of the Arabian Peninsula (Vincent, 2008). Jebel Tuwaiq is narrow escarpment that cuts through the plateau of Najd in central Arabia. It is made of limestone from the Middle Jurassic-stratigraphic section (Figure 4). The central Najd region is dominated by several prominent Jurassic cuestas (dip slope plus escarpment) that extend for some 1,600 km in an arc from Al-Nafud in the north to Rub' al Khali in the south, which runs approximately along Wadi ad-Dawasir. On average, it is 600 m high and has an altitude of 800–1000 m a.s.l.

The Tuwaiq Mountain Limestone is named after Jabal Tuwaiq, the spectacular, nearly parallel sequence of west-facing scarps (cuestas) that developed in the Jurassic rocks of central Arabia (Powers et al., 1996). It forms the largest and most persistent of these escarpments and, as such, constitutes the backbone of Jabal Tuwaiq. The lithostratigraphy of the Tuwaiq Mountain Limestone has been described by Steineke & Bramkamp (1952), Steineke et al. (1958), Powers et al. (1966), Powers (1968), Manivit et al. (1990), Al-Husseini et al. (2006), Hughes (2006), and Basyoni & Khalil (2013). The thickness of the Tuwaiq Mountain limestone reaches a maximum of between 200 and 250 m in the Darb al-Hijaz to the Nisah (lat. 24° 150'N) area and uniformly becomes thinner as it moves to the south and to the south, where it becomes 45–60 m thick at its northern and southern extremities. The lower Tuwaiq Mountain Limestone comprises a series of fine-grained, fairly clayey limestone intercalated with beds of brown calarenites and white bioturbated nodular limestone. The Middle Tuwaiq Mountain Limestone comprises a monotonous assemblage of fine-grained or gravelly bioclastic limestone, relatively bioturbated and clayey and containing isolated colonies. The Upper Tuwaiq Mountain Limestone consists of very extensive bioclastic limestone and calcarenite, and is rich in silicified corals and stromatoporoids that give rise to reef forms with bioherms in the middle of the basin. Many narrow valleys (wadis) run along its sides, such as Wadi Hanifa, and a group of towns lie on its central section, including the Saudi capital, Riyadh. Many settlements have historically existed on either side of it as well, such as Sudair and Al-Washm. The Tuwaiq Escarpment is mentioned in Yaqut's 13th century geographical encyclopedia under the name Al-Aridh, although for the past few centuries, that name has only been applied to its central section around Riyadh.

Table (1): Climatic records during 2005 and 2006 for Ibex Protectorate, Saudi Arabia (Al-Khamis *et al.,* 2012).

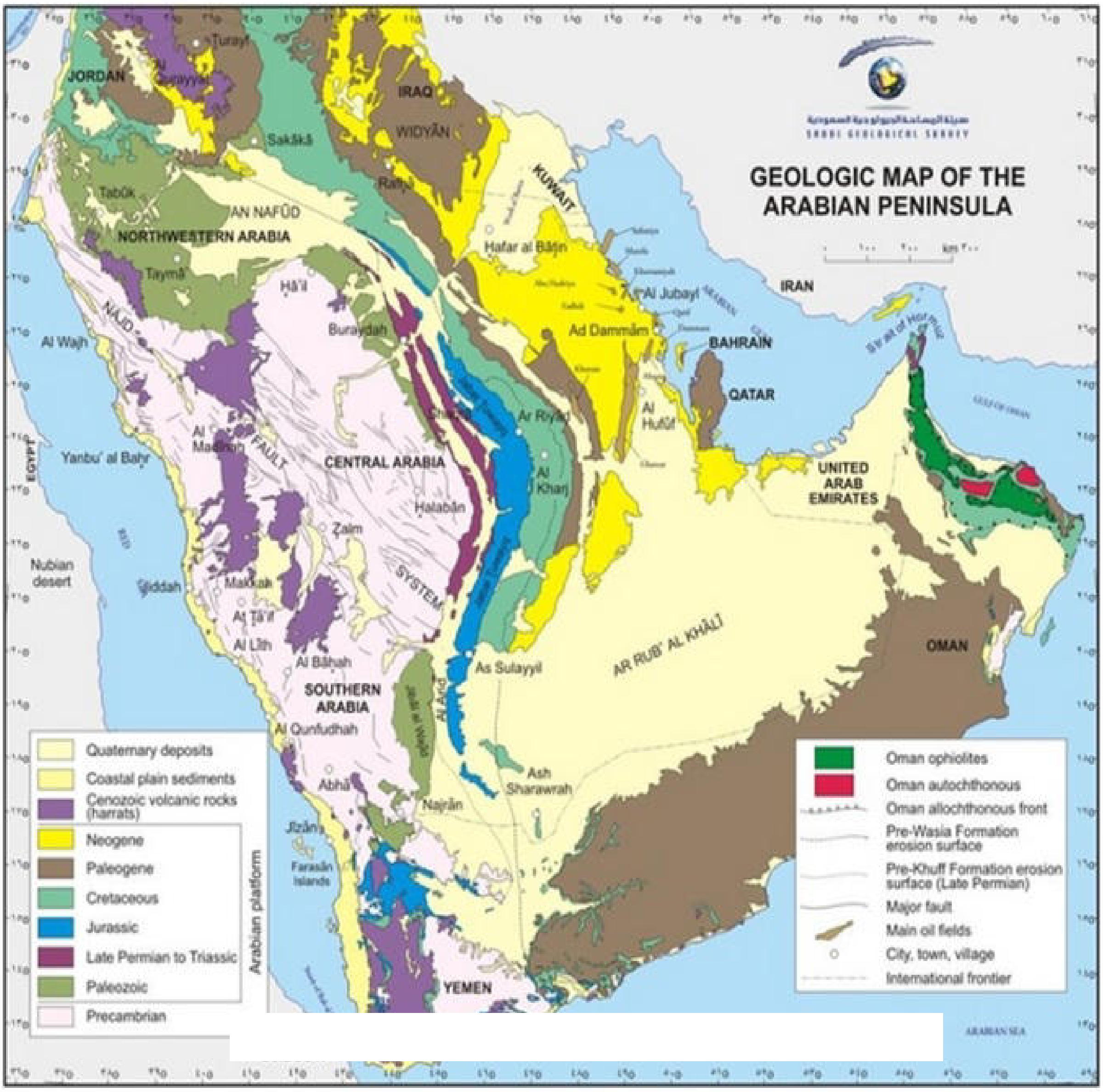
Month	**Temp. °C**			**RH (%)**	**Rain fall (mm)**	**Wind (km/h)**
	Max.	**Mini.**	**Average**			
January	20.2	8.1	14.0	48.1	19.2	5.6
February	23.1	10.2	16.6	38.4	17.1	6.5
March	27.4	14.2	20.8	34.3	28.5	6.9
April	33.3	19.3	26.4	29.2	28.1	6.7
May	39.2	24.6	32.3	17.7	4.8	6.3
June	42.4	26.5	35.0	11.1	0.0	6.9
July	43.5	27.8	36.2	10.6	0.0	6.9
August	43.4	27.6	36.0	12.4	0.0	5.9
September	40.3	24.3	32.8	14.1	0.0	4.8
October	35.2	19.6	27.7	21.0	2.8	4.0
November	27.9	14.5	21.1	36.2	18.8	5.0
December	22.1	9.8	15.8	47.9	15.1	5.3
Average	33.2	18.9	26.2	26.7	11.2	5.9

The present geo-environmental study aims to update knowledge and shed light on the Ibex Protectorate, with a focus on the sustainable conservation of wildlife and geologic heritage by using a remote sensing approach supported by field verification.

2. Methods

2.1 Image enhancement and classification

SPOT+5 satellite data were utilized to achieve the objectives of the present study. The SPOT images were acquired in 2004, 2010, and 2013. Physical parameters related to the earth’s surface and atmosphere show different behaviours when observed at different space-time scales using remote sensing or traditional ground-based techniques (Herold et al., 2002). Monitoring techniques rely on the principles that land cover changes result in persistent changes in the spectral signature of the affected land surface. The accuracy of the results is strongly dependent on the processing procedure, which mainly consists of geometric correction, spectral enhancement, image classification, etc (Foody, 2003; and Yuan et al., 2005).



The general geological map of the Arabian Peninsula

Figure 3. Geologic map showing major structural elements and rock units in Saudi Arabia.

