

Vegetation-Soil Relationships in Wadi El-Rayan Protected Area, Western Desert, Egypt

Mohamed S. Abbas¹, Abdelwahab A. Afefe^{2,*}, El-Bialy E. Hatab² And El-Sayed I. Gaber¹

¹Natural Resources Department, Institute of African Research and Studies, Cairo University, Cairo, Egypt

²Nature Conservation Sector, Egyptian Environmental Affairs Agency, Egypt

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Abstract

The present study provides an analysis of the soil and vegetation composition at 10 sites in Wadi El Rayan Protected Area and concentrates on the environmental factors that affect plant species distribution. A total of 17 vascular plant species belonging to 13 botanical families was recorded. Poaceae, Chenopodiaceae, and Zygophyllaceae were the largest families identified. Chorological analysis revealed that 47% of the studied species are Pluri-regional, 41% are Bi-regional and 12% are Mono-regional. The recorded species extend their distribution all over the Saharo-Arabian (33%) followed by Irano-Turanian (24%), Mediterranean (22%), Palaeotropical (8%), Sudano-Zambezian (5%), Neotropical (5%), and Euro-Siberian (3%). The life-form spectrum revealed that the phanerophytes (35%) and geophytes helophytes (23%) are the most frequent, followed by chamaephytes (18%), therophytes (12%), hemicryptophytes (6%), and helophytes (6%). The dominant species were *Phragmites australis*, *Tamarix nilotica* and *Zygophyllum album*; while the co-dominant species were *Juncus rigidus*, *Nitraria retusa*, *Alhagi graecorum*, *Typha domingensis*, *Zygophyllum coccineum* and *Eucalyptus camaldulensis*. Variation in species diversity among different locations were evident, the Northeast of the Lower Lake(9 species), followed by the Southwest of the Lower Lake and the Northeast of the Upper Lake(6 species each) showed highest species richness, while the Southeast of the Lower Lake showed the lowest recorded species richness (one species). Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA) Ordination techniques were used to examine the relationship between the vegetation and soil parameters; pH, electric conductivity, CaCO₃, organic matter and relative concentrations of cations.CCA analysis showed positive correlations of species and sites along the most important ecological gradients. Both ordination techniques clearly indicated the importance of these ecological factors on the distribution of the vegetation pattern in the area.

Keywords: Vegetation, Plant distribution, Wadi El Rayan, Soil, Desert, Egypt, Protected Area.

1. Introduction

Wadi El Rayan is located 140 km southwest of Cairo in the Fayoum Governorate on the Western Desert of Egypt. Its total area is 1759 Km² and it is classified by the Egyptian Environmental Affairs Agency (EEAA) as a managed Protected Area for the conservation of wild species and the sustainable utilization of natural resources (Nels, 1995). Although the Western Desert is characterized, in general, by poor plant diversity and cover (Boulos, 1975), Wadi El Rayan is rich with fauna and flora diversity (Osborn and Helmy, 1980; Saleh, 1987; Saleh *et al.*, 1988a) and it also has unique geological and geomorphological features (Said, 1962). In 2011, Wadi El Rayan was recognized by the International Union for Conservation of Nature (IUCN) as one of the 20 Important Plant Areas (IPAs) in Egypt (Radford *et al.*, 2011) and it was nominated by Egypt in 2012 as a

wetland area of the Ramsar Convention (EEAA, 2012). The area is hyper-arid with low precipitation (mean annual precipitation of 10.1 mm of irregular rainfall) and hot summer (temperature is as low as 1.2°C in winter and as high as 48.4°C in summer) (Ayyad and Ghabbour, 1986; Saleh *et al.*, 1988b). Wadi El Rayan depression has been used as a water reservoir for storing excess agricultural drainage water above the capacity of Lake Qarun. Two man-made lakes joined by a connecting channel, were constructed at two different levels (Zahran, 1970). Throughout time, Wadi El Rayan lakes have created a variety of habitats surrounding it, although the adverse consequences of their creation on the ecology of the area cannot be ignored (Saleh, 1987; Saleh *et al.*, 1988a, b). The area became increasingly inhabited by people from adjacent villages and consequently a rapid economic development was established (IUCN, 1998). By February 2000, around 4840 feddans of reclaimed land were established. Irrigation water of these fields is

* Corresponding author. e-mail: abdoafefe@hotmail.com.

pumped from the upper lake through pipeline running towards the west, entering the project area from the northwest and drains into the lower lake from southwest following the natural landscape gradient (Abdou, 2006).

Throughout the recent century, many researchers attempted to determine the factors controlling the plant species distribution (Glenn *et al.*, 2002; He *et al.*, 2007). The spatial distribution of plant species and communities in a small area of desert ecosystems is related to heterogeneous topography and landform pattern (Parker, 1991). The physiographic and edaphic factors play a paramount role in the distribution of plant communities in the Western Desert of Egypt (Ayyad, 1976). The distribution, pattern and abundance of plant species and communities in desert environments have been most often related to three groups of factors: rainfall (Kadmon and Danin, 1999), soil chemistry (Abd El-Ghani, 1998; Abd El-Ghani and Amer, 2003) and human impact including overgrazing and plant overcollection (Kassas, 1962). The distribution of species in saline and marshy habitat in many arid regions has been a subject of study by numerous authors (Kassas, 1957; Ungar, 1968; Maryam *et al.*, 1995). The objective of the present study is to study the vegetation composition of Wadi El Rayan and to portray the relationship between the vegetation and the prevailing soil factors at the coastal zones of the lakes located in the study area.

2. Materials and Methods

2.1. Vegetation Sampling

Quantitative surveys of the vegetation in the study area were carried out between March and September 2013. Ten stands in the surrounding area of the lakes, including the upper and lower lakes and the connecting channel, were carefully identified ensuring a reasonable degree of physiographic and physiognomic homogeneity of habitat and vegetation. Also, care was taken to ensure a reasonable degree of physiographic and physiognomic homogeneity of both habitat and vegetation (Figure 1). At each stand, a total of five random quadrates were sampled (each of 10m × 10m; 50 quadrates in total), and a floristic list and count were recorded to determine flora density. Species richness was also determined according to Barbour *et al.* (1987).

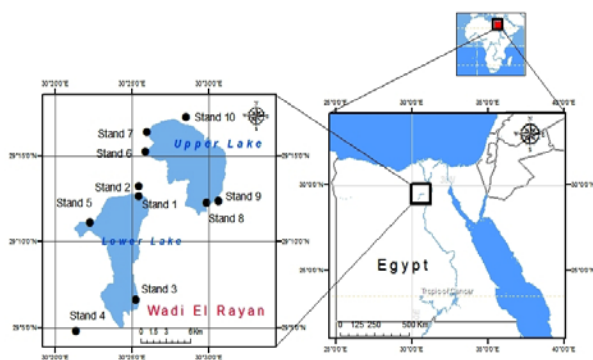


Figure 1. Egypt map focusing on Wadi El-Rayan and study stands

2.2. Soil Analysis

Surface soil samples (at depth of 25 cm, excluding the surface crust) were randomly collected at different stands to determine their physical and chemical characteristics.

Physical analysis: the soil texture was determined using a series of sieves: Soil samples were air-dried and passed manually through a 2-mm sieve to evaluate the gravel percentage. Particle size analysis was accomplished according to Piper (1950) to calculate the percentages of sand, silt, and clay and the classification of the soil texture type was accomplished according to the USDA soil texture triangle (USDA, 1993).

