ECOLOGIA BALKANICA
2014, Vol. 6, Issue 2 December 2014 pp. 7-24

Vegetation Analysis in the Red Sea-Eastern Desert Ecotone at the Area between Safaga and South Qusseir, Egypt

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Abstract. The current work is concerned with the studying the impact of environmental conditions on the vegetation in the arid ecotone located between Red Sea and Eastern Desert from Safaga to south Qusseir. Ninety eight quadrats inside 13 transects were selected to cover the environmental gradient across the ecotone, from the coastal region to the boundary of Eastern Desert. Forty five species were recorded belonged to 24 different families and 38 genera. The perennial species were 38 while the annuals were seven species. *Zygophyllum coccineum* had the highest presence value (89.8%) followed by *Tamarix nilotica* (56.1%) and *Zilla spinosa* (51.02%). Chamaephytes and Hemicryptophytes were the most prevailed life-forms. Chrological analysis exhibited that Saharo-Sindian and Sahro-Sindian with its extension to Sudano-Zambezian elements were the most dominant. TWINSPAN classification technique produced three vegetation groups include nine clusters at the fourth level. These groups identified according to the first and second dominant species as follows: *Convolvulus hystrix - Panicum turgidum, Tamarix aphylla - Limonium pruinosum* and *Nitraria retusa - Tamarix nilotica.* DECORANA results indicated a reasonable segregation among these groups along the ordination axis 1 and 2. Vegetation analysis showed that ecotonal clusters have highest number of species/cluster, high species richness and high species turnover. Therefore, the largest group existed in the ecotone (34 species) while the desert group contained eight species and the coastal group included three species. Among the estimated soil variables in this study, pH, coarse sand, HCO_3^-, SO_4^{2-}, clay and PO_4^{3-} have the highest effect on species distribution. Sodium adsorption ratio (SAR) was the effective factor in detecting the ecotonal species, *Aeluropus lagopoides* and *Limonium pruinosum*.

Keywords: Ecotone, Vegetation Analysis, Red Sea, ordination, Eastern Desert, TWINSPAN.

Introduction

Ecotone is one of the most important subjects in ecological research. It is unstable part at any ecosystem due to its sensitivity to environmental changes (KAMEL, 2003). CLEMENTS (1905) used the term "ecotone" from the combination of two words (eco) *oikos* (home) and *tonos* (tension). Ecotones have received a great attention from ecologists for over 100 years, especially in the context of transition between biomes, geographic vegetation unit and movement of tree lines (FARINA, 2010). According to NAIMAN *et al.* (1988), ecotones may include riparian forests, marginal wet land, littoral lake zones, floodplain lakes, forests areas of significant groundwater-surface water changes and arid lands.

Several researchers investigated the different ecotonal areas around world. For instance, PETERS (2002) studied species dominance at a grassland-shrubland ecotone. HARPER *et al.* (2005) studied the edge effect on forest structure and

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composition in fragmented landscapes. TANG & CHUNG (2002) studied rural-urban transition zones in China. TRAUT (2005) studied the role of coastal ecotones by studying the salt marsh/upland transition zone. The arid ecotones took less attention, may due to the poor and scattered vegetation in these region (KARK & RENSBURG, 2006). Diversity at ecotones is dependent on multiple factors, including environmental heterogeneity, spatial mass effect, invasive species spread, animal activities, and hybridization (SENFT, 2009). Ecotones are zones of relatively high vegetation turnover between two relatively homogenous areas (SENFT, 2009). One reputed characteristic of ecotones is that they have higher biological diversity than adjoining areas and thus hold high conservation value (ODUM, 1983; NAIMEN *et al.*, 1988; PETTS, 1990; RISSER, 1995). SHMIDA & WILSON (1985), WOLF (1993) and KERNAGHAN & HARPER (2001) found higher species richness between predetermined altitudinal zones. KIRKMAN *et al.* (1998) and CARTER *et al*. (1994) found higher species richness in wetland/upland boundaries. BROTHERS (1993) found higher species richness at anthopogenic forest edges. Other studies looking at grassland/forest ecotones have found species diversity at ecotones to be intermediate between the two bounded communities (MESZAROS, 1990; TURTON & DUFF, 1992; HARPER, 1995; MEINERS *et al.*, 2000). Ecotones have unique environmental and structural characteristics that may contribute to higher species richness (GOSZ, 1992; RISSER, 1995).

The Red Sea coastal ecotone is a major ecosystem encompassing three countries, Egypt, Sudan and Eretria (about 2200 km). The soil salinity is the main stable limiting factor affects the plant growth. The rain may decrease the soil salinity but quickly the later increases under the effect of high temperature and continued evaporation. The other environmental factors as the physical characteristics of the soil and the compatible ions as K^+ and Ca^{2+} can decrease the effect of the high concentration of sodium chloride and soil sodicity (TAIZ & ZEIGER, 2002).