The principal objective of enhancement techniques is to process a given image so that the result is more suitable than the original for a specific application, more effective for display of subsequent visual interpretation, and more information extracted. That means that modification of a subjective feature of the image emphasizes certain information and improve focus on the target of interest by amplifying slight differences to make them more readily observable (Lillesand *et al.* 2004). The basic premise in multi-spectral computer classification is that terrestrial objects manifest sufficiently different reflectance properties (digital values commonly known as spectral signatures) in different regions of the electromagnetic spectrum. Based on these spectral signatures, natural and cultural surface features can be discriminated, and a new output image can be created that has a specific number of classes or categories.

Image classification is the automatic categorization of all pixels making up multi-spectral images into several land cover classes or themes. An essential aspect of any classification system is the development of training samples for the spectral signatures of all objects existing within the scene. The statistics of these training samples characterize the different classes and enable the computer to assign each point in the data to one of these classes. Accordingly, the classification techniques divided into two general types—unsupervised and supervised classification.

The unsupervised classification technique applied to the satellite data for the area of study. In this technique, an arbitrary number of classes selected to represent all types of features. Supervised classification techniques require the analyst to specify the types of ground cover in a scene using training data (Lillesand *et al*. 2004). The generation of a classification has two distinct steps: training and classification. Training is the process of setting a spectral envelope for a class and, for supervised classification, requires a priori information about the image data and habitats to be mapped (Green *et al.* 2000).

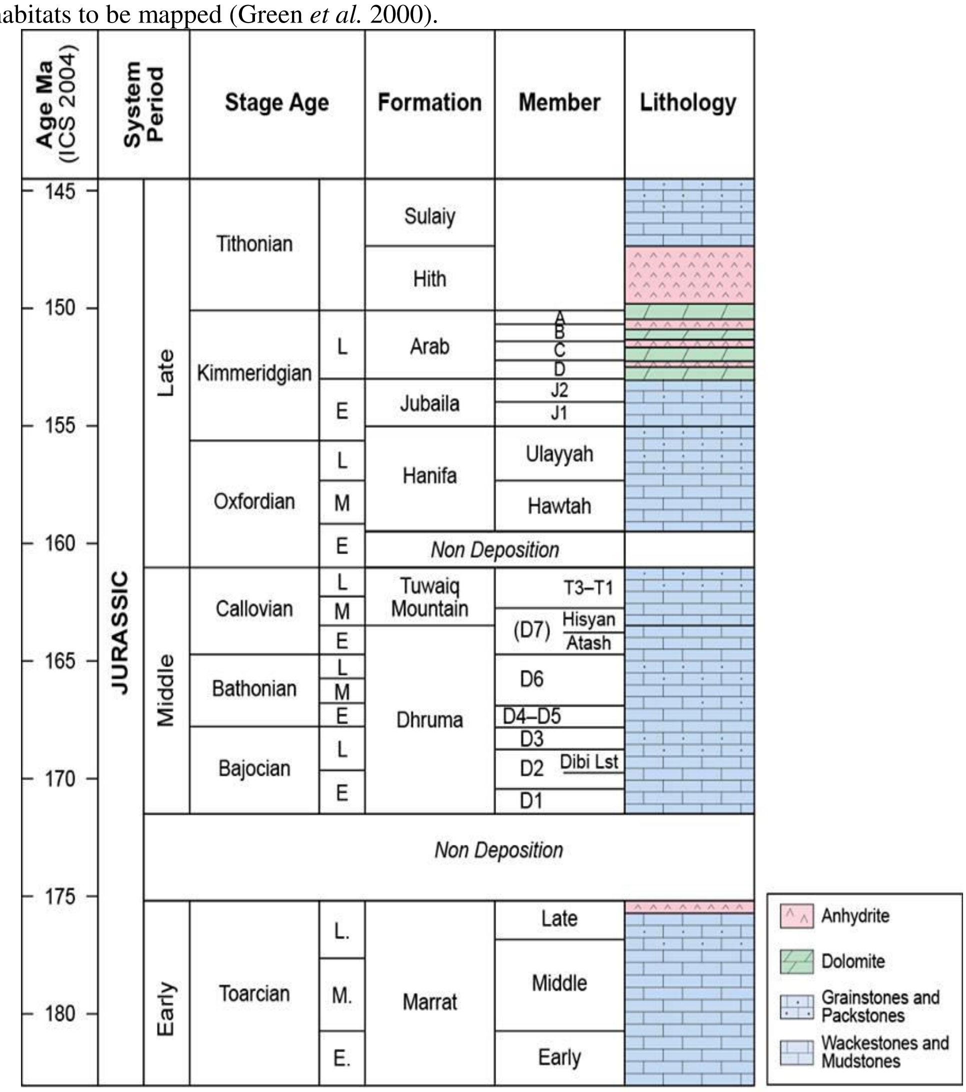


Figure 4. Generalized stratigraphic column for the Jurassic sediments in Saudi Arabia showing ages, formations, and lithology (modified from Carrigan *et al.* 1995).

Field validation was conducted by selecting random points for each habitat class along the entire area of study. About 32 points were selected as reference for each habitat class at different locations for all areas in this study. GPS points were also taken to validate the image data. About five points per class were chosen for each region and were the same for both SPOT+5 and Landsat images. These points were randomly selected and places at the same latitude and longitude in both images. The algorithm then compared the pixel data in the image to the user-defined parameters and produced a classification output. A maximum likelihood algorithm using ENVI 5.0 software performed the supervised classification.

2.2 Digital elevation model (DEM)

Shuttle radar topography mission (SRTM) data used in this study for mapping the terrain characteristics of the study area. The SRTM with 30 m spatial resolution data found to be the most suitable for national scale mapping. The Kingdom of Saudi Arabia political boundary used to clip USGS GTOPO_U30 topographic data in the digital elevation model (DEM) for the KSA terrain. Using the DEM produced by SRTM, different GIS layers were created using ArcGIS 10.0 software. These layers included all the necessary base map layers for terrain analysis, namely contour, elevation zones, and drainage networks.

ENVI 5.0 used to perform spatial sub-setting, radiance conversion, atmospheric correction, glint removal, water column correction, and benthic classification on both types of the satellite imagery used in this study. ENVI's band math function was used extensively throughout image processing. ENVI 5.0 software opens single SRTM DEM files as ENVI-format files; when there are multiple DEMs, it automatically mosaics them into one ENVI-format image file. The file contains missing data points, which we then corrected for its missing values; the missing values replaced by values interpolated from valid neighbouring pixels. ENVI software retains the original input file and creates a new file containing the interpolated data points.

3. Results

3.1 Geomorphology

The present study demonstrates the occurrence of two major valleys (wadis): Wadi Metaam and Wadi Berek (Figure 5). Wadi Metaam represents the fourth order type of drainage pattern. Three tributaries (2^{rd} order) drained to Wadi Metaam: Al-Ghaba, Ghafar, and Al-Agmaa (Figure 4). Wadi Berek, on the other hand, is a wider and more flat, with surface soil subjected to human activities of reclamation and cultivation. It opens to the Bowydan tributary; the major source of rain waters is through the other 2^{nd} and 3^{rd} order tributaries, especially the Nokhailan tributary (Figure 4). The present dendritic drainage pattern indicates that most rains that reach Wadi Metaam come to the drainage basin from the high land of the Tuwaiq Escarpemnt at El-Onouk, then bifurcate in two ways: one to the east at Abu Kaff and one to south and southeast toward Nokhailan, Bowydan, and Wadi Berek (Figure 5).

Field research reveals that Wadi Metaam is a flat, low-lying land covered with the detritus of carbonate rock fragments the size of gravel and boulders (Figure 6A). The geomorphology of Wadi Metaam reflects its cut through the Tuwaiq carbonate cuesta to form gullies of steep slope banks. Heavy rains have widened its course and possibly combined with tectonics to manifest a huge escarpment with a steep slope and accumulation of talus (Figure 6B) to form a fan-like shape (Figure 6C) at the foot of the escarpment. The region is extremely arid with an average annual rainfall of 11.2 mm/yr (Khamis *et al.* 2012). During the wet season of March and April, the region receives almost 28 mm/yr. This amount is not adequate to create permanent springs or sinkholes of fresh, clear water (Figure 7F), which supports the presence of a perched aquifer 5–10m thick that receives its water from the fractured Tuwaiq limestone. However, further investigation of this aquifer is important. The percolating water dissolves the carbonates, which leads to karstification (Figure 6D).