Chemical analysis: Calcium carbonate was measured by titration against 1.0 N HCl following Allen *et al.* (1976). Oxidizable organic carbon (as an indication of the total organic matter content) was measured according to Black (1965). Soil reaction (pH value), electrical conductivity, sulphates and chlorides were measured according to Jackson (1967). Bicarbonate was determined by titration using 0.1 N HCl (Allen *et al.*, 1976). Extractable cations (Ca⁺⁺ and Mg⁺⁺) were determined (meq/L) by titration following Richard (1954), while, sodium and potassium ions (meq/L) were measured from air-dried soil using ammonium acetate solution at pH=7 (Allen *et al.*, 1976).

2.3. Data Analysis

A floristic data; presence/absence data matrix of 10 stands and 17 species was applied for the classification by cluster analysis with the Community Analysis Package version (1.2) (Henderson and Seaby, 1999) using a Squared Euclidean Distance Dissimilarity Matrix with minimum variance (Ward's method) as the agglomeration criterion.

For vegetation classification, TWINSpan (Two-Way Indicator Species Analysis; Hill, 1979) was applied using the Community Analysis Package software and the analysis was based on the Importance Values (IV) of the species. The diversity indices (Alpha diversity) were calculated at each site (Harper, 1999).

The vegetation and environmental factors were analyzed using ordination techniques. Classification (Siebert *et al.*, 2002) and ordination (Pavluet *et al.*, 2003) are two possible ways to obtain results from multivariate data analysis.

All ordinations were performed using the CANOCO program (version 4.5) (TerBraak and Šmilauer, 2002; Hejmanová-Nežerková and Hejman, 2006). Detrended Correspondence Analysis (DCA) was performed to detect the length of the environmental gradient. After DCA, Canonical Correspondence Analysis (CCA) was performed because the dataset was relatively heterogeneous and, therefore, the length of ordination axes in DCA was relatively long (Lepš and Šmilauer, 2003).

3. Results

3.1. Floristic Relations

In total, 17 plant species representing 13 families were identified throughout the surveys. The largest represented families were Poaceae (with three species), followed by Chenopodiaceae, and Zygophyllaceae (with two species for each) (Table 1). The life-form spectrum was dominated by phanerophytes (35%) and geophytes helophytes (23%), followed by chamaephytes (18%), therophytes (12%), hemicryptophytes (6%), and helophytes (6%) (Table 1).

Results of the chorological analysis (Table 2) show that the majority of the recorded species belong to the Saharo-Arabian chorotype (12 species; 33 %), followed by Irano-Turanian region (9 species / 24 %), Mediterranean region (8 species; 22 %), Palaeotropical (3 species; 8 %), Sudano-Zambezian (2 species; 5%), Neotropical (2 species; 5 %), and Euro-Siberian (1 species; 3 %). The relation between the frequencies of the recorded species and the number of the global phytogeographical regions show that the recorded species can be classified into 8 pluri-regional, 7 bi-regional and 2 mono-regional. Dominant species were *P. australis*, *T. nilotica* and *Z. album*, whereas the co-dominant species were *J. rigidus*, *N. retusa*, *A. graecorum*, *T. domingensis*, *Z. coccineum* and *E. camaldulensis*.

Variation in species richness was observed at different sites: Highest at Northeast of the Lower Lake (9 species), followed by the Southwest of the Lower Lake and the Northeast of the Upper Lake (6 species each); while the Southeast of the Lower Lake showed the lowest species richness (1 species) (Table 3).

Examination of more detailed diversity indices enhanced the exploration of diversity in Wadi El Rayan. Table 3 shows different diversity indices along different stands. Stand 3 has the highest dominance value (=1) followed by stand 7 (=0.999). In contrary, the lowest Simpson's index value was recorded at stand 3 (=0) and highest at stand 4 (=0.574). Similarly, the highest Shannon's diversity index value was at stand 1 (=1.135) and lowest at stand 3(=0). The highest Buzas and Gibson's evenness index value was at stand 3(=1) and the lowest at stand 9 (=0.208). The highest Brillouin's index value was at stand 1 (=1.120) and the lowest at stand 3(=0). The highest Menhinick's richness index value was recorded at stand 4 (=0.570) and the lowest at stand 10 (0.012). Meanwhile, the highest Margalef's richness index value was recorded in stand 1 (=1.118) and the lowest at stand 3 (=0). Also, the highest equitability value was recorded at stand 5 (evenness index = 0.845) and the lowest value at stand 3 (=0). However, the highest Fisher's alpha index value was recorded at stand 4 (=1.359) and the lowest at stand 3 (=0.164). Berger-Parker dominance was the highest at stand 3 (=1), and the highest value of Chao1 index was recorded at stand 1 (=9).

The spatial distribution of some species showed wide ecological ranges; for example:

- *T. nilotica* and *P. australis* were commonly found around the two lakes.
- *J. rigidus* was distributed around the two lakes, with less representation around the Lower Lake (not recorded on its southern edge).
- *A. graecorum* was distributed at the edges of the Connecting Channel, northeast of the Lower Lake; southwest and northeast of the Upper Lake.
- *P. dactylifera* was sparse distributed around the two lakes.
- *I. cylindrica* and *P. dioscoridis* were distributed at the edges of the Connecting Channel and at the northeastern part of the Lower Lake.

Table 1. Recorded species, their families and life form at Wadi El Rayan.

No.	Species	Family	Life form
1	<i>Arthrocnemum macrostachyum</i> (Moric.)k. Koch	Chenopodiaceae	Chamaephytes
2	<i>Chenopodium murale</i> L.	Chenopodiaceae	Therophytes
3	<i>Pluchea dioscoridis</i> (L.)DC.	Compositae (Asteraceae)	Phanerophytes
4	<i>Cyperus laevigatus</i> L.	Cyperaceae	Geophytes Helophytes
5	<i>Imperata cylindrica</i> (L.) Rausch.	Gramineae (Poaceae)	Geophytes Helophytes
6	<i>Phragmites australis</i> (Cav.)Trin. ex Steud.	Gramineae (Poaceae)	Geophytes Helophytes
7	<i>Polypogon monspeliensis</i> (L.) Desf.	Gramineae (Poaceae)	Therophytes
8	<i>Juncus rigidus</i> Desf.	Juncaceae	Geophytes Helophytes
9	<i>Alhagi graecorum</i> Boiss	Leguminosae (Fabaceae)	Hemicryptophytes
10	<i>Eucalyptus camaldulensis</i> Dehnh.	Myrtaceae	Phanerophytes
11	<i>Nitraria retusa</i> (Forssk) Asch	Nitrariaceae	Phanerophytes
12	<i>Phoenix dactylifera</i> L.,	Palmae (Arecaceae)	Phanerophytes
13	<i>Calligonum polygonoides</i> subsp. <i>comosum</i> (L' Hér.)Soskov	Polygonaceae	Phanerophytes
14	<i>Tamarix nilotica</i> (Ehrenb.) Bunge	Tamaricaceae	Phanerophytes
15	<i>Typha domingensis</i> (Pers.) Poir. ex Steud.	Typhaceae	Helophytes
16	<i>Zygophyllum album</i> L.f.	Zygophyllaceae	Chamaephytes
17	<i>Zygophyllum coccineum</i> L.	Zygophyllaceae	Chamaephytes

Table 2. The floristic regions of the flora around the lakes of Wadi El Rayan

Plant species	Floristic regions*
<i>Alhagi graecorum</i>	IR-TR + SA- AR + ME
<i>Arthrocnemum macrostachyum</i>	ME +SA-AR
<i>Calligonum polygonoides sub. comosum</i>	SA-AR + IR-TR
<i>Chenopodium marale</i>	Cosmopolitan
<i>Cyperus laevigatus</i>	Cosmopolitan
<i>Eucalyptus camaldulensis</i>	IR-TR
<i>Imperata cylindrica</i>	ME + IR-TR + SA-AR+PAL+NEO
<i>Juncus rigidus</i>	ER-SR + ME + IR-TR
<i>Nitraria retusa</i>	SA-AR + SU-ZA
<i>Phoenix dactylifera</i>	SA-AR + SU-AZ
<i>Phragmites australis</i>	ME + IR-TR + SA-AR + PAL + NEO
<i>Pluchea dioscoridis</i>	SU-ZA + SA-AR
<i>Polypogon monospliensis</i>	ME + IR-TR+ SA-AR
<i>Tamarix nilotica</i>	SA-AR + IR-TR
<i>Typha domingensis</i>	ME + IR-TR + PAL
<i>Zygophyllum album</i>	SA-AR + ME
<i>Zygophyllum coccineum</i>	SA-AR

*The floristic regions are abbreviated as follows: **ME**: Mediterranean, **IR-TR**: Irano-Turanian, **SA-AR**: Saharo-Arabian, **ER-SR**: Euro-Siberian, **SU-ZA**: Sudano-Zambezian, **NEO**: Neotropical, and **PAL**: Palaeotropical.