Several Egyptian researchers studied the vegetation in the Red Sea and Eastern Desert. ZAHRAN (2010) divided the Red Sea coastal lands into two main habitat groups: saline and non-saline. SALAMA & El-NAGGAR (1991) in the wadi system west of Qusseir province showed that two community types were recognized: *Capparis decidua* and *Tamarix nilotica* covering the deltaic areas and the end parts of the wadis. Some members of these communities were halophytes. SHALTOUT *et al.* (2003) studied the phytosociological behavior and size structure of *Nitraria retusa* along the Egyptian Red Sea coast in relation to the prevailing environmental gradients. The vegetation of important wadis that drain into the Red Sea, Wadi Araba, Abu-Ghusun and Gemal, has been investigated under different aspects (EL-SHARKAWY *et al.*, 1982, 1990; SHARAF EL-DIN & SHALTOUT, 1985; DARGIE & EL-DEMERDASH, 1991; ZAREH & FARGALI, 1991; SHEDED, 1992; GALAL, 2011; GALAL & FAHMY, 2012).

Understanding the relationship between the prevailing environmental conditions and the responses of the survived plants can explain how the ecotonal vegetation formed. The aim of the current study is to investigate the impact of soil characteristics on the vegetation structure and species distribution, across the chemo-ecotone between Eastern desert and Red Sea. Chemo-ecotone is (KAMEL, 2003) generally controlled by soil sodicity (Sodium adsorption ratio - SAR).

Material and Methods

Study area

The study area extends along the Red Sea, between latitudes 26° 39′ 47″ N and 25° 43′ 20″ N and altitudes 33° 56′ 28″ E and 34° 32′ 26″ E starting from Safaga till 50 km south Qusseir, which represent a part of the ecotone between Red Sea coast and Eastern Desert (Fig. 1). The study area includes the deltas of 13 drainage basins that represent the main flooding sites in this area.

The selected transects were located at the deltas of wadis (Nuqara, Safaga, Abu Shiqili El-Bahari, Abu Hamra El-Bahari, She'b Goma'a, Quei, Abu Hamra El-Qibli, Hamrawein, Abu Shiqili El-Qibli, Transect10, Esel, Sherm El-Qibli and Um Gheig) which run across the ecotone to discharge into the Red Sea.

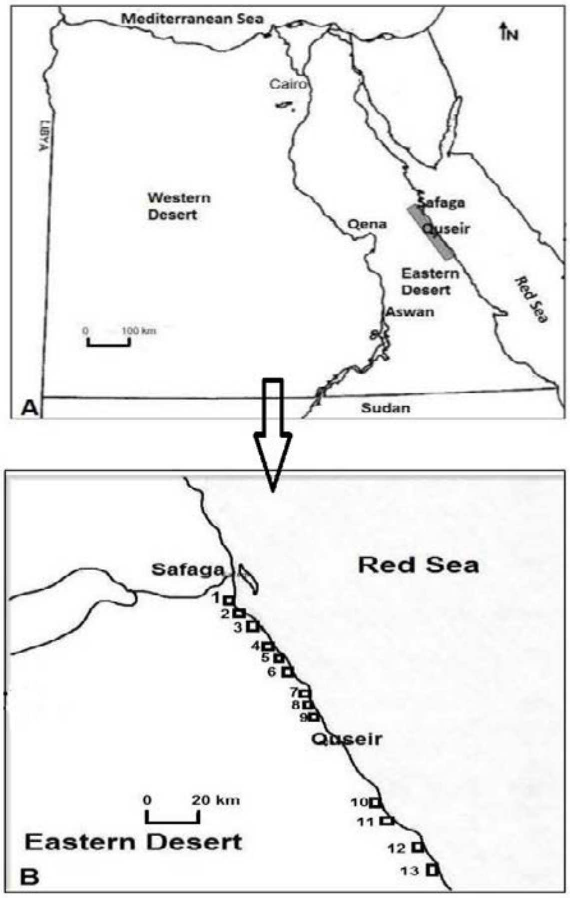

Fig. 1: The transects (1-13) in the study area, a part of the ecotone between Red Sea and Eastern Desert, were selected at the deltas of following wadis: 1. Nuqara; 2. Safaga; 3. Abu Shiqili El-Bahari; 4. Abu Hamra El-Bahari; 5. She'eb Goma'a; 6. Quei; 7. Abu Hamra El-Qibli; 8. Hamrawein; 9. Abu Shiqili El-Qibli; 10. Transect10; 11. Esel; 12. Sherm El-Qibli; 13. Um Gheig.

Geology and Geomorphology

The area from Safaga to south Qusseir represents a part of the Eastern Desert of Egypt at the Red Sea Coast forming a narrow coastal plain boarded from the west by the basement relief. The coastal plain strip of the Red Sea in the study area is occupied by Cenozoic rocks of both Tertiary and Quaternary age. The Tertiary rocks are represented by sandstone, lime-grits, conglomerates, carbonate terrigenous sediments, and gypsum. The Quaternary rocks are composed of wadi and terrace deposits consisting of detritus sand, pebbles, and rare boulders (HUME, 1912, 1934; AKAAD & DARDIR, 1966; SAID, 1990).