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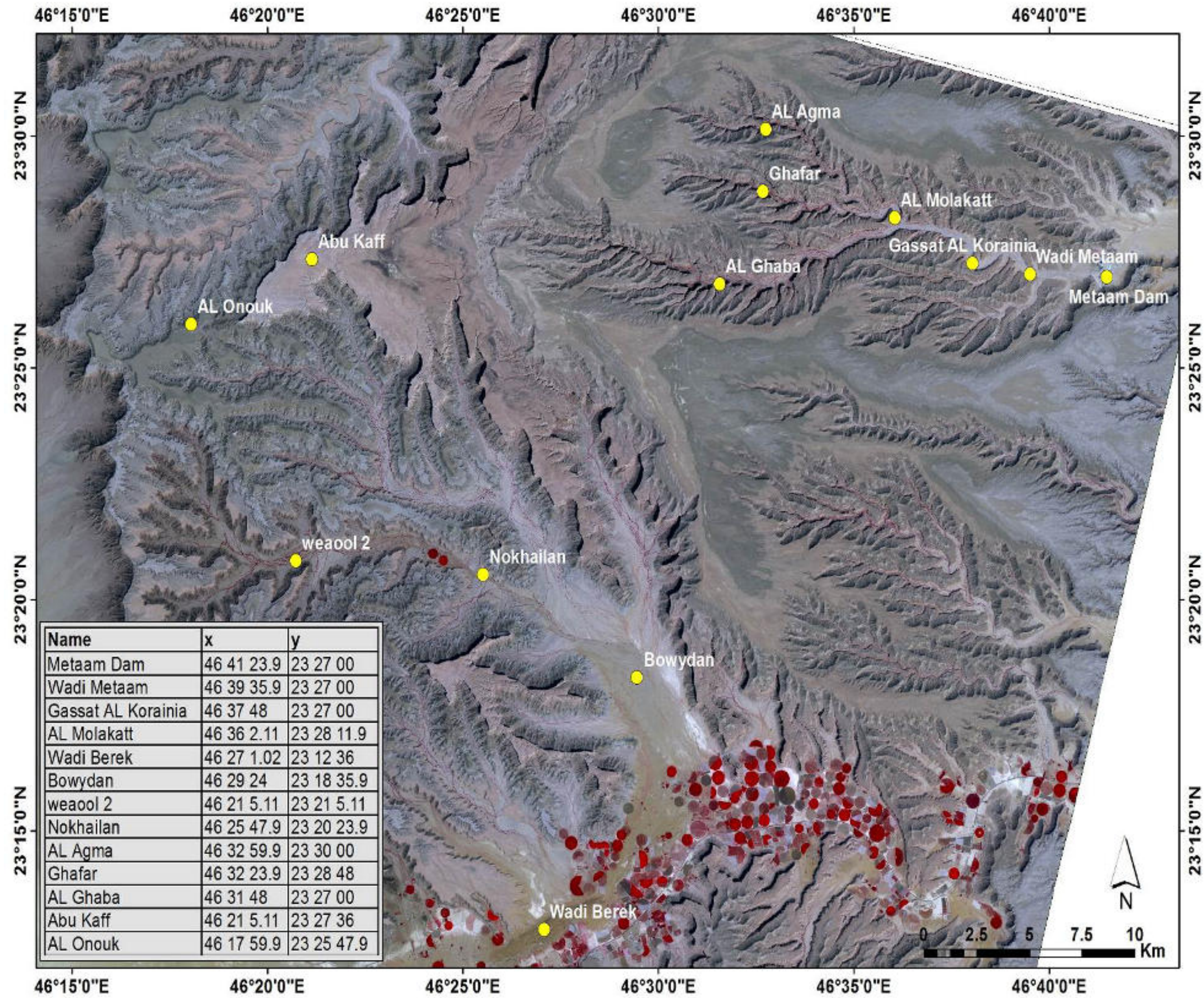

Name	x	y
Metaam Dam	46 41 23.9	23 27 00
Wadi Metaam	46 39 35.9	23 27 00
Gassat AL Korainia	46 37 48	23 27 00
AL Molakatt	46 36 2.11	23 28 11.9
Wadi Berek	46 27 1.02	23 12 36
Bowydan	46 29 24	23 18 35.9
weaool 2	46 21 5.11	23 21 5.11
Nokhailan	46 25 47.9	23 20 23.9
AL Agma	46 32 59.9	23 30 00
Ghafar	46 32 23.9	23 28 48
AL Ghaba	46 31 48	23 27 00
Abu Kaff	46 21 5.11	23 27 36
AL Onouk	46 17 59.9	23 25 47.9

Figure 5. Satellite image showing the main geomorphologic units at Ibex Protectorate southwest of Riyadh, Saudi Arabia.

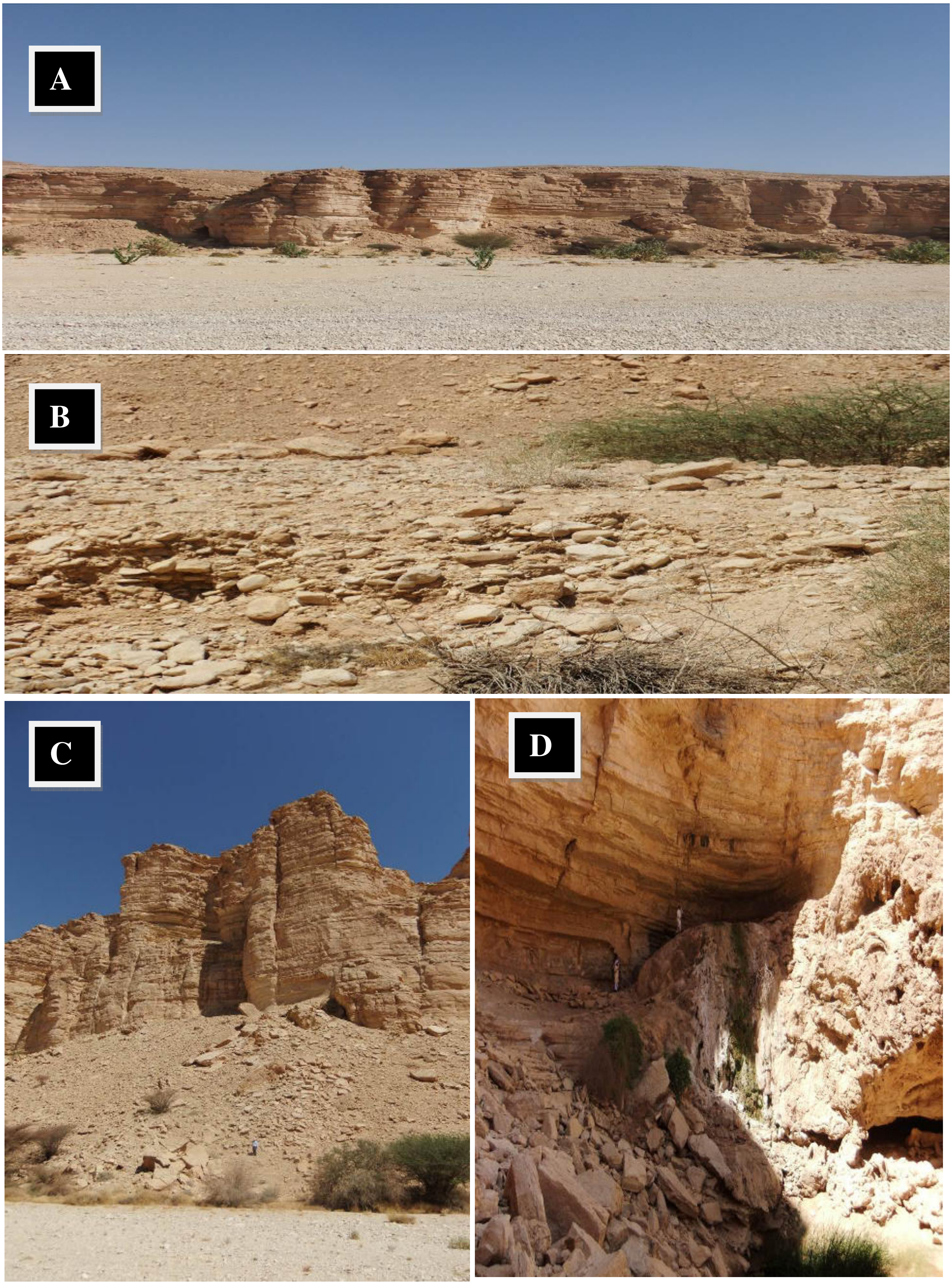

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Figure 6. The geomorphologic units at Wadi Metaam: (A) low-lying land and plant cover inside the wadi; (B) coarse-grained gravel and boulders on slopes that form the talus area suitable for plant growth due to rainwater accumulation; (C) fan-like shape down the escarpment of Tuwaiq Mountain, and (D)

karstification and sinkhole in the fenced area.