Table 3. Diversity indices along the study stands in Wadi El Rayan

	Stand 1	Stand 2	Stand 3	Stand 4	Stand 5	Stand 6	Stand 7	Stand 8	Stand 9	Stand 10
Taxa_S (species richness)	9	5	1	6	2	5	4	3	6	4
Dominance_D	0.487	0.843	1.000	0.426	0.603	0.915	0.999	0.995	0.920	0.978
Simpson_1-D	0.513	0.157	0.000	0.574	0.397	0.085	0.001	0.005	0.080	0.022
Shannon_H	1.135	0.335	0.000	1.119	0.586	0.203	0.006	0.018	0.223	0.062
Evenness_e^H/S	0.346	0.280	1.000	0.510	0.898	0.245	0.252	0.339	0.208	0.266
Brillouin	1.120	0.332	0.000	1.045	0.529	0.202	0.006	0.018	0.219	0.062
Menhinick	0.251	0.088	0.118	0.570	0.348	0.043	0.024	0.015	0.116	0.012
Margalef	1.118	0.495	0.000	1.062	0.286	0.422	0.293	0.190	0.633	0.259
Equitability_J	0.517	0.208	0.000	0.625	0.845	0.126	0.005	0.017	0.124	0.045
Fisher_alpha	1.306	0.580	0.164	1.359	0.469	0.490	0.354	0.252	0.731	0.313
Berger-Parker	0.679	0.915	1.000	0.604	0.727	0.956	0.999	0.998	0.959	0.989
Chao-1	9	5	1	7	2	5	4	3	6	4

3.2. Multivariate Analysis

3.2.1. Classification

Cluster analysis of species composition for each of the 10 studied stands is shown in Figure 2. Based on the results of the TWINSpan analysis (using importance values 'IV' of the recorded species), the vegetation can be categorized into four vegetation groups (Figure 3), named after their leading dominant species: (A) *P. australis*-*T. nilotica*, (B) *J. rigidus*, (C) *A. graecorum*, and (D) *Z. album*-*N. retusa*. Different species of these groups can be easily linked to a habitat type: wetlands, Sabkha, sand sheets, sand dunes, desert areas edges of wetlands.

Statistical analysis of the physical properties of the soil showed a variation in soil texture: the most frequent type was sandy (70%) while the loamy sand was detected only at three stands (30%) (Table 4). The lowest recorded

elevation was at El Modwara (-19m b.s.l) while the highest was at the northeastern part of the Upper Lake (16m a.s.l). The analyses of the chemical properties of the soil showed that it was slightly alkaline (with pH values ranging from 7.89 to 8.5); while the electrical conductivity values of soil extract showed a great variation ranging from 5.88 to 63.0 ds/m. The soil organic matter was low, ranging from 0.08 to 1.2 % with the most frequent value of 0.61 %. However, significant differences in the soil chemical and physical characters were found (Table 5). The analyses of the soil chemical properties relationship with vegetation (Table 6) showed that the mean soil pH value for *P. australis* and *T. nilotica* was 8.14; 8.17 for *A. graecorum*; 8.19 for *J. rigidus*; and 8.5 for each of *P. monospliensis*, *C. laevigatus* and *C. murale*. However, soil analyses showed that the soil was slightly alkaline, with pH values ranging from 7.89 at

Stand 10 (species: *J. rigidus*, *P. australis*, *T. nilotica* and *T. domingensis*) to 8.5 at Stand 1 (species: *A. graecorum*, *C. murale*, *C. laevigatus*, *I. cylindrica*, *J. rigidus*, *P. australis*, *P. dioscoridis*, *P. monspeliensis* and *T. nilotica*). However, the most frequent value of soil pH in the study area was 8.11.

There was a great variation in Total Dissolved Solids (T.D.S) of different plant species. The mean T.D.S for *P. australis* was 11135.29 ppm; *T. nilotica*: 11212.16; *A. graecorum*: 6636.80; *Z. coccineum* and *A. macrostachyum*: 40320. However, high T.D.S variation across stands was measured ranging from 3763.2 ppm at Stand 9 (species: *A. graecorum*, *E. camaldulensis*, *J. rigidus*, *P. dactylifera*, *P. australis* and *T. nilotica*) to 40320 ppm at Stand 7 (species: *A. macrostachyum*, *P. australis*, *T. nilotica* and *Z. coccineum*).

Results showed that the study area is poor inorganic matter content, ranging from 0.08 % at Stand 4 (species: *C. polygonoides*, *N. retusa*, *P. dactylifera*, *P. australis*, *T. nilotica* and *Z. album*) to 1.2% at Stand 8, with the most frequent value of 0.61%. The study area showed a great variation of soil carbonate content, ranging from 3.81% at Stand 6 (species: *A. graecorum*, *J. rigidus*, *P. dactylifera*, *P. australis* and *T. nilotica*) to 37.9 % at Stand 1 (species: *A. graecorum*, *C. murale*, *C. laevigatus*, *I. cylindrica*, *J. rigidus*, *P. australis*, *P. dioscoridis*, *P. monspeliensis* and *T. nilotica*), with the most frequent value of 7.16 %.

The soil calcium content ranged from 19.3 meq/L at Stand 5 (species: *P. australis* and *T. nilotica*) to 115 meq/L at Stand 7 (species: *P. australis*, *T. nilotica*, *Z. coccineum* and *A. macrostachyum*). While, the soil magnesium content ranged from 3.6 meq/L at Stand 9 (species: *A. graecorum*, *E. camaldulensis*, *J. rigidus*, *P. dactylifera*, *P. australis* and *T. nilotica*) to 107 meq/L at Stand 7 (species: *P. australis*, *T. nilotica*, *Z. coccineum* and *A. macrostachyum*).

The soil sodium content ranged from 22.2 meq/L at Stand 4 (species: *C. polygonoides*, *N. retusa*, *P. dactylifera*, *P. australis*, *T. nilotica* and *Z. album*) to 590 meq/L at Stand 7 (species: *P. australis*, *T. nilotica*, *Z. coccineum* and *A. macrostachyum*). The soil potassium content ranged from 2.8 meq/L at Stand 10 (species: *J. rigidus*, *P. australis*, *T. nilotica* and *T. domingensis*) to 8.1 meq/L at Stand 3 (*T. nilotica*), with the most frequent value of 3.2 meq/L. The data indicated that Stand 7 has the highest value of bicarbonate content (4.01 meq/L - species: *P. australis*, *T. nilotica*, *Z. coccineum* and *A. macrostachyum*), while the lowest value was recorded at Stand 5 (1 meq/L - species: *P. australis* and *T. nilotica*), with the most frequent value of 2.11 meq/L. Soil collected at Stand 7 (species: *P. australis*, *T. nilotica*, *Z. coccineum* and *A. macrostachyum*) showed the highest chloride content value (700 meq/L), while the lowest value was recorded at Stand 5 (33.1 meq/L - species: *P. australis* and *T. nilotica*). Furthermore, soil sulphate contents were highest at Stand 7 (114.8 meq/L – species: *P. australis*, *T. nilotica*, *Z. coccineum* and *A. macrostachyum*) and lowest at Stand 9 (6.79 meq/L – species: *A. graecorum*, *E. camaldulensis*, *J. rigidus*, *P. dactylifera*, *P. australis* and *T. nilotica*).