Climate

The climate is generally subtropical. Meteorological data during the period 2011-2012 was obtained from El-Qusseir station. The average of mean temperature ranged between 18.43°C in January and 30.81°C in August. The average of maximum temperature was 33.50°C in August and 22.70°C in December, while the average of minimum temperature was 27.09°C in August and 13.89°C in January. The relative humidity (%) ranged between 42.94 in May and 56.06 in December. Wind speed was 2-4 m/s around the year. The rainfall is scanty generally and irregular, yet in the period of study it was rainless.

Transects

Thirteen locations (transects) were selected, perpendicular to the Red Sea coast, depending on the vegetation richness. Transects were named according to the name of the opposite wadi (Table 1). The area of transects and number of stands were dependent on the width of the deltas of different wadis. For example, transect of Wadi Abu Shiqili El-Bahari has length 160m and width 100m while Wadi Sherm El-Qibli (Fig. 2) - 1900m and 300m respectively.

Table 1. Locations of the studied transects along Safaga-Qusseir Road

Location	Latitude	Altitude
Nuqara	26°39'40.50"N	33°56'24.68"E
Safaga	26°37'55.83"N	33°59'15.21"E
Abu Shiqili El-Bahari	26°33'20.69"N	34°02'10.08"E
Abu Hamra El-Bahari	26°24'13.78"N	34°06'37.02"E
She'eb Goma'a	26°22'43.68"N	34°07'55.92"E
Quei	26°20'58.09"N	34°09'00.99"E
Abu Hamra El-Qibli	26°16'40.97"N	34°11'06.78"E
Hamraween	26°15'10.51"N	34°12'01.45"E
Abu shiqili El-Qibli	26°13'48.47"N	34°12'38.78"E
Transect 10	25°53'53.00"N	34°24'34.01"E
Esel	25°51'51.31"N	34°24'42.24"E
Sherm El-Qibli	25°45'49.56"N	34°30'32.51"E
Um Gheig	25°43'23.73"N	34°32'29.55"E

After a reconnaissance survey in 2011, 98 stands were selected in the different transects to represent as much as possible the variation in the vegetation and geo-referenced using GPS techniques. The stands were distributed as possible as to cover all the vegetation depending on the width of wadi delta and the topography of the place. The area of used stand was $625\ m^2$ (25×25 m).

In each stand, ecological notes, presence or absence of plant species were recorded. The recorded taxa were classified according to the life-form system that proposed by RAUNKIAER (1937) and HASSIB (1951). The presence value of each species was expressed as the number of times a plant species is present in a given number of stands. The number of species within each life-form category was expressed as a percentage of total number of species in the study area. Analysis of phyto-geographical ranges was carried out after ZOHARY (1966, 1972); ABD EL-GHANI (1981, 1985). Taxonomic nomenclature was according to TĂCKHOLM (1974); COPE & HOSNI (1991); BOULOS (1995, 1999, 2000, and 2002) and EL HADIDI & FAYED (1995). Voucher specimens of each species were collected, and identified at the Herbaria of South Valley and Aswan Universities.

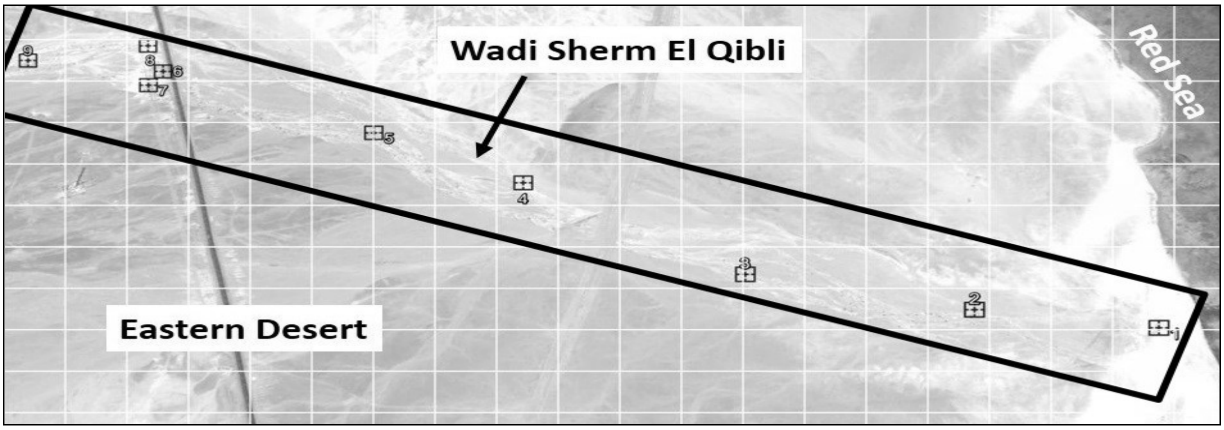

Fig. 2. Transect of Wadi Sherm El-Qibli (1900 m × 300 m) and the distributed quadrats on a gridded map.