3.2 Plant cover

The present study aims to: 1) Update knowledge and understanding of the plant diversity of Wadi Metaam under its harsh conditions and dry climate; 2) Determine the impact of wildlife protection on plant cover, and 3) Compare the natural vegetation cover in the non-protected (open) pastoral areas and the fully protected (fenced) one in Wadi Metaam to assess the change in plant density and determine the relative importance of plant species in both areas. To achieve these aims, several field trips to Wadi Metaam and Tuwaiq Mountain were conducted during different seasons from 2011–2014.

The open pastoral area at Wadi Metam starts from Metaam Dam (23° 27′ 3.6″N and 46° 41 ′ 28.3″E) and ends at the fenced areas (23° 27′ 53.3″N and 46° 33′ 43.8″E). The fenced area reaches to 23° 26′ 43.1″N and 46° 32′ 31.4″E at the Al-Ghaba tributary (Figure 12A). The collected perennial plants listed in Table 2 and illustrated in Figure 7. The preserved plant specimens identified at the herbarium for Science and Technology in Al-Mezahmia, King Abdulaziz City. The collected plants represent four different sites (A, B, C, and D) (Figure 8): Wadi Metaam floor (Figure 6A), the talus (Figure 6B), on slopes of Tuwaiq Mountain (Figure 6C), and at the fenced area (Figure 6D). The density, plant cover, frequency, and relative importance indicators were calculated for each detected plant, either inside the open area (Table 3) or in the fenced one (Table 4).

Table (2): The recorded perennial plants at Wadi Metaam, Ibex Protectorate, Saudi Arabia.

Family	**Species**	**Growth**	**Wadi Metaam (A)**	**Talus (B)**	**Tuwaiq M slopes (C)**	**Fenced (D)**
Mimosaceae	*Acacia gerrardii*	SP	√	√	√	√
	Acacia tortilis	SP	√	√	-	√
	Acacia ehrenbergiana	SP	-	-	√	√
Asteraceae	*Anvillea garcinii*	HP	√	-	√	√
Acanthaceae	*Blepharis ciliaris*	HP	√	√	-	√
Asclepiadaceae	*Calotropis Procera*	SP	√	√	√	√
Cucurbitaceae	*Citrullus colocynhis*	HP	√	√	√	-
	Cucumis prophetarum	HP	√	√	-	-
Chenopodiaceae	*Haloxylon solicomicum*	SP	√	-	-	√
Solanaceae	*Lycium shawii*	SP	√	√	√	√
Asteraceae	*Rhanterium epapposum*	SP	-	-	-	√
Rhamnaceae	*Ziziphus nummularia*	SP	-	-	-	√
Zygophyllaceae	*Zygophyllum migahidi*	SP	√	√	-	√
Poaceae	*Panicum turgidum*	SP	√	√	√	√
Brassicaceae	*Zilla spinosa*	SP	√	√	-	√
Apocynaceae	*Rhazya stricta*	SP	√	√	√	√
Capparaceae	*Capparis sinaica*	SP	-	-	-	√
Zygophyllaceae	*Fagonia bruguieri*	HP	-	√	-	√
Capparaceae	*Cleome amblyocarpa*	HP	-	-	-	√
Convolvulaceae	*Convolvulus oxyphyllus*	SP	-	-	-	√
Boraginacae	*Heliotrapium bacciferum*	HP	-	-	-	√
			13	12	8	19

SP Shrub Perennial HP Herbal Perennial

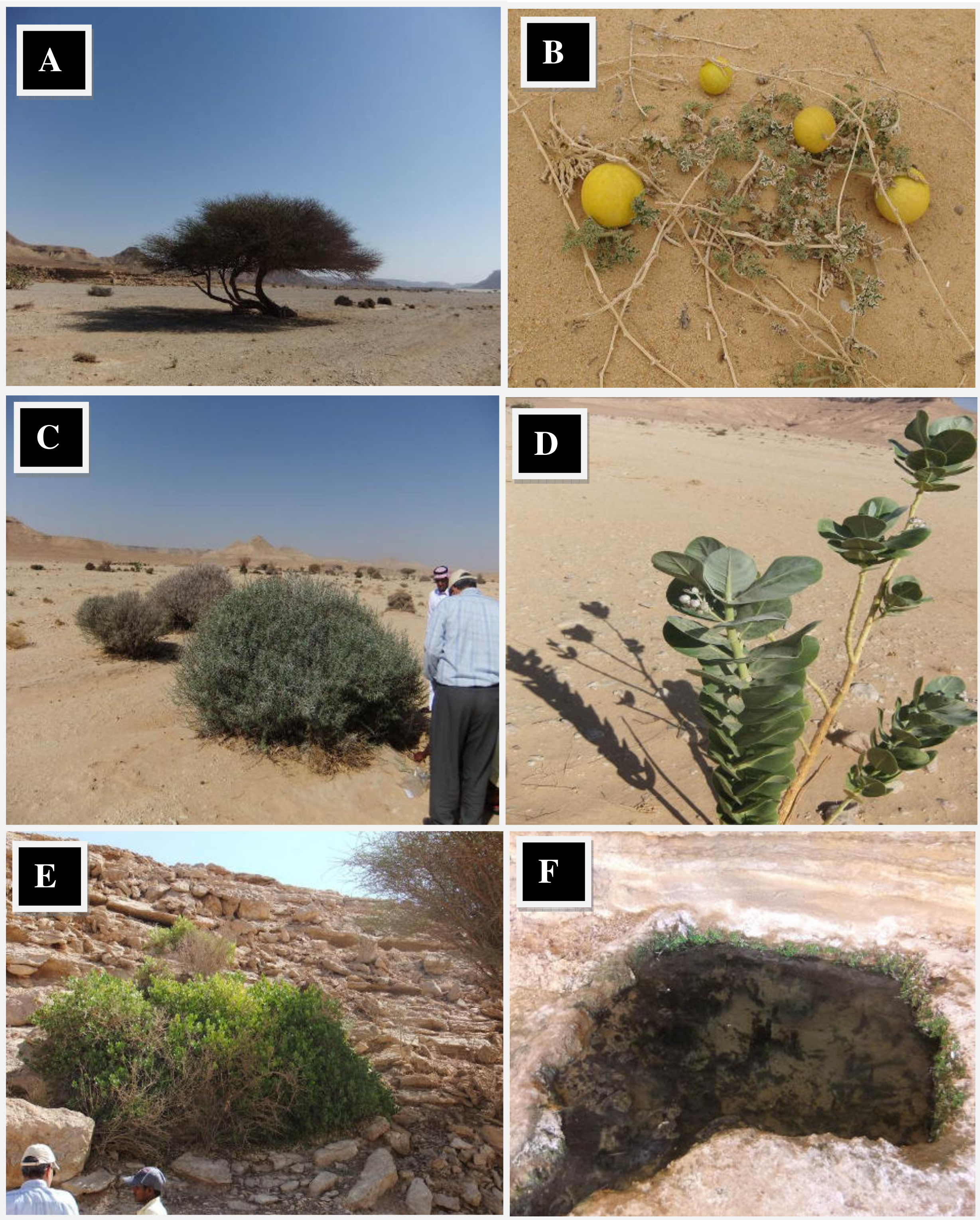
In the present study, 21 perennial plant species identified belonging to 15 families. These are; *Acacia gerrardii, Acacia tortilis,* and *Acacia ehrenbergian*a (Mimosaceae), *Anvillea garcinii* and *Rhanterium epapposum* (Asteraceae), *Blepharis ciliaris* (Acanthaceae), *Calotropis Procera* (Asclepiadaceae), *Citrullus colocynhis* and *Cucumis prophetarum* (Cucurbitaceae), *Haloxylon solicomicum* (Chenopodiaceae), *Lycium shawii* (Solanaceae), *Ziziphus nummularia* (Rhamnaceae), *Zygophyllum migahidi* and *Fagonia bruguieri* (Zygophyllaceae), *Panicum turgidum* (Poaceae), *Zilla spinosa* (Brassicaceae), *Rhazya stricta* (Apocynaceae), *Cleome amblyocarpa and Capparis sinaica* (Capparaceae), *Convolvulus oxyphyllus* (Convolvulaceae), and *Heliotrapium bacciferum* (Boraginacae) (Table 2).

Table (3): Details of plant cover along the fenced area at Wadi Metaam, Ibex Protectorate, Saudi Arabia.