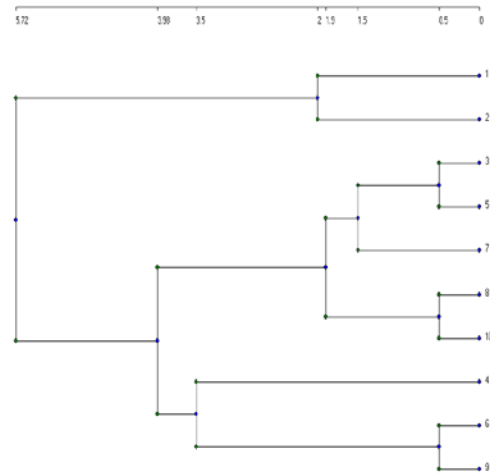
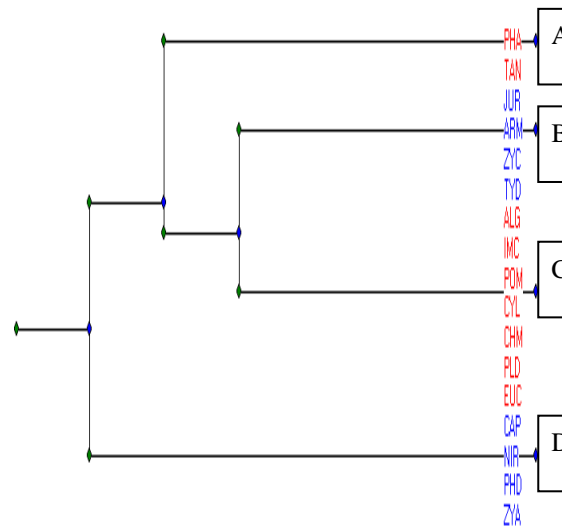


Figure 2. Dendrograms showing cluster analysis of the studied stands.



Abbreviations:

<i>PHA</i>	<i>Phragmites australis</i>	<i>CAP</i>	<i>Calligonum polygonoides sub. comosum</i>
<i>TAN</i>	<i>Tamarix nilotica</i>	<i>ARM</i>	<i>Arthrocnemum macrostachyum</i>
<i>JUR</i>	<i>Juncus rigidus</i>	<i>NIR</i>	<i>Nitraria retusa</i>
<i>ALG</i>	<i>Alhagi graecorum</i>	<i>PHD</i>	<i>Phoenix dactylifera</i>
<i>IMC</i>	<i>Imperata cylindrica</i>	<i>ZYA</i>	<i>Zygophyllum album</i>
<i>POM</i>	<i>Polypogon monspeliensis</i>	<i>ZYC</i>	<i>Zygophyllum coccineum</i>
<i>CYL</i>	<i>Cyperus laevigatus</i>	<i>TYD</i>	<i>Typha domingensis</i>
<i>CHM</i>	<i>Chenopodium murale</i>	<i>EUC</i>	<i>Eucalyptus camaldulensis</i>
<i>PLD</i>	<i>Pluchea dioscoridis</i>		

Figure 3. TWINSPAN dendrogram of the 10 studied stands of the study area and 17 species based on their importance values. A-D are the four separated vegetation groups.

Table 4. The physical properties of soil samples collected within the study stands in Wadi El Rayan.

Location	Stand No.	Alt (m)	The saturation percentage (SP)	Texture (%)				Texture
				Coarse Sand	Fine Sand	Silt	Clay	
North East of the Lower Lake	1	-18	0.61	35.6	42.7	14.2	7.5	Loamy Sand
The Connecting channel	2	-2	0.43	39.6	46.4	9.5	4.5	Sandy
Southeast of the Lower Lake	3	-14	0.81	39.4	46.1	9.8	4.7	Sandy
Southwest of the Lower Lake	4	-3	0.08	38.8	44.5	10.4	6.3	Sandy
El Modwara (Northwest of Lower Lake)	5	-19	0.61	41.7	43.7	9.6	5.0	Sandy
Southwest of the Upper Lake	6	13	0.68	42.5	43.2	10.3	4.0	Sandy
Northwest of the Upper Lake	7	9	1.1	32.8	40.3	19.5	7.4	Loamy Sand
Southeast of the Upper Lake	8	9	1.2	35.0	42.5	16.2	6.3	Loamy Sand
Northeast of the Upper Lake	9	16	0.96	35.4	49.3	10.5	4.8	Sandy
North of the Upper Lake	10	13	20.1	44.7	47.5	5.3	2.5	Sandy

Table 5. Chemical properties of soil samples that collected within the study stands in Wadi El Rayan.

Location	Stand No.	pH	T.D. S ppm	EC ds/m	%	%	%	Cations (meq/l)				Anions (meq/l)		
					Organic matter	Organic carbon	CaCO ₃	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ⁻
Northeast of the Lower Lake	1	8.50	4928	7.70	0.61	0.35	37.9	22.2	14.4	32.1	3.31	1.2	45.2	25.61
The Connecting Channel	2	8.11	9664	15.10	0.43	0.24	6.7	37.1	53.3	99.1	5.5	2.01	122.0	70.99
Southeast of the lower lake	3	8.15	11904	18.60	0.81	0.46	7.16	50.1	35.8	140.0	8.1	2.11	205.0	26.89
Southwest of the lower lake	4	8.12	3974.4	6.21	0.08	0.046	6.60	26.1	8.5	22.2	3.20	1.33	42.1	16.57
El Modwara (Northwest of Lower Lake)	5	8.11	3840	6.0	0.61	0.35	5.05	19.3	9.7	25.1	2.9	1.0	33.1	22.9
Southwest of the Upper Lake	6	8.05	8192	12.8	0.68	0.39	3.81	35.2	38.4	78.2	4.2	3.0	100.0	53.0
Northwest of the Upper Lake	7	8.0	40320	63.0	1.1	0.63	7.16	115.0	107.0	590.0	6.8	4.01	700.0	114.8
Southeast of the Upper Lake	8	8.49	10496	16.4	1.2	0.69	28.6	55.0	37.8	110.0	5.2	3.02	180.0	24.98
Northeast of the Upper Lake	9	8.02	3763.2	5.88	0.96	0.55	22.7	20.0	3.6	25.2	3.2	2.11	43.1	6.79
North of the Upper Lake	10	7.89	15040	23.5	0.2	0.11	8.6	57.8	25.1	199.2	2.8	2.9	244.2	37.8

Table 6. Mean values of chemical analysis of soil for different plant species within the study stands in Wadi El Rayan.