Soil samples were collected from the studied stands at 0-50 cm depth. The different fractions of the collected sandy soil samples were separated using the dry sieving method (PIPER, 1950; RYAN *et al.*, 1996). Calcium carbonate was determined after JACKSON (1967). The soil organic matter was determined after SPARKS *et al.* (1996). Soil water content was determined by weighing a fresh sample of the soil and dried it in the oven at 105°C for 24 hours. The soil soluble solutes were extracted by shaking 20 g of soil with 100 ml distilled water for one hour. Filtration through a filter paper was carried to obtain a clear filtrate. Reaction (pH) and electrical conductivity (C, $mS\ cm^{-1}$) was estimated in the clear soil filtrate using pH-meter and conductivity meter according to JACKSON (1967). Sodium and potassium were determined by flame photometry according to ALLEN *et al.* (1986). Calcium and magnesium were determined volumetrically by the versene titration method described by UPADHYAY & SHARMA (2005). Chlorides were volumetrically determined as AgCl (KOLTHOFF & STENGER, 1974; HAZEN, 1989). Sulphates wasv estimated by turbidimetry as $BaSO_4$, according to BLACK *et al.* (1965). Phosphates were determined colourimet-rically as phospho-molybdate according to WOODS & MELLON (1941). Nitrates were determined spectrophotometrically by the hydrazine reduction method described by KAMPHAKE *et al.* (1967), carbonates and bicarbonates were estimated by titration using the method described by RICHARD (1954).

Two-Way Indicator Species Analysis (TWINSPAN), as a classification technique and Detrended Correspondence Analysis (DECORANA), as an ordination technique, were applied to the presence estimates of the recorded taxa in 98 stands (HILL, 1979a,b). Species richness (α-diversity) of each vegetation cluster was calculated as the average number of species per stand and species turnover (β-diversity) as the ratio between the total species recorded in a certain vegetation cluster and its alpha diversity (PIELOU, 1975; SHALTOUT, 1985). The statistical evolution of vegetation-environmental relationships was done using the linear correlation coefficient (r); the Karl Pearson's Correlation Analysis statistical tool was calculated using SPSS version-20 (PALLANT, 2005).

The relationship between plant species variation and environmental variation was assessed using canonical correspondence analysis (CCA) (TER BRAAK, 1986, 1995). For this analysis, a second samples-by environmental factors data matrix was also constructed; it consisted of 19 environmental factors and 98 quadrats.

Results

The survey resulted in 45 species (38 perennials and 7 annuals) belonged to 38 genera from 24 families (Table 2). Leguminosae was represented by six species and five genera followed by Zygophyllaceae (5 species and 2 genera), Compositae (4 species and 3 genera). Both Boraginaceae and Graminae had three species from 3 different genera. Every family of Caryophyllaceae, Chenopodiaceae, Cruciferae and Resedaceae was represented by two species and 2 genera. Tamaricaeae represented by one genus and 2 species. The other recorded families were represented by only one genus and one species.