Species	**Density p/area**	**Density %**	**Plant cover p/area**	**Plant cover %**	**Frequency**	**Frequency %**	**Relative importance indicator**
Acacia gerrardii	1,40	2,60	2,87	6,64	12.00	2,60	14,39
Acacia tortilis	6,20	11,52	5,64	13,05	26.00	11,52	35,73
Acacia ehrenbergiana	0,30	0,56	3,20	7,40	6.00	0,56	10,53
Anvillea garcinii	4,40	8,18	2,30	5,33	12.00	8,18	18,66
Blepharis ciliaris	2,40	4,46	0,45	1,05	8.00	4,46	8,94
Calotropis Procera	0,40	0,75	2,85	6,59	4.00	0,75	9,06
Citrullus colocynhis	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cucumis prophetarum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haloxylon solicomicum	6,40	11,89	1,65	3,82	21.00	11,89	24,72
Lycium shawii	4,50	8,36	7,30	16,89	20.00	8,36	33,83
Rhanterium epapposum	4,50	8,37	1,80	4,16	15.00	8,37	18,97
Ziziphus nummularia	3.00	5,58	4,30	9,95	8.00	5,58	18,96
Zygophyllum migahidi	1,00	2,79	1,15	2,66	7.00	2,79	8,45
Panicum turgidum	3,60	6,69	1,65	3,82	20.00	6,69	19,09
Zilla spinosa	5.00	9,29	2,00	4,62	21.00	9,29	22,92
Rhazya stricta	1,50	2,79	2.00	4,62	7.00	2,79	10,41
Capparis sinaica	2,01	3,90	1,05	2,43	14.00	3,90	12,34
Fagonia bruguieri	5,70	10,59	1,36	3,14	22.00	10,59	23,17
Cleome amblyocarpa	0,10	0,18	0,43	0,99	3.00	0,18	2,46
Convolvulus oxyphyllus	0,40	0,75	0,60	1,38	4.00	0,75	3,85
Heliotrapium bacciferum	0,40	0,75	0,63	1,45	3.00	0,75	3,49
Total	53,80	-	43,22	-	233.00	-	

Table (4): Details of plant cover along the open pastoral area at Wadi Metaam, Ibex Protectorate, Saudi Arabia

Species	Density p/area	Density %	Plant cover p/area	Plant cover %	Frequency	Frequency %	Relative importance indicator
Acacia gerrardii	0,08	0,37	1,36	5,41	4.00	1,46	7,24
Acacia tortilis	1,4	6,5	2,86	11,37	24.00	8,76	26,63
Acacia ehrenbergiana	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Anvillea garcinii	0,20	0,93	0,46	1,82	4.00	1,45	4,20
Blepharis ciliaris	0,32	1,48	0,32	1,27	4.00	1,45	4,20
Calotropis Procera	5,40	25,06	5,49	21,83	35.00	12,77	59,66
Citrullus colocynhis	0,20	0,93	0,86	3,42	13.00	4,74	9,09
Cucumis prophetarum	0,04	0,18	0,73	2,90	5.00	1,82	4,90
Haloxylon solicomicum	1,20	5,57	0,46	1,83	16.00	5,84	13,24
Lycium shawii	2,80	12,99	2,70	10,74	12.00	4,38	28,11
Rhanterium epapposum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ziziphus nummularia	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zygophyllum migahidi	2,30	10,67	2,30	9,14	35.00	12,77	32,58
Panicum turgidum	0,65	3,02	0,65	2,58	17.00	6,20	11,80
Zilla spinosa	0,50	2,32	0,50	1,99	17.00	6,20	10,51
Rhazya stricta	3,05	14,15	3,05	12,13	38.00	13,87	40,15
Capparis sinaica	0,68	3,15	0,68	2,70	10.00	3,65	9,50
Fagonia bruguieri	1,08	5,01	1,08	4,29	12.00	4,30	13,60
Cleome amblyocarpa	0,87	4,04	0,87	3,46	19.00	4,93	14,43
Convolvulus oxyphyllus	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heliotrapium bacciferum	0,78	3,62	0,78	3,1	9.00	3,28	10.00
Total	21,55	-	25,15	-	274.00	-	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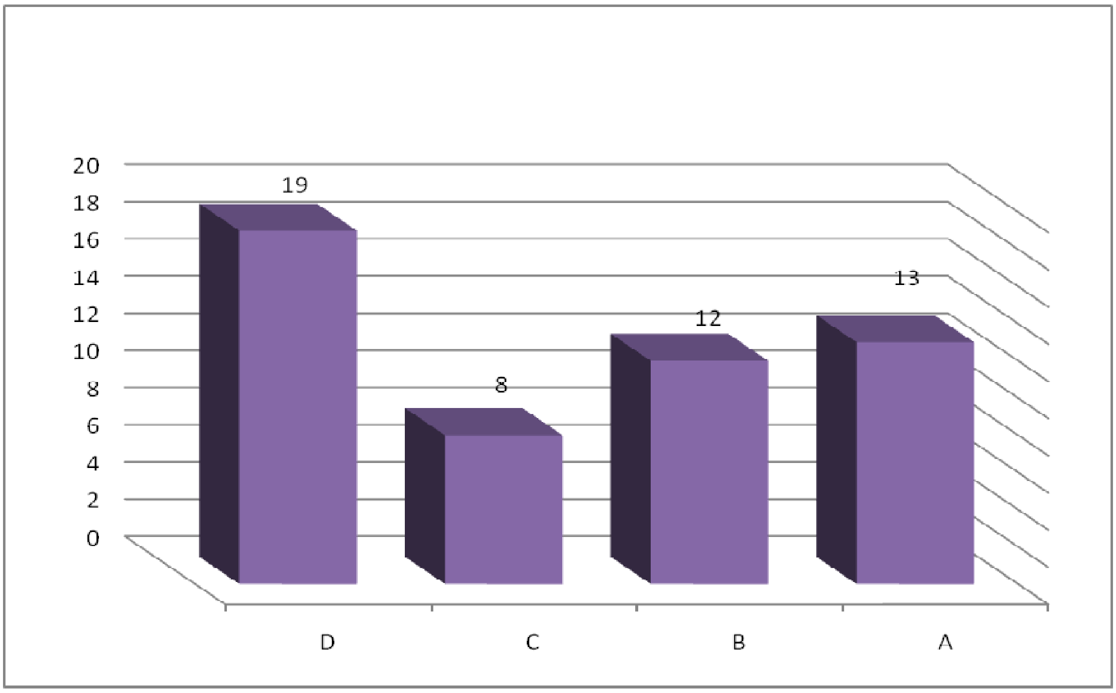


Figure 8. Distribution of the total recorded plants in the studied areas A, B, C, and D shown in Table 2 and Figure 6 (A-D).

The results reflect the impact of protection to increase plant species in general and plant species with nutritional value in particular. The results show that the palatable plants (pastoral) such as *Acacia tortilis, Lycium shawii, Haoxylon salicomicum,* and *Panicum rungidum* have higher density, plant cover, and frequency in the fenced area (Table 3, Figure 9) when compared with the open area (Table 4, Figure 10). The values of the relative importance indicators for these plants are 35.73%, 24.72%, 19.09%, and 33.83%, respectively, as compared with 26.63%, 28.11%, 13.24%, and 11.8% in the open area (Figures 11). On the other hand, unpalatable species such as *Calotropis procena, Rhazya stricta,* and *Zygophylum migahidi* have a higher density and relative importance in the open area as compared with the fenced area (Figure 11). The recorded importance values for these plants are 59.66%, 40.15%, and 32.58%, respectively, in the open area, as compared with 9.06%, 10.41%, and 8.45% in the fenced area. This emphasizes the impact of protection on the homogeneity and quantitative and qualitative characteristics of vegetation cover; protection allows for a greater opportunity for plant growth and reproduction.

Al-Khamis *et al.* (2012) studied the perennial plants of the Ibex Protectorate and recorded six major perennial plant communities. *Haloxylon salicornicum* was the major community and had a relative importance of 140.4%, followed by *Rhazya stricta* (115.6%), *Ziziphus nummularia* (115%), *Acacia tortilis* (113.7%), *Rhanterium epapposum* (109.7%), and *Calotropis procera* (102.8%). In addition to the major plant communities, 62 perennial species, representing 34 families, recorded in Ibex Protectorate. The largest family was *Poaceae,* which was represented by six species, followed by *Mimosaceae* (five species), *Capparaceae* (four species), *Asteraceae* (three species), *Lamiaceae* (three species), *Rhamnaceae* (three species), *Zygophyllaceae* (three species), *Boraginaceae* (two species), *Brassicaceae* (two species), *Cucurbitaceae* (two species), *Scrophulariaceae* (two species), and *Urticaceae* (two species).

The National Commission for Wildlife Conservation and Development (NCWCD) was established in 1406 (H) and has enacted legislation to control grazing, wood gathering, and hunting in the protected areas of Saudi Arabia. However, its efforts have not been successful in putting an end to uncontrolled grazing, tree felling, and hunting in protected areas. This is due to the non-enforcement of the ban on hunting, which considered a local tradition, freedom of trade in both allowed and non-allowed animals, and people's low levels of awareness about the rules and regulations of hunting, grazing, and tree felling. In addition, new human activities including camping and picnicking with concurrent heating and grilling.