Species Name	pH	T.D.S ppm	EC ds/m	%	%	%	Cations (meq/l)				Anions (meq/l)		
				Organic matter	Organic carbon	CaCO ₃	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ⁻⁻
<i>Phragmites australis</i>	8.14	11135.29	17.40	0.65	0.37	14.12	43.08	33.09	131.23	4.12	2.29	167.74	41.49
<i>Tamarix nilotica</i>	8.14	11212.16	17.52	0.67	0.38	13.43	43.78	33.36	132.11	4.52	2.27	171.47	40.03
<i>Juncus rigidus</i>	8.19	8483.84	13.26	0.73	0.42	20.32	38.04	23.86	88.94	3.74	2.45	122.50	29.64
<i>Alhagi graecorum</i>	8.17	6636.80	10.37	0.67	0.38	17.78	28.63	27.43	58.65	4.05	2.08	77.58	39.10
<i>Imperata cylindrica</i>	8.31	7296.00	11.40	0.52	0.30	22.30	29.65	33.85	65.60	4.41	1.61	83.60	48.30
<i>Polypogon monspeliensis</i>	8.5	4928	7.7	0.61	0.35	37.9	22.2	14.4	32.1	3.31	1.2	45.2	25.61
<i>Cyperus laevigatus</i>	8.5	4928	7.7	0.61	0.35	37.9	22.2	14.4	32.1	3.31	1.2	45.2	25.61
<i>Chenopodium murale</i>	8.5	4928	7.7	0.61	0.35	37.9	22.2	14.4	32.1	3.31	1.2	45.2	25.61
<i>Pluchea dioscoridis</i>	8.31	7296.00	11.40	0.52	0.30	22.30	29.65	33.85	65.60	4.41	1.61	83.60	48.30
<i>Calligonum polygonoides</i>	8.12	3974.4	6.21	0.08	0.046	6.6	26.1	8.5	22.2	3.2	1.33	42.1	16.57
<i>Arthrocnemum macrostachyum</i>	8	40320	63	1.1	0.63	7.16	115	107	590	6.8	4.01	700	114.8
<i>Nitraria aetusa</i>	8.12	3974.4	6.21	0.08	0.046	6.6	26.1	8.5	22.2	3.2	1.33	42.1	16.57
<i>Phoenix dactylifera</i>	8.06	5309.87	8.30	0.57	0.33	11.04	27.10	16.83	41.87	3.53	2.15	61.73	25.45
<i>Zygophyllum album</i>	8.12	3974.4	6.21	0.08	0.046	6.6	26.1	8.5	22.2	3.2	1.33	42.1	16.57
<i>Zygophyllum coccineum</i>	8	40320	63	1.1	0.63	7.16	115	107	590	6.8	4.01	700	114.8
<i>Typha domingensis</i>	7.89	15040	23.5	0.2	0.11	8.6	57.8	25.1	199.2	2.8	2.9	244.2	37.8
<i>Eucalyptus camaldulensis</i>	8.02	3763.2	5.88	0.96	0.55	22.7	20	3.6	25.2	3.2	2.11	43.1	6.79

3.2.2. Ordination

There was a successive decrease in the Eigenvalues of the first three CCA axes. These Eigenvalues were somewhat higher for the DCA axes (Tables 7 and 8), which indicates that the important explanatory stand variables were not measured and included in the analysis or some of the variations were not explained by environmental variables (Franklin & Merlin, 1992; McDonald *et al.*, 1996).

However, The DCA analysis revealed information about the range of variation among the stands at the two lakes (Table 7 and Figure 4). Results showed that the first gradient is the longest, explaining about 36.8 % of the total species variability, whereas the second and higher axes explain much lower. Also, the first axis was very well correlated with the environmental data ($r=1$), and the correlation for the other axis was considerably lower. This suggests that the whole data set was governed by a single dominant gradient. The number of axis scores calculated for a species–environmental variable bi-plot was restricted in a DCA, by one or two defaults.

The first axis was negatively correlated with the altitude (Alt) and soil contents (fine sand and clay), with the increasing concentration of (K⁺, Mg⁺⁺ and organic matter), positively correlated with (Na⁺, Cl⁻, total dissolved salts with electrical conductivity), and with the

increasing concentration of (SO₄⁻, Ca⁺⁺, and HCO₃⁻), with the increasing concentration of CaCO₃ and pH gradient.

The positions of arrows for environmental variables suggest that there was a group of variables that were mutually highly positive correlated (Alt, CaCO₃, pH, clay and fine soil) and negative correlated with (Cl⁻, K⁺, Ca⁺⁺ and organic matter) with the total dissolved salts and electrical conductivity. A closer inspection of the correlation matrix in the CANOCO Log View showed that the variables were indeed correlated, but in some cases the correlation is not very strong. The correlation matrix also confirmed that the correlation of all measured variables with the second axis was rather weak (Figure 4).

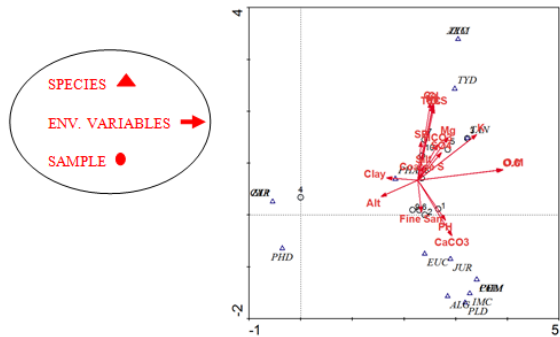
This pattern also appeared in the summary (Table 8), where the first axis explained more than the second, third and fourth axes do together. Comparing this summary with that from the DCA, it is noticed that the percentage variance explained by the first axis was the same as that explained by the first axis in the unconstrained DCA (36.8), where the species environment correlation was only slightly higher. The first axis of CCA was very similar (both for the species and for the sample scores) to the first axis of DCA (Figures 4 and 5). However, the second axis was different: The CCA showed a remarkable arch effect – the quadratic dependence of the second axis on the first one.

Table7. Environmental parameters used in the DCA and their Eigenvalues.

Axes	1	2	3	4
Eigenvalues	0.756	0.25	0.099	0.02
Lengths of gradient	3.224	1.478	1.402	0.841
Species-environment correlations	1	1	1	1
of species data	36.8	49	53.8	54.8
of species-environment relation	28.7	43.5	0	0
The saturation percentage (SP)	0.0633	0.291	-0.1671	0.3675
Coarse S	0.0333	0.0572	-0.3723	-0.3823
Fine San	-0.0168	-0.2297	-0.2635	0.1383
Silt	0.0482	0.1123	0.4083	0.1891
Clay	-0.1756	-0.0325	0.3047	0.2017
PH	0.1121	-0.2511	-0.1829	-0.2658
EC	0.1754	0.5593	0.4979	0.3654
O.M	0.499	0.2137	0.4848	0.3654
CaCO ₃	0.1318	-0.3548	-0.211	0.089
Ca	0.161	0.5932	0.4958	0.0906
Mg	0.2234	0.3657	0.3026	0.2062
Na	0.1689	0.5712	0.5148	0.3373
K	0.3882	0.4296	0.4114	0.0226
HCO ₃	0.1553	0.2945	0.2447	0.3962
Cl	0.1775	0.5926	0.5381	-0.2252
SO ₄	0.1667	0.2415	0.1335	0.1818
Altitude	-0.2286	-0.1794	-0.0585	0.3902

Table8. Environmental parameters used in the CCA and their Eigen values.