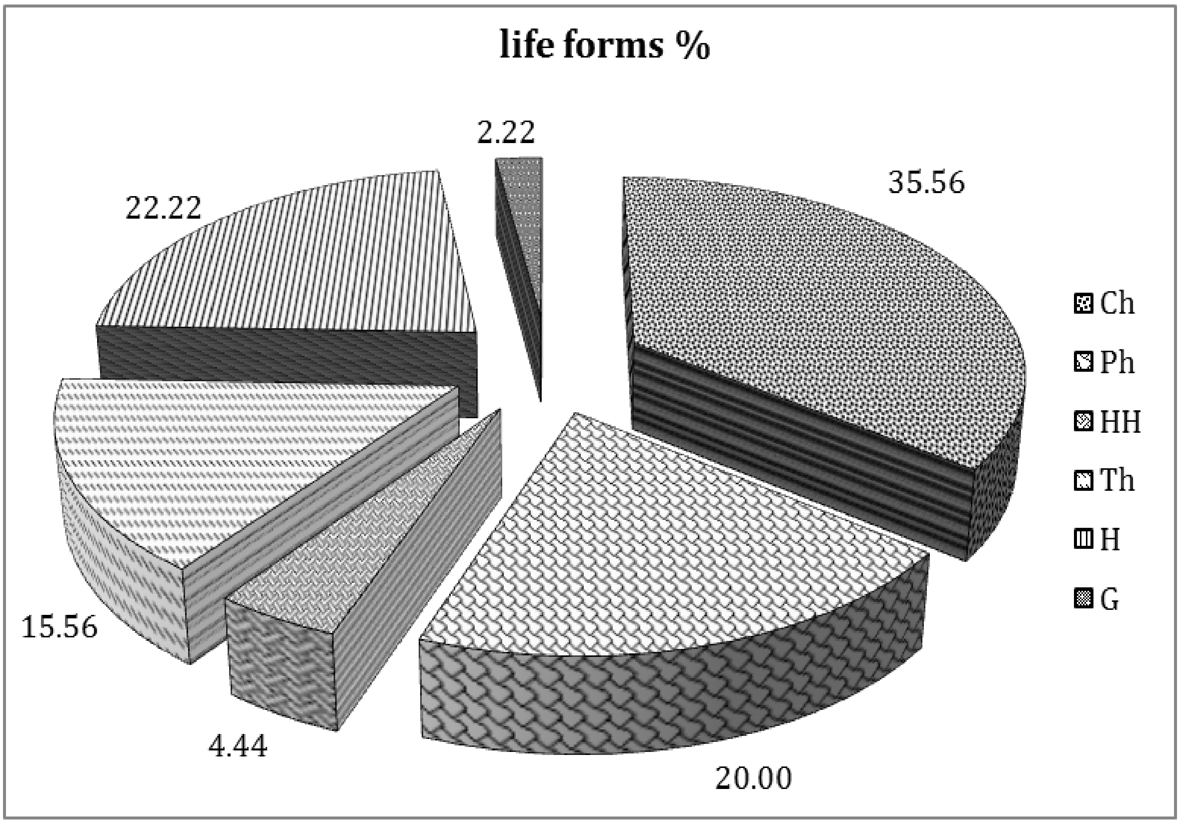

Fig 3. The percent of different plant life forms represented in the study area.

Table 2. Floristic composition, life span (L.S.), life forms (L.F.), chorology and presence value (P%) of the recorded species in the study area.

Species	L.S.	L.F.	Chorology	P%
Amaranthaceae				
Aerva javanica (Burm. f.) Juss. ex Schult.	Per	Ch	SA-SI+S-Z	1.02
Asclepiadaceae				
Leptadenia pyrotechnica (Forssk.) Decne	Per	Ph	S-Z+SA-SI	1.02
Avecinniaceae				
Avicennia marina Forssk.	Per	HH	SA-SI+S-Z	1.02
Boraginaceae				
Arnebia hispidissima Lehm.	Ann	Th	S-Z+SA-SI	2.04
Heliotropium bacciferum Forssk.	Per	Ch	S-Z+SA-SI	3.01
Trichodesma africanum v. *heterotrichum* Bornm.	Per	Ch	IR-TR+SA-SI	7.14
Capparaceae				
Capparis sinaica Veill. in Duh.	Per	Ph	SA-SI+S-Z	2.04
Caryophyllaceae				
Polycarpaea robbairea Kuntze.	Per	H	SA-SI+S-Z	5.1
Polycarpaea repens Forssk.	Per	H	SA-SI+S-Z	9.2
Chenopodiaceae				
Arthrocnemum macrostachyum Moric.	Per	Ch	ME+SA-SI+IR-TR	4.08
Suaeda pruinosa Lange.	Per	Ch	ME+IR-TR	1.02
Cleomaceae				
Cleome droserifolia Forssk.	Per	H	SA-SI+S-Z	5.1
Compositae				
Pulicaria arabica L.	Per	Ch	ME+IR-TR	9.18
Pulicaria incisa Lam.	Per	Ch	S-Z+SA-SI	11.2
Sonchus oleracous L.	Ann	Th	COSM	5.1
Cotula cinerea Delile.	Ann	Th	SA-SI	2.04
Convolvulaceae				
Convolvulus hystrix Vahl.	Per	Ch	S-Z+SA-SI	10.2
Cruciferae				
Morettia philaeana (Delile) DC.	Per	H	SA-SI+S-Z	4.08
Zilla spinosa (L.) Prantl.	Per	Ch	SA-SI	51.02
Leguminosae				
Acacia tortilis (Forssk.) Hayne subsp *raddiana* (Savi) Brenan	Per	Ph	S-Z+SA-SI	2.04
*Acacia tortilis (*Forssk.) Hayne subsp *tortilis*	Per	Ph	S-Z+SA-SI	18.37
Astragalus vogelii Webb.	Ann	Th	SA-SI+S-Z	16.33
Lotus hebranicus Hochst. ex Brand.	Per	H	SA-SI	29.59
Crotalaria aegyptiaca Benth.	Per	H	SA-SI+S-Z	4.08
Taverniera aegyptiaca Boiss.	Per	Ch	S-Z+SA-SI	6.12
Geraniaceae				
Monsonia nivea v. *intermedia* Tackh. & Boulos.	Per	H	SA-SI+S-Z	2.04
Gramineae				
Aeluropus lagopoides Fresen.	Per	H	SA-SI	5.1
Panicum turgidum Forssk.	Per	G	SA-SI+S-Z+IR-TR+ME	9.18
Phragmites australis (Cav.) Trin. ex Steud.	Per	HH	PAN	13.27
Juncaceae				
Juncus acutus L.	Per	Ch	ME+IR-TR	1.02
Malvaceae				
Malva parviflora L.	Ann	Th	ME+IR-TR+SA-SI	1.02
Nitrariaceae				
Nitraria retusa	Per	Ph	SA-SI+S-Z	43.88
Palmae				
Phoenix dactylifera L.	Per	Ph	S-Z+SA-SI	1.02
Plumbaginaceae				
Limonium pruinosum L.	Per	H	SA-SI	9.18