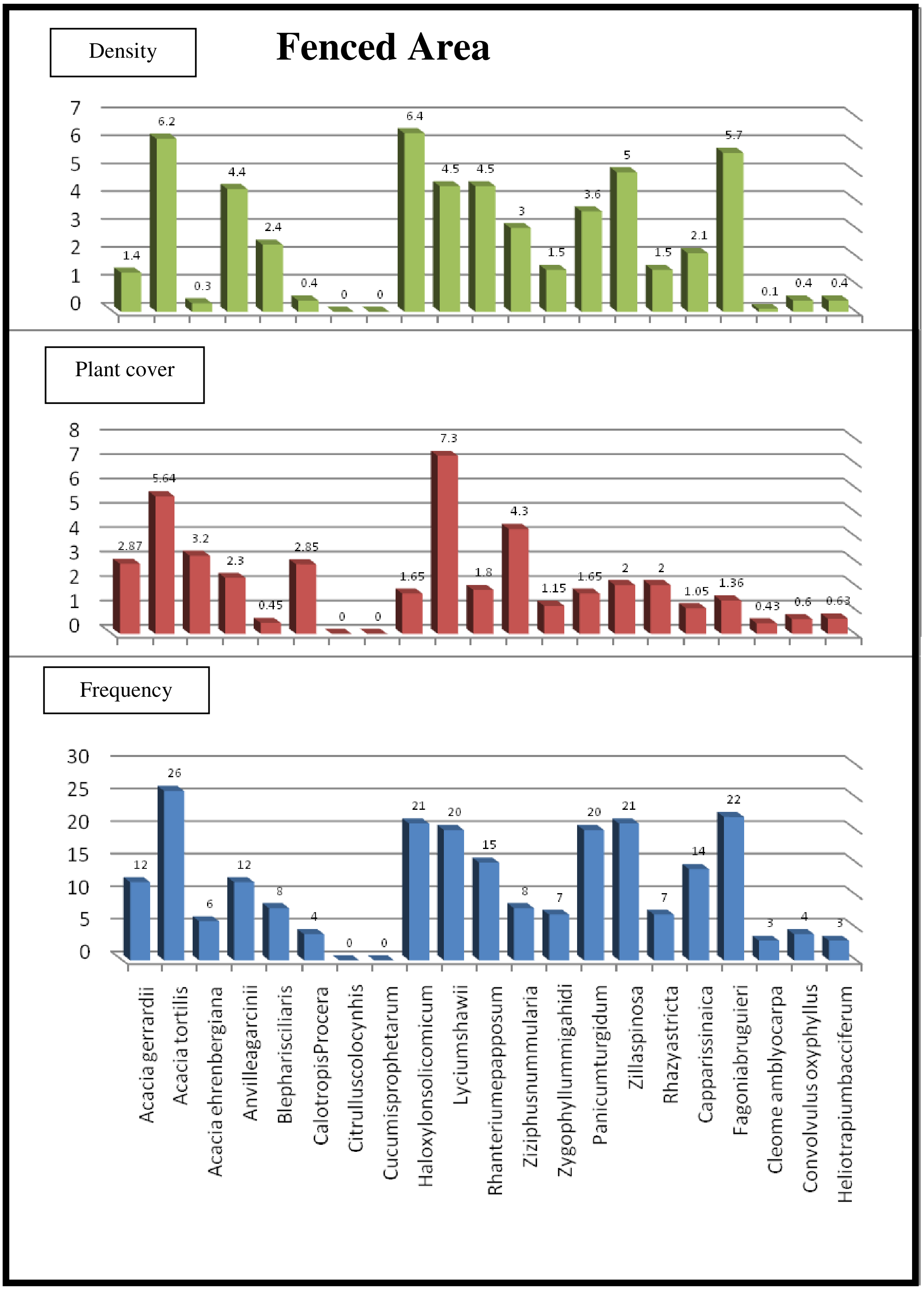


Figure 9. Density, plant cover, and frequency distributions of the plants detected in the fenced area of Wadi Metaam, Ibex Protectorate, Saudi Arabia.

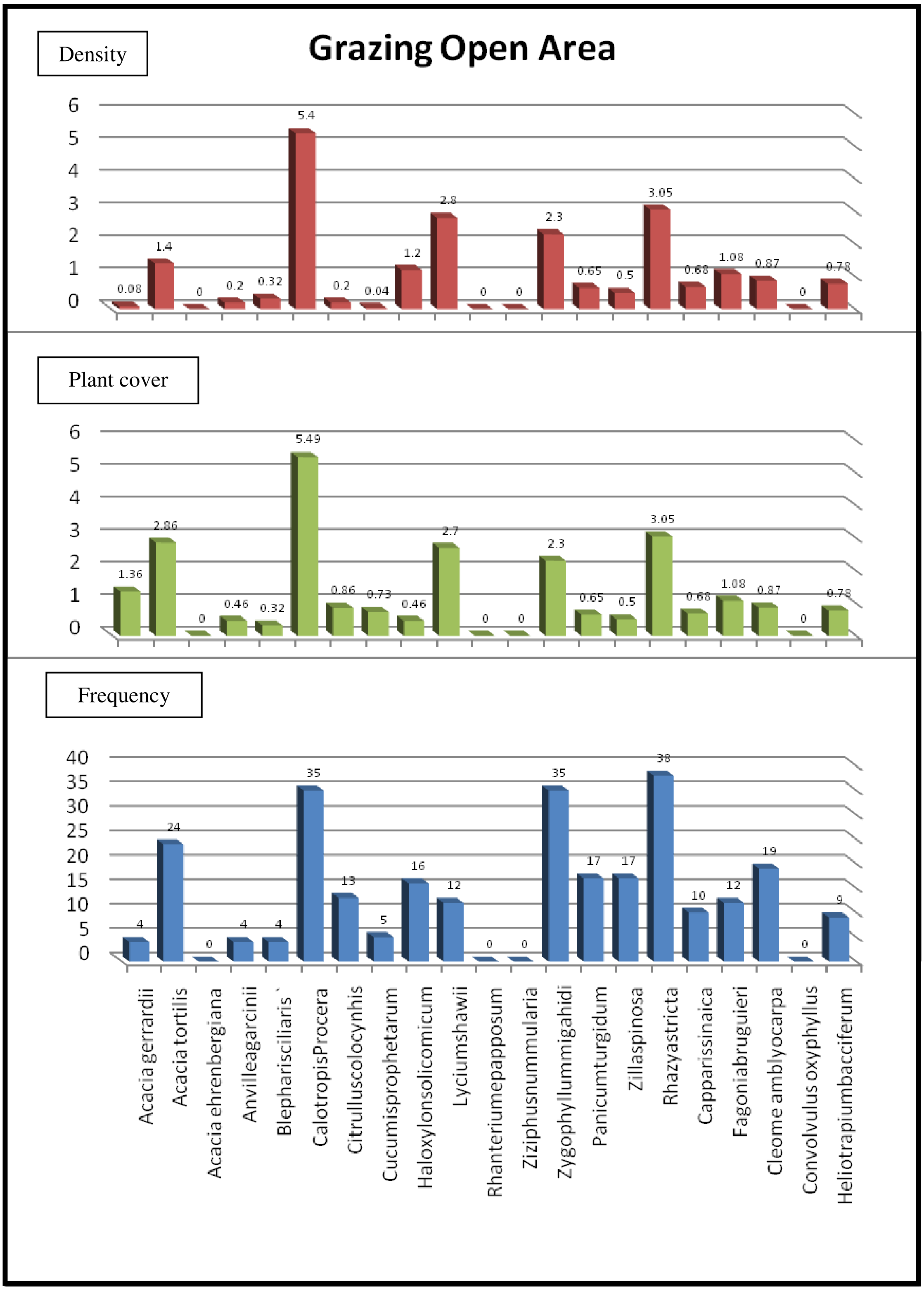


Figure 10. Density, plant cover, and frequency distributions of the plants detected in the open area of Wadi Metaam, Ibex Protectorate, Saudi Arabia.