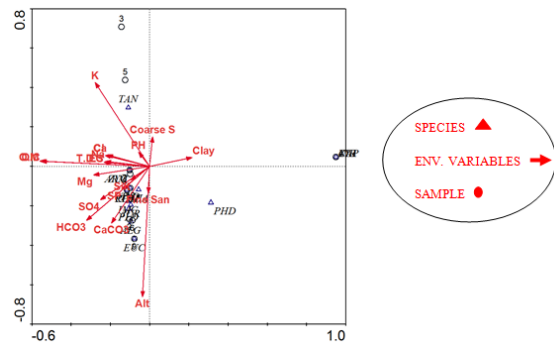
Axes	1	2	3	4
Eigenvalues	0.756	0.421	0.251	0.213
Species-environment correlations	1	1	1	1
of species-environment relation	36.8	57.3	69.5	79.9
The saturation percentage (SP)	-0.1404	-0.117	0.4948	0.8326
Coarse S	0.016	0.1498	-0.0919	0.7283
Fine San	-0.0061	-0.1349	-0.2887	0.5317
Silt	-0.0951	-0.0685	0.2729	-0.7654
Clay	0.2161	0.0451	0.0172	-0.7096
PH	-0.0557	0.0719	-0.4951	-0.1779
EC	-0.2312	0.0214	0.8418	-0.3918
O.M	-0.5586	0.0272	0.0966	-0.5516
CaCO ₃	-0.1941	-0.2875	-0.3408	-0.0102
Ca	-0.2148	0.0581	0.848	-0.3053
Mg	-0.2848	-0.0435	0.6292	-0.5363
Na	-0.2242	0.0255	0.8548	-0.3825
K	-0.2772	0.4249	0.1586	-0.484
HCO ₃	-0.3214	-0.2736	0.6972	-0.1547
Cl	-0.2264	0.0559	0.8486	-0.378
SO ₄	-0.2508	-0.1699	0.6065	-0.4855
Altitude	-0.0358	-0.6612	0.438	0.1003



Abbreviations:

- | | | | |
|-----|--------------------------------|-----|-------------------------------------------|
| PHA | <i>Phragmitesaustralis</i> | CAP | <i>Calligonumpolygonoidessub .comosum</i> |
| TAN | <i>Tamarixnilotica</i> | ARM | <i>Arthrocnemummacrostachyum</i> |
| JUR | <i>Juncusrigidus</i> | NIR | <i>Nitrariaretusa</i> |
| ALG | <i>Alhagigraecorum</i> | PHD | <i>Phoenix dactylifera</i> |
| IMC | <i>Imperatacylindrica</i> | ZYA | <i>Zygophyllum album</i> |
| POM | <i>Polypogonmonospeliensis</i> | ZYC | <i>Zygophyllumcoccineum</i> |
| CYL | <i>Cyperuslaevigatus</i> | TYD | <i>Typhadomingensis</i> |
| CHM | <i>Chenopodiummurale</i> | EUC | <i>Eucalyptus camaldulensis</i> |
| PLD | <i>Plucheadioscoridis</i> | | |

Figure 4.The samples, species and environmental (circles, triangle and arrow, respectively) triplot of the DCA of the whole data set.



Abbreviations:

- | | | | |
|-----|--------------------------------|-----|-------------------------------------------|
| PHA | <i>Phragmitesaustralis</i> | CAP | <i>Calligonumpolygonoidessub .comosum</i> |
| TAN | <i>Tamarixnilotica</i> | ARM | <i>Arthrocnemummacrostachyum</i> |
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| CHM | <i>Chenopodiummurale</i> | EUC | <i>Eucalyptus camaldulensis</i> |
| PLD | <i>Plucheadioscoridis</i> | | |

Figure 5.The samples, species and environmental (circles, triangle and arrow, respectively) triplot of the CCA of the whole data set.

4. Discussion

The present study examined the environmental correlates of species distribution at different geomorphologic locations of Wadi El Rayan Protected Area along the coast of the two lakes. Both DCA and CCA assessed the soil-vegetation relationships: CCA analysis showed the relative positions of species and sites along the most important ecological gradients. Both ordination techniques clearly indicated that soil pH, electric conductivity (salinity), CaCO₃, organic matter, and relative concentrations of cations (Ca⁺⁺, Mg⁺⁺, Na⁺ and K⁺) were the most important parameters for the distribution of the vegetation pattern in the area.

The organic matter, considered as a key factor affecting the soil fertility of some desert ecosystems in Egypt (Sharaf El Din and Shaltout, 1985; Abd El-Ghani, 1998, 2000) and soils of arid lands have a low level of organic matter, are slightly acid to alkaline in reaction (pH) at the surface (Dregne, 1976). The soil chemistry affects the plant species composition through salinity levels (Sharma and Shankar, 1991; Kumar, 1996; Abbadi and El Sheikh, 2002), pH, calcium and organic carbon (Abd El-Ghani, 1998). The present study showed that Wadi El Rayan is characterized by a variety of soil types (based on their physical and chemical attributes), which is in accordance to its varying nutrient status (Amin, 1998). Literature reported, on average, a higher species richness in the area of Wadi El Rayan than the one recorded in the present study (60 species: Abdou, 2002; 38 species: EEAA, 2003; 27 species: Azzazi, 2009; 13 species: Saleh *et al.*, 1984). The lower number of the recorded species here is due to our confined scope towards wetlands and desert ecosystems; while others have also included species from the springs' oases and the cultivated lands. Furthermore, the human pressures may play a role in the distribution of the species (e.g., overgrazing, land encroachment, reduction in water levels due to decreased water collected in the lakes and tourism). Conservation of the vegetation in Wadi El Rayan requires stopping the severe human impacts that lead to the elimination of certain plant populations and, hence, the modification of the complex plant communities into simple fragile ones. However, water supply is of great importance as it determines the Wadi El Rayan's future and its vegetation cover.

The ecosystems investigated in the present study are relatively simple, in which the survived species with stand stress environmental conditions, as Wadi El Rayan is located at the Sahara eco-region of the Palearctic ecozone, the world's largest hot desert. However, the desert ecosystem of Wadi El Rayan consists of arid vegetation (xerophytic and halophytic plants) with a sparse plant cover except in wetlands ecosystem at the shoreline of the lakes which are characterized by some hydrophytic and halophytic plants.

Our results are in accordance with those of Amin (1998), who identified three major ecosystems in Wadi El-Rayan area: desert, lake and spring ecosystems. However, the spring ecosystem was not recognized in the area of the current study. Each of these ecosystems has its own habitat features that support the growth of variant

plant communities, mainly hydrophytes, reed swamps, halophytes, and xerophytes. In the present study, the wetlands are represented by species *P. australis*, *T. nilotica*, *J. rigidus*, *T. domingensis*, *C. laevigatus*, *C. marale*, *P. monspeliensis*, *P. dioscoridis*, *E. camaldulensis* and *I. cylindrica*; while the desert is represented by *T. nilotica*, *A. graecorum*, *C. polygonoides* sub. *comosum*, *N. retusa*, *Z. album*, *Z. coccineum*, *A. macrostachyum* and *P. dactylifera*. The study area is dominated by two species: *P. australis* and *T. nilotica*. The latter is the most widely distributed plant in Wadi El Rayan and can be considered as the most successful species in the study area as it grows at a variety of ecosystems and habitats (e.g., desert areas, edges of wetlands and salt marshes). Other 15 species were recorded in a very limited abundance (see Table 1), amongst them are *T. domingensis* (which has a very limited distributional range in the study area to the northern edge of the Upper Lake) and *E. camaldulensis* an exotic (non-native to the area) species represented with very limited distribution (northeast edges of the Upper Lake) and typically grows along river banks and in alluvial valleys (El-Hadidi and Boulos, 1989). Amin (1998) demonstrates the adaptation of different plant species in Wadi El Rayan to environmental stresses (extreme drought and salinity conditions), via (a) having a shedded green cortex (*Z. album* and *Z. coccineum*); (b) defoliation (*N. retusa*); (c) salt removal by secretion (*T. nilotica*); and (d) the ability to phytogenic mounds controlled mainly by the life-form of the species (*C. polygonoides*, *N. retusa*, *Z. album*, *Z. coccineum* and *T. nilotica*). Simpson (1932) reported that *T. domingensis* is more sensitive to salt than *P. australis* as the latter grows well in the Lake Mariut area, while the former is present only where the Lake receives fresh water from the Mahmudiya Canal. *A. graecorum* was a widely distributed species (Kassas, 1952) and was considered as a groundwater-indicating plant (Girgis, 1972). However, the dominant species *P. australis* was the most adaptive and suitable plant species for the quality of the water in Wadi El Rayan (EEAA, 2003).