Species	L.S.	L.F.	Chorology	P%
Resedaceae				
Ochradenus baccatus Delile.	Per	Ph	SA-SI+S-Z	4.08
Reseda pruinosa Delile.	Ann	Th	SA-SI	17.35
Scrophulariaceae				
Kickxia acerbiana (Boiss.) Tackh. &. Boulos.	Per	Ch	SA-SI	4.08
Tamaricaceae				
Tamarix aphylla (L.) H.Karst.	Per	Ph	SA-SI+S-Z+IR-TR+ME	10.2
Tamarix nilotica (Ehrenb.) Bunge.	Per	Ph	SA-SI+S-Z+IR-TR+ME	56.12
Urticaceae				
Forsskaolea tenacissima L.	Per	H	SA-SI+S-Z	9.18
Zygophyllaceae				
Fagonia arabica L.	Per	Ch	SA-SI	4.08
Fagonia indica Burm. F.	Per	Ch	SA-SI+S-Z	4.08
Zygophyllum album L.	Per	Ch	SA-SI+ME+IR-TR+S-Z	23.5
Zygophyllum coccineum L.	Per	Ch	SA-SI+S-Z	89.8
Zygophyllum simplex L.	Ann	Th	S-Z+SA-SI	22.45

Legend: Per, Perennial; Ann, Annual; Ch, Chamaephyte; Ph, Phanerophyte; Th, Therophyte; H, Hemicryptophyte; G, Geophyte; HH, Hydrophytes and Helophytes; PAN, Pantropical; S-Z, Sudano-Zambezian; ME, Mediterranean; IR-TR, Irano-Turanian; SA-SI, Saharo-Sindian; COSM, Cosmpolitan

As shown in Fig. 3, chamaephytes were the most prevailed life form (16 species, 35.56 % of the recorded species). Hemicryptophytes was represented by 10 species (22.22%) while phanerophytes was represented by 9 species forming 20% of recorded species. Therophytes was represented by 15.56% of recorded species (7 species). Geophytes were represented by 2.2% (only one species) while hydrophytes and helophytes were represented by 4.4% of the recorded species (2 species).

Chorological analysis (Fig. 4) showed that the bi-regional species was the most dominant. There was 29 bi-regional species represent 64.44% of the total species. Most of the bi-regional species belong to saharo-sindian/sudano-zambezian. Eight species (17.78%) represented the mono-regional element. They were saharo-sindian. The pluri-regional elements were six species (13.33%) belong to saharo-sindian, sudano-zambezian, irano-turanian and Mediterranean. One species is cosmopolitan element (*Sonchus oleraceous*) and another is pantropical element (*Phragmites australis*).

TWINSPAN classified vegetation into nine clusters at fourth hierarchical level (Fig. 5). The clusters according to the indicator species were as follows: *Convolvulus hystrix* (I), *Astragalus vogelii- Lotus hebranicus* (II), *Acacia tortillis* subspecies *tortilis-Tamarix aphylla- Forsskaolea tenacissima* (III), *Zygophyllum cocineum-Zilla spinosa* (IV), *Limonium pruinosum* (V), *Nitraria retusa-Zygophyllum album* (VI), *Phragmites australis* (VII), *Zygophyllum coccineum* (VIII), *Arthrocnemum macrostachyum* (IX).

The Detrended Correspondance Analysis (DCA) distributed the vegetation on axis 1 to three groups (A, B and C) according to the soil salinity gradient (Fig. 6). The clusters I and II on the left part of axis 1 (group A) are mainly restricted to the desert ecosystem. The ecotonal group (group B) occupied the middle place and contained four clusters (III, IV, V and VII). Group B contained a mixture of species from the two neighbor ecosystems. *Aeluropus lagopoides* and *Zygophyllum album* belong to the coastal ecosystem while *Ochradenus baccatus* and *Reseda pruinosa* belong to desert ecosystem. Finally, group C included three clusters (VI, VIII and IX) occupied the right part of axis 1. It distributed near the seashore as a coastal ecosystem. The familiar halophytic species in the coastal ecosystem are (*Arthrocnemum macrostachyum, Avicennia marina* and *Suaeda pruinosa*). The highest species richness was in of cluster I, III and IV (10.67, 10.57 and 5.75 sp./stand, respectively) while cluster IX have the lowest species richness (2.5 sp./stand). Species turnover (Table 4) was the highest in clusters V, VI, VII (2.79, 2.78, 2.80; respectively).