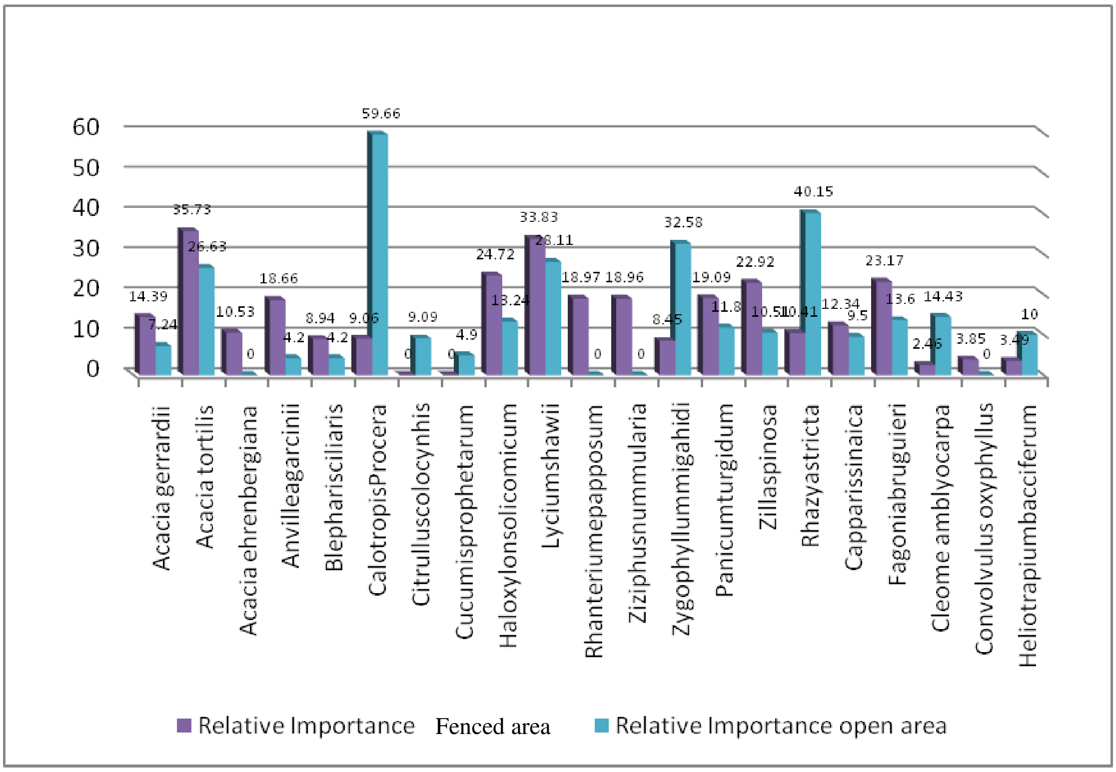


Figure 11. Correlation of relative importance indicators for the plants studied in both the open and fenced areas of Wadi Metaam, Ibex Protectorate, Saudi Arabia.

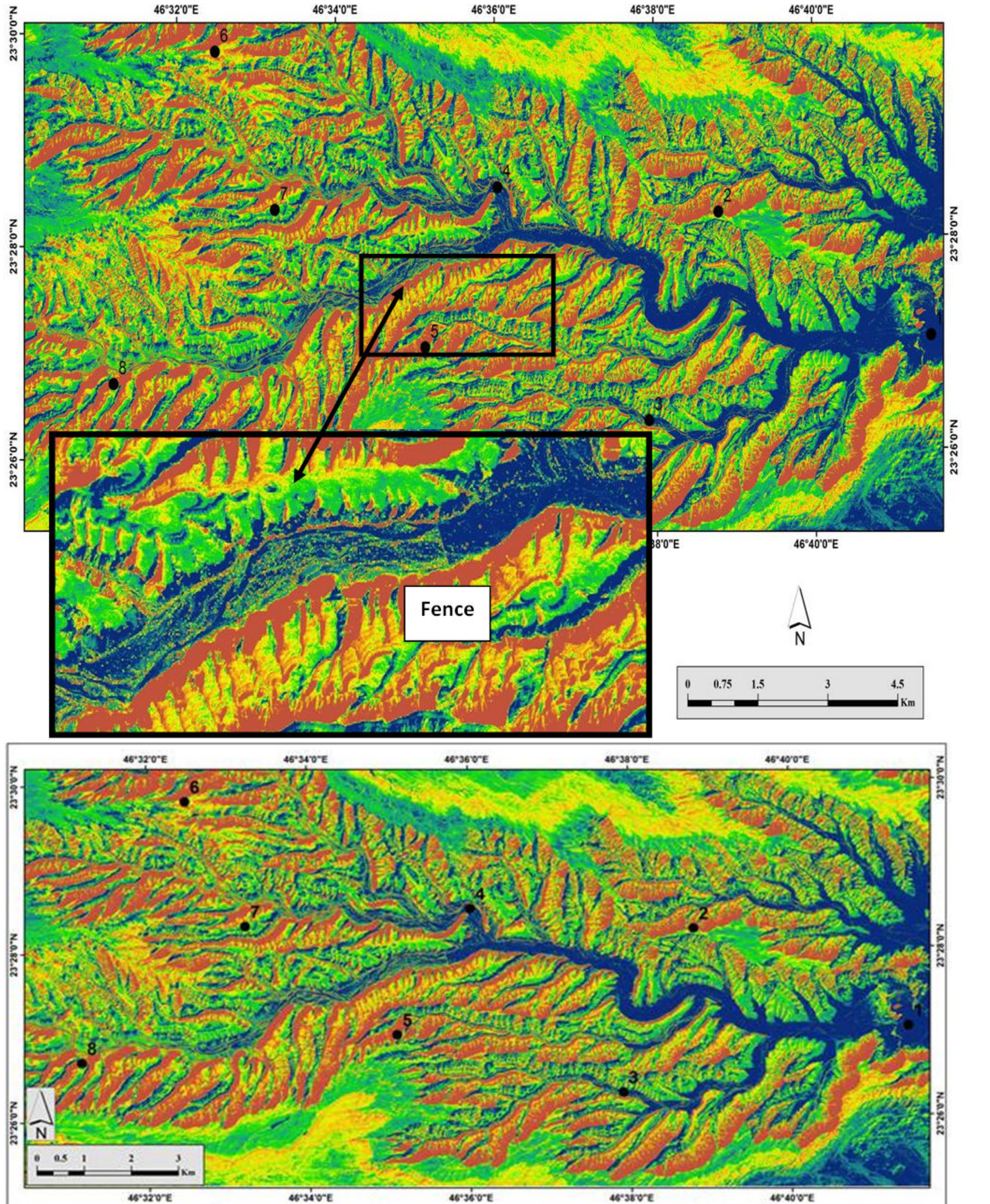
In their study on the role of knowledge on people's attitudes toward and behaviours in the Ibex Protectorate, AL-Shayaa *et al.* (2007) studied 400 people, randomly chosen from the population of those residing around the Ibex Protectorate in the towns of Haotat Bany Tamim, Al-Helwa, and Al-Hareek. The study indicated that the young generation's level of knowledge regarding the importance of wildlife is low. The main reason for this is the lack of educational programs that deal with the importance of wildlife conservation. The study also showed that the respondents have good knowledge of the Ibex Protectorate's location and the patrolling system used to protect it, while their knowledge about the plant and animal life in the protectorate is limited. The respondents perceived that the enforcement of punishment is the only way to put an end to illegal grazing and hunting in the protectorate.

3.3 Remote sensing applications

The image classification techniques in the present study reflect two general subdivisions: unsupervised and supervised classification. The unsupervised classification technique (Figure 12A) was applied to the satellite data for the study area. An arbitrary 15 classes were selected to represent all types of features. Figure 12A also indicates a clear difference in plant cover on either side of the fence built to prevent pastoral grazing. The supervised classification technique requires the analyst to specify the types of ground cover for a given area by using training data. Field verification for the eight sites detected on the unsupervised classification map (Figure 12A) led to grouping the unsupervised 15 classes into four major supervised classes (Figure 12B) based on a digital elevation model. These are Wadi Metaam and its tributaries, which represent classes 12–15 (blue), the Tuwaiq Escarpment, which represents classes 8–11 (green), Tuwaiq Plateau, which represents classes 5–7 (yellow), and finally, the talus slopes along Wadi Metaam and its tributaries, which represent classes 1–4 (orange).

The digital elevation model suggests a change in elevation from the watershed area and drainage divides at Al-Onouk to the west (1125–990 m) and at Abu Kaff (890–800 m), which then slope down to Wadi Metaam at 540–600 m (Figure 5). Due to this difference in topography and eastward slopes, while Wadi Metaam receives only 28 mm/yr of rainfall, the watershed area at Al-Onouk receives 100–150 mm/yr, as previously mentioned in El-Shayaa *et al.* (2007).

The future research prospects should direct to groundwater potentialities of the whole area. The rains that carved the wadi and tributaries for more than 700 m in the limestone plateau may suggest high potentialities of ground water Evidences of such great potentialities are offered. The development of the plant diversity and revision of roles related to environmental protection as well as spreading the culture of preserving wildlife from traditional unprompted and prohibited habits should applied and subjected to intensive research.