A high variability of the recorded plants' growth forms was noticed, including shrubs with photosynthetic stems (e.g. *C. polygonoides*), succulent xerohalophytic semi-shrubs (e.g. *Z. album*), virgate and thorny trees and shrubs (e.g. *N. retusa*). The results of the present study are in accordance with the results of Beeftink (1977) and Zahran (1982) that the life-form chamaephytes and geophytes are able to withstand water logging, high salinity levels and a wide range of temperature variability. Also a high percentage of hemicryptophytes and therophytes in sandy dune habitats could be related to their ability to resist drought, sand accumulation and grazing (Danin and Orshan, 1990; Danin, 1996).

Chorological analysis of the floristic data showed that the Saharo-Arabian chorotype (33 %), Irano-Turanian (24 %) and Mediterranean (22 %) formed the major components of the floristic structure along the study area. Abd El-Ghani and Amer (2003) reported that the plants of the Saharo-Arabian species are good indicators for the quality of desert environmental conditions, while the Mediterranean species are more related to the mesic

environment. In arid and semi-arid regions, seasonal variations may lead to differential physiological responses in the plants inhabiting such environments, including adaptations to high temperature, drought, and salt stresses (Joyce *et al.*, 1984; Murakozy *et al.*, 2003; Kusaka *et al.*, 2005). Wickens (1977) and Boulos (1997) reported that the Saharo-Arabian region is characterized by few endemic species and genera, and the absence of endemic families.

Zahran and Willis (2009) reported that, in the extreme environmental conditions of arid lands, the interactions between its different components are of high significance, so that small changes in one component of the ecosystem can lead to substantial variations in others, creating distinct micro-habitats. In arid lands, the inter-relationships between soils, vegetation and atmosphere are so interconnected that they can hardly be considered, ecologically, as separate entities. However, extreme arid conditions, notably high salinity and high aridity, act as filters to species that are able to adapt in the hyper-arid environment.

5. Conclusion

In Wadi El Rayan, as hyper-arid environment, the wild plants have adapted to survive extreme climate conditions and soil factors, where both ordination techniques clearly indicated that soil pH, electric conductivity (salinity), CaCO₃, organic matter, and relative concentrations of cations were the most important parameters for the distribution of the vegetation pattern in the area. Considerations of the exploitation and conservation of wild plants must take ecological principles into account. Sustainable management of the floral biodiversity in Wadi El Rayan requires the termination of the severe human impacts that lead to eliminating certain plant populations and, hence, the modification of the complex plant communities into simple fragile once.

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References

- Abbadi GA and El Sheikh MA. 2002. Vegetation analysis of Failaka Island (Kuwait). *Arid Environ J*, **50**: 153–165.
- Abd El-Ghani M and Amer WM. 2003. Soil–vegetation relationships in a coastal desert plain of southern Sinai, Egypt. *Arid Environ J*, **55**: 607–628.
- Abd El-Ghani MM. 1998. Environmental correlates of species distribution in arid desert ecosystems of eastern Egypt. *Arid Environ J*, **38**: 297–313.
- Abd El-Ghani MM. 2000. Floristics and environmental relations in two extreme desert zones of western Egypt. *GLOBAL ECOLOGICAL BIOTROPICS*, **9**: 499–516.
- Abdou WA. 2002. Environmental study on Wadi El Rayan, El Fayoum Governorate. MSc Thesis, Mansoura University, Mansoura
- Abdou WA. 2006. Biodiversity study in Wadi El-Rayan, Nature Conservation Sector, Egyptian Environmental Affairs Agency, Egypt, pp. 32.
- Allen SE, Grimshaw HM, Parkinson JA, Quarmby C and Roberts JD. 1976. Chemical Analysis of Ecological Materials. Edited by S.B. Chapman. Blackwell Sci. Publ., Oxford, Chapter 8:166-411.
- Amin SA. 1998. Ecological Study on the Plant Life in Wadi El-Rayan Area, El-Fayium, Egypt. PhD Thesis, Faculty of Science, Cairo University, Egypt.
- Ayyad M. 1976. The vegetation and environment of the western Mediterranean coastal land of Egypt. IV. The habitat of non-saline depressions. *Ecol J*, **64**: 713–722.
- Ayyad MA and Ghabbour SI. 1986. Hot deserts of Egypt and the Sudan. In: Evannari, M., Noy Meir, I. & Goodall, D (Eds.), *Ecosystems of the world*. Elsevier, Amsterdam, pp. 149-202
- Azzazi MF. 2009. Present and Ancient Vegetation of Wadi El Raiyan, Egypt. *The desert institute bulletin*, Egypt. 69, No. 8 (2009): 463-475.
- Barbour MG, Burk JH and Pitts WD. 1987. *Terrestrial Plant Ecology*, second ed. Benjamin/Cummings, Menlo Park, California.
- Beetink WG. 1977. The coastal salt marshes of western and northern Europe. In: Chapman V.J (Eds.), *Ecosystems of the World 1*. Elsevier, Amsterdam, pp. 109–155.
- Black CA. 1965. *Methods of Soil Analysis*. American Society of Agronomy. Series 9, part 2: 771-1572.
- Boulos L. 1975. The Mediterranean element in the flora of Egypt and Libya. – *Colloques Internat. CNRS* 235. La flore du Bassin Méditerranéen: essai de systématique synthétique: 119-124.
- Boulos L. 1997. Endemic flora of the Middle East and North Africa. In: Barakat, H.N., Hegazy, A.K (Eds.), *Reviews in Ecology: Desert Conservation and Development Metropole*, Cairo, pp. 331
- Danin A and Orshan G. 1990. Distribution of Raunkiaer life forms in Israel. *Vege Sci J*, **1**: 41–48.
- Danin A. 1996. Plants of desert dunes. In: Cloudsley-Thompson J.L (Eds.), *Adaptation of Organisms to the Desert*. Springer Verlag, Heidelberg, pp. 156.
- Dregne HE. 1976. *Soils of Arid Regions*. Elsevier, Amsterdam, pp.237.
- EEAA [Egyptian Environmental Affairs Agency]. 2003. Monitoring Report on the third year of monitoring program. Wadi El-Rayan Protected Area, Nature Conservation Sector, Egyptian Environmental Affairs Agency. Egypt, pp.65.
- EEAA [Egyptian Environmental Affairs Agency]. 2012. Information Sheet on Ramsar Wetlands to designate of Wadi El Rayan and Qaroun lakes as new Ramsar sites, submitted to Convention on Wetlands of International Importance (Ramsar Convention). Designation date: 04/06/12, Ramsar Site no. 2041.
- El-Hadidi MN and Boulos L. 1989. The street trees of Egypt. The American University in Cairo. ISBN.977-424-173-8.
- Franklin J and Merlin M. 1992. Species–environment patterns of forest vegetation on the uplifted reef limestone of Atiu, Managua, Ma'uke and Miti'aro, Cook Islands. *Vege Sci J*, **3**: 3–14.
- Girgis WA. 1972. Plant indicators in the Egyptian deserts. *Bulletin of the Desert Institute, Arab Republic of Egypt*, 21:511–515.
- Glenn M, Robert E, Brian H, David RF, Jonathan H and Dana M. 2002. Vegetation variation across Cape Cod, Massachusetts:

- environmental and historical determinants. *Biogeogr J*, **29**: 1439–1454.
- Harper DAT. 1999. Numerical Palaeobiology. John Wiley & Sons. Chichester, 1999. ISBN 0 471 97405 6: pp. 468.
- He MZ, Zheng JG, Lia XR and Qian YL. 2007. Environmental factors affecting vegetation composition in the Alxa Plateau, China. *Arid Enviro J*, **69**: 473–489.
- Hejmanová-Nežerková P and Hejman M. 2006. A canonical correspondence analysis (CCA) of the vegetation–environment relationships in Sudanese savannah, Senegal. *S. Afr. J. Bot.*, **72**: 256 – 262.
- Henderson PA and Seaby RMH. 1999. Community Analysis Package (CAP) Version 1.2. Lymington, UK: Pisces Conservation Ltd, IRC House, Pennington, Lymington, S041 8GN, UK.
- Hill MO. 1979. TWINSPLAN-A FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. Ithaca, NY: Ecology and Systematics, Cornell University.
- IUCN 1998. Wadi el Rayan Protected Area Project. Guidelines for overall Work Plan (1998 – 2001). Report 1. Prepared by G.H. MattraversMessana.
- Jackson ML. 1967. Soil Chemical Analysis-Advanced Course. Washington Department of Soil Sciences.
- Joyce PS, Paleg G and Aspinall D. 1984. The requirement for low-intensity light in the accumulation of proline as a response to water deficit. *Journal of Experimental Botany*, **35**: 209–218.
- Kadmon R and Danin A. 1999. Distribution of plant species in Israel in relation to spatial variation in rainfall. *Veg Sci J*, **10**: 421–432.
- Kassas MM. 1952. On the distribution of *Alhagimaurorum* in Egypt. Egyptian Academic of Science. Proc. **3**, 140–151.
- Kassas MM. 1957. On the ecology of the Red Sea coastal land. *Ecol J*, **45**: 187–203.
- Kassas MM. 1962. On the phytosociology of the desert vegetation of Egypt. *Annals of Arid Zone*, **I**: 54–83.
- Kumar S. 1996. Trends in structural compositional attributes of dune-interdune vegetation and their edaphic relations in the Indian desert. *Veg*, **124**: 73–93.
- Kusaka M, Ohta M and Fujimura T. 2005. Contribution of inorganic components to osmotic adjustment and leaf folding for drought tolerance in pearl millet. *Physiol Plant*, **125** (4): 474–489.
- Lepš J and Šmilauer P. 2003. Multivariate Analysis of Ecological Data Using CANOCO. Cambridge University Press, Cambridge, UK, pp. 282.
- Maryam H, Ismail S, Alaa F and Ahmed R. 1995. Studies on growth and salt regulation in some halophytes as influenced by edaphic and climatic conditions. *Pak J Bot*, **27**: 151–163.
- McDonald DJ, Cowling RM and Boucher C. 1996. Vegetation–environment relationships on a species-rich coastal mountain range in the fynbos biome (South Africa). *Veg*, **123**: 165–182.
- Murakeozy EP, Nagy Z, Duhaze C, Boucherean A and Tuba Z. 2003. Seasonal changes in the levels of compatible osmolytes in three halophytic species of island saline vegetation in Hungary. *Plant Physiol J*, **160**: 395–401.
- Nels CJ. 1995. Biodiversity in the balance Approaches to setting Geographic Conservation Priorities, Corpotate Press. Inc., Landover, Maryland, pp. 125.
- Osborn DJ and Helmy I. 1980. The contemporary land mammals of Egypt including Sinai. *Fieldiana Zool* (New Series), **5**: 455–459.
- Parker K. 1991. Topography, substrate, and vegetation patterns in the northern Sonoran Desert. *J. Biogeogr*, **18**: 151–163.
- Pavlůet V, Hejman M, Pavlůet L and Gaisler J. 2003. Effect of rotational and continuous grazing on vegetation of an upland grassland in the Jizerské Hory Mts., Czech Republic. *Folia Geobot J*, **38**: 21–34.
- Piper CS. 1950. Soil and Plant Analysis, University of Adelaide press. Australia, pp. 368.
- Radford EA, Catullo G and Montmollin Bde. 2011. Important Plant Areas of the south and east Mediterranean region: priority sites for conservation. IUCN, Gland, Switzerland and Malaga, Spain. Gland, Switzerland and Malaga, Spain: IUCN, VIII, pp. 108.
- Richard LA. 1954. Diagnosis and Improvement of Saline and Alkaline, Soils. U. S. Department Agr. Handbook, pp. 66.
- Said, R. 1962. The Geology of Egypt. Elsevier, Amsterdam-New York, pp. 1–377p
- Saleh MA, Fouda M, Saleh MA, Abdel-Latif M and Wilson B. 1988a. Inorganic pollution of the Wadi El Raiyan lakes in Egypt and its impact on their fish and wildlife. *Arch Environ Contam Toxicol J*. **17**: 391–403.
- Saleh MA, Saber SA and Saleh MA. 1988b. The structure of sand dune ecosystem of Wadi El Raiyan, Egypt, *Arid Enviro J*, **15**: 283–296.
- Saleh MA. 1984. Investigations of Inorganic Pollutants in El Faiyum Aquatic Environment. FRCU Report, American. Egyptian Universities linkage program, AID, USA.
- Saleh MA. 1987. The decline of gazelles in Egypt. *Biological Conservation*. **39**, 83–95.
- Sharaf El Din A and Shaltout KH. 1985. On the phytosociology of Wadi Araba in the Eastern Desert of Egypt. Proceedings of the Egyptian Botanical Society, **4**: 1311–1325.
- Sharma SK and Shankar V. 1991. Classification and ordination of vegetation of the Kailana catchments in the Indian Thar Desert ii. Woody Vegetation. *Trop Ecol J*, **32**: 269–286.
- Siebert SJ, Van Wyk AE and Bredenkamp GJ. 2002. Vegetation ecology of Sekhukhuneland, South Africa: Combretum hereroense–Grewia vernicosa Open Mountain Bushveld. *S. Afr. J. Bot*, **68**: 475–496.
- Simpson ND. 1932. A Report on the Weed Flora of the Irrigation Channels in Egypt. Ministry of Works, Government Press, Cairo.
- Ter Braak CJ and Šmilauer P. 2002. CANOCO Reference manual and CanoDraw for Windows user's guide: Software for Canonical. Microcomputer power, Itaca, 500 p
- Ungar IA. 1968. Species-soil-relationships on the great salt plains of northern Oklahoma. *AM MIDL NAT J*, **80**: 392–406.
- USDA [U.S. Department of Agriculture]. 1993. Soil Survey Manual. Handbook No. 18. Washington D.C, pp. 503
- Wickens GE. 1977. Some of the phytogeographical problems associated with Egypt. Publications Cairo University Herbarium **7&8**: 223–230.
- Zahran MA and Willis AJ. 2009. The Vegetation of Egypt. Springer, 2nd edition, 437pp.
- Zahran MA. 1970. Wadi El-Raiyan: A natural water reservoir, Western Desert, Egypt. Bull. Soc. Geogr. Egypte, XLIII–XLIV, 83–98.
- Zahran MA. 1982. Ecology of the halophytic vegetation of Egypt. In: Sen D.N. and Rajpurohit K.S (Eds.), Tasks for Vegetation Science. Dr W. Junk Publisher, The Hague, pp. 3–20.