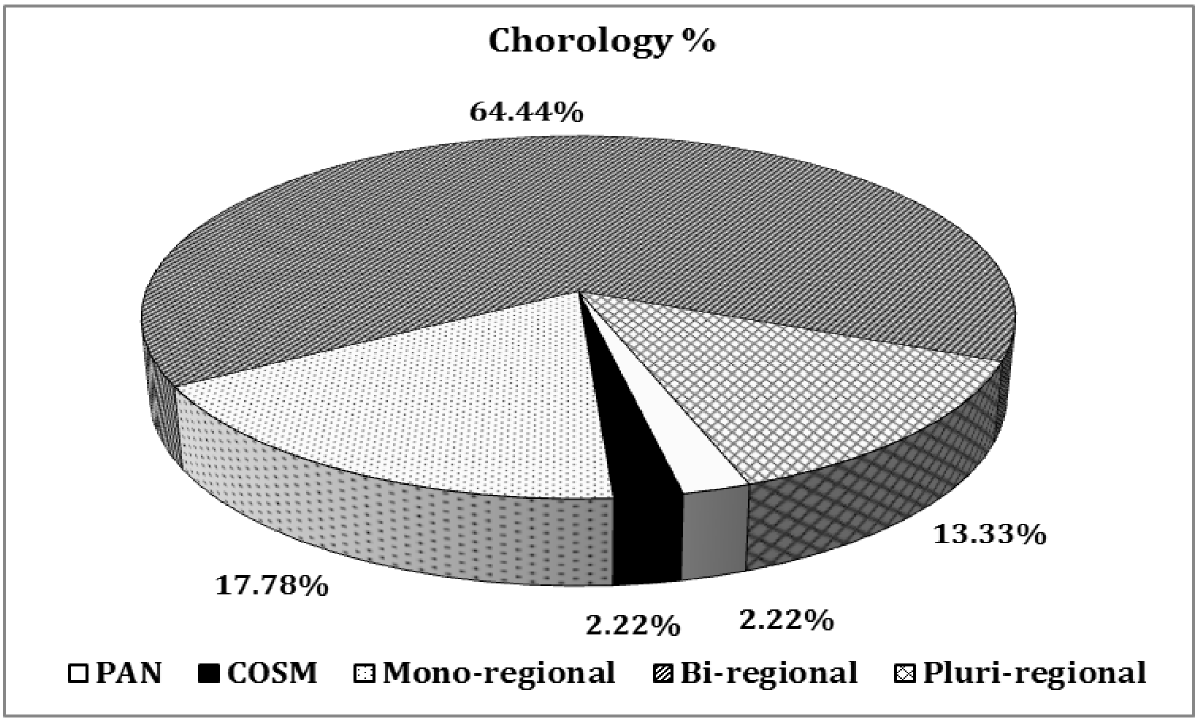

Fig. 4. The chorological affinities of different species as recorded in the study area.