Supervised Classes	Geomorphic units
1-4	Talus slopes along Wadi Metaam and its tributaries
5-7	Tuwaiq Plateau
8-11	Tuwaiq slope scarp
12-15	Wadi Metaam and its tributaries

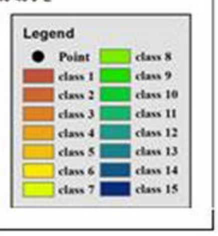


Figure 12 (A) Unsupervised classification of satellite images of Wadi Metaam and its tributaries showing the arbitrary classes and the difference in plant cover and density along the fence in Wadi Metaam; (B) supervised classification into four major classes based on DEM and major geomorphic units.

4. Conclusions

The present study is a geo-environmental study on Wadi Metaam and its tributaries in the Ibex Protectorate, Saudi Arabia. The study demonstrates that Wadi Metaam was excavated in Tuwaiq Escarpment (Mountain) in the eastern periphery of the Tuwaiq Plateau. The latter extends for more than 600 km and is called the Najd Plateau. It is made of limestone from the Middle-Upper Jurassic epoch; during that time, the climate was humid enough to excavate Wadi Metaam and its tributaries for more than 400 m through the escarpment in a general west to east trend. The drainage patterns of Wadi Metaam and its tributaries reflect a dendritic pattern. The drainage basin is located at the highest mountain at Al-Onouk at an elevation of 1125 m and slopes down along Abu Kaff toward the three tributaries of Wadi Al-Ghaba (4th order), Wadi Ghafar (4th order), and Wadi Al-Agma (3rd order). These are connected at Al-Molakatt to form the major Wadi Metaam.

While the watershed area receives about 150 mm/yr of rainwater at Al-Ounouk, the situation is completely different at Wadi Metaam, where only 28 mm/yr of rainwater is received. In Saudi Arabia's ambitious plan to secure water, the government has established a concrete dam 903 m long and 15 m high to store up to 10 million m3 of rainwater. However, the dam has never been filled to more than half of its capacity. These rains enrich Wadi Metaam with a wide diversity of shrubs and herbal perennial plants and sculpt its geomorphic features, which include karstfication and sinkholes.

The density and plant cover in the fenced area at Wadi Metaam are 53.80p/area and 43.22p/area, respectively, and decrease to 21.55p/area and 25.15p/area in the open area. The palatable plants have higher density, plant cover, and frequency in the fenced when compared with the open one. The values of the relative importance indicators for these plants higher compared with that of the open area. On the other hand, unpalatable have a higher density and relative importance in the open area as compared with the fenced area. This emphasizes the impact of protection on the homogeneity and quantitative and qualitative characteristics of vegetation cover; protection allows for a greater opportunity for plant growth and reproduction.

The enforcement of laws of conservations of wildlife and increasing the awareness of peoples with their unacceptable behaviours and traditions toward wildlife conservation are very important tasks

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References

Al-Asad, M. (2004), "Wadi Hanifa Development Plan. Riyadh, Saudi Arabia". On Site Review Reports, 26 pp.

Al-Husseini, M., Matthews, R. K. & Mattner, J., (2006), "Stratigraphic Note: Orbital-forcing calibration of the Late Jurassic (Oxfordian-early Kimmeridgian) Hanifa Formation, Saudi Arabia". GeoArabia, **11** (1), 145–149.

Al-Huquial, A. & Al-Turki T. A., (2006), "Ecological studies on the natural vegetation at Sabkha Al-Aushaiza in Al-Gassim region, Saudi Arabia". Saudi Journal of Biological Science, **13**, 79–110.

Al-Khamis, H. H., Al-Hemaid, F. M. & Ibrahim A. S., (2012), Diversity of perennial plants at Ibex Reserve in Saudi Arabia. The Journal of Animal & Plant Sciences, **22**(2), 484–492.

Al-Motairi M., (2004), " The Diversity of Fauna in the Ibex Reserve". M.Sc. thesis, Fac. Sci., King Saud University, 389 pp.

AL-Shayaa, M. S., El Hag, E. A. & Muneer, S. E., (2007), "The role of people's knowledge and attitudes in conservation of wildlife in the natural reservations: A case study of the ibex reservation in Al-riyadh region, Saudi Arabia. Saudi ". Journal of Biological Sciences, **14** (1), 123–135. doi: ISSN 1319-562 X

Al-Turki, T. A. & Al-Olayan H. A., (2003), "Contribution to the flora of Saudi Arabia: Hail region". Saudi Journal of Biological Science, **10**, 190–222.

Basyoni, M.H. & Khalil, M., (2013), "An overview of the diagenesis of the Upper Jurassic carbonates of Jubaila and Hanifa formations, Central Saudi Arabia". Arab Journal of Geosciences, **6**, 557–572.

Carrigan W. J., Cole G. A., Colling E. L., & Jones P. J., (1995), "Geochemistry of the Upper JurassicTuwaiq Mountain and Hanifa Formation petroleum source rocks of eastern Saudi Arabia". 67-87. In: B. Katz (Ed.), Petroleum Source Rocks, Springer Verlag, 1–327.

Chaudhary, S. A., (2000), "Flora of the Kingdom of Saudi Arabia". National Agriculture and Water Research Center. Riyadh (Saudi Arabia).

El-Bana, M. I. & Al-Mathnani A., (2009), Vegetation–soil relationships in the Wadi Al-Hayat Area of the Libyan Sahara. Austoralian Journal of Basic and Applied Science, **3**(2), 740–747.

El-Deen, H. M., (2005), "Population Ecology of Rhazya stricta Decne in Western Saudi Arabia". International Journal of Agriculture Biology, **7**(6), 932–938.

El-Ghanim, W. M. & Hassan, T. M., (2010), "Floristic composition and vegetation analysis in Hail region north of central Saudi Arabia". Saudi Journal of Biological Sciences, 17, 119–128.

Fahmy, A. G. & Hassan L. M., (2005), "Plant diversity of wadi el Ghayl, Aseer Mountains, Saudi Arabia". Egypt Journal Desert Research, 55, 39–52.

Foody G (2003) Remote sensing of tropical forest environments: towards the monitoring of environmental resources for sustainable development. Internat. J. Remote Sensing 24 4035–4046.

Green, E.P., Mumby, P.J., Edwards, A.J. & Clarck, C.D., (2000), "Remote sensing handbook for tropical coastal management". Coastal Management Sourcebook, 3, UNESCO, Paris.

Herold M, Scepan J, Clarke KC (2002) The use of remote sensing and landscape metrics to describe structures and changes in urban land uses. Environment and Planning, 34 1443–1458.

Hughes, G. W., (2006), "Biofacies and palaeoenvironments of the Jurassic Shaqra Group of Saudi Arabia". Volumina Jurassica, 4, 89–90.

Lillesand T. M., Kiefer R. W. & Chipman, J. W., (2004), "Remote Sensing and Image Interpretation". John Wiley & Sons

Manivit, J., Le Nindre, Y.M. & Vaslet D., (1990), "Le Jurassique d'Arabie Centrale". Document du Bureau de Recherches Géologiques et Minières no. 194, Histoire Géologique de la Bordure Occidentale de la Plate-forme Arab, 4.

Migahid, A. M. & Hammuda, M., (1974), Flora of Saudi Arabia. (2nd ed.), Riyadh (Saudi Arabia).

Powers, R. W., Ramirez, l. F., Redmond, C. D. & Elberg, E. L. jr., (1966), "Geology of the Arabian Peninsula". Sedimentary Geology of Saudi Arabia. United States Government Printing Office. Washington, 134 pp.

Powers, R. W., (1968), "Arabie Saoudite. Lexique Stratigraphique International, Asie, III.

Steineke, M. & Bramkamp, R. A., (1952), "Mesozoic rocks of eastern Saudi Arabia [abs.]": American Association of Petroleum Geologists Bulletin, 36 (5). 909pp.

Steineke M, Bramkamp R. A. & Sander, N. J., (1958), "Stratigraphic relations of Arabian Jurassic oil. Habitat of Oil," 1294–1329. American Association of Petroleum Geologists.

Vincent, P., (2008), "Saudi Arabia: An Environmental Overview. Taylor & Francis, London". 332 pp.

Yuan, F., Sawaya, K.E., Loeffelholz, B.C., Bauer, M.E. Land cover classification and change analysis of the Twin Cities (Minnesota) Metropolitan Area by multitemporal Landsat remote sensing. Remote Sensing of Environment 98 317–328.

Zahran, M., (1982), "Vegetation Types of Saudi Arabia". King Abdel Aziz University Press, Jeddah, (Saudi Arabia).