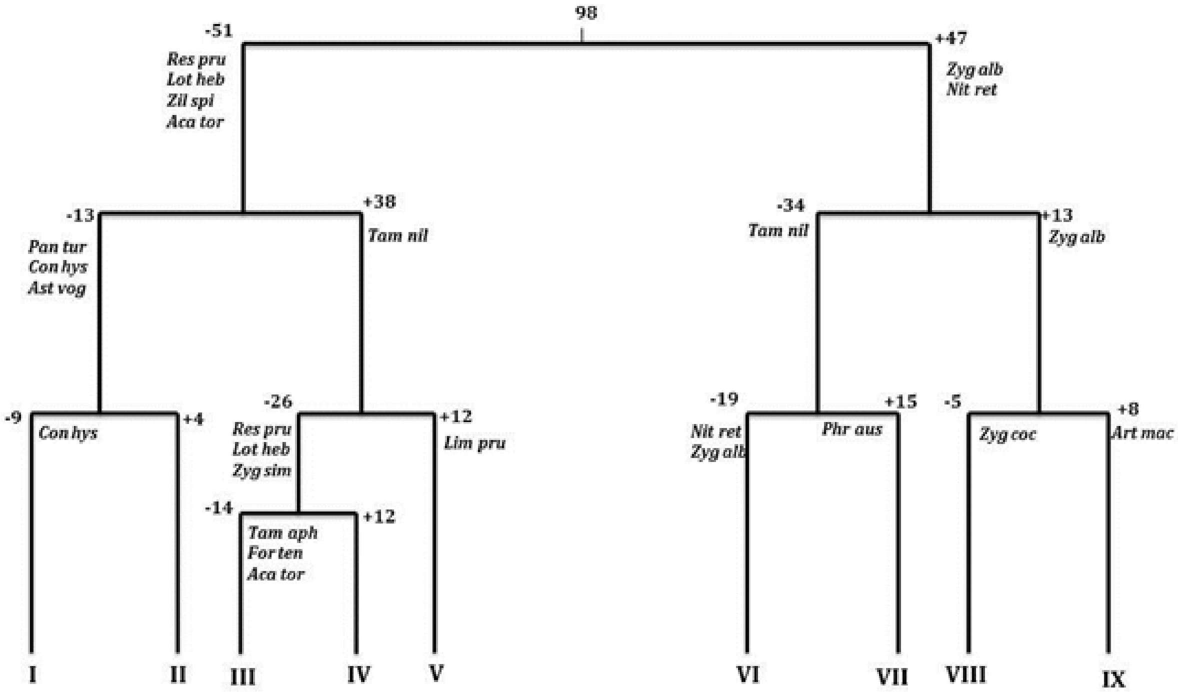

Fig. 5. TWINSPAN dendogram produced 9 clusters at the 4th level of hierarchy.

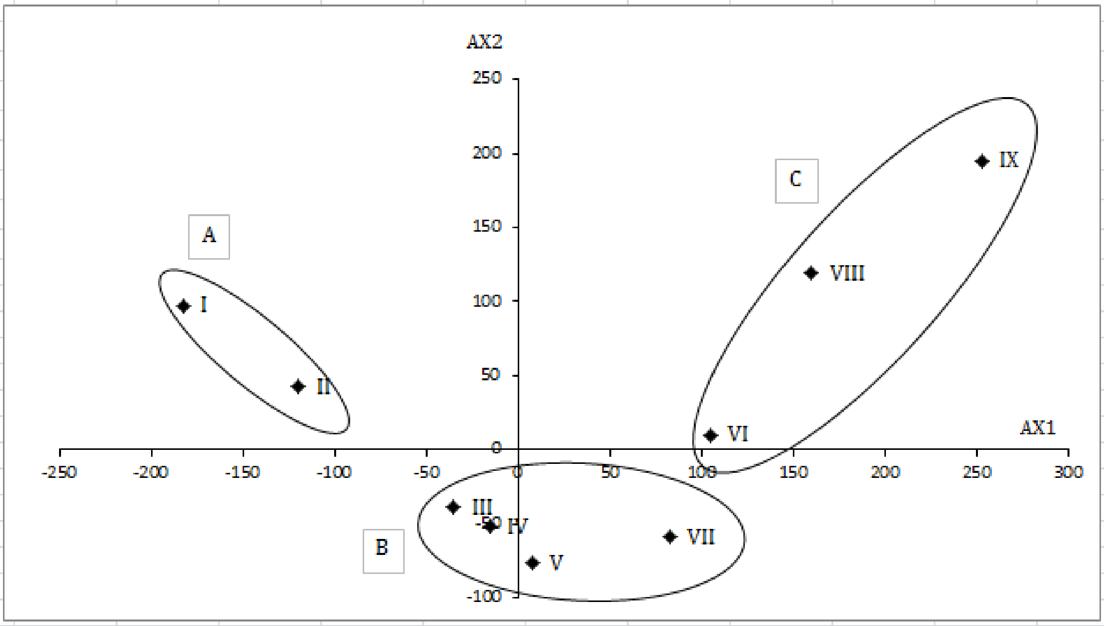

Fig. 6. Relationship between the nine vegetation TWINSPAN clusters of stands and the DCA axes 1 and 2.

Alkalinity, HCO_3^- and SO_4^{-2} correlated significantly positive with axis 1 (Table 3). Coarse sand correlated positively significant with axis 2 (r = 0.849) while clay and PO_4^{3-} correlated significant negatively. Nitrates correlates positively with axis 3. Estimated soil variables for the nine clusters represented in Table 3.

The lowest value of organic matter (2.3%), EC (1.47 mS cm^{-1}), HCO_3^- (0.91 mg g^{-1}), Cl^- (1.61 mg g^{-1}) and Na^+ (0.98 mg g^{-1}) in the soil samples of cluster I. The soil of cluster II had the highest value of fine sand (37.5%) and the lowest values of water content (0.24%), pH (7.64), K^+ (0.77 mg g^{-1}) and Mg^{2+} (0.51 mg g^{-1}). The soil of cluster III had the lowest values of $CaCO_3$ (9.62%), SO_4^{2-} (0.62 mg g^{-1}) and NO_3^- (0.12 mg g^{-1}). Cluster (IV) soil had the highest value of silt (25.67%) and the lowest value of Ca^{2+} (1.17 mg g^{-1}). The soil of cluster (V) had the highest value in EC (47.64 mS cm^{-1}), clay (60.74%), Cl^- (18.25 mg g^{-1}), NO_3^- (0.18 mg g^{-1}), Na^+ (4.48 mg g^{-1}), K^+ (6.51 mg g^{-1}) and Ca^{2+} (6.04 mg g^{-1}) and the lowest values of coarse sand (14.38%) and fine sand (12.99%). The soil of cluster (VII) had the highest value of water content (8.57%), oraganic matter (8.82%) and PO_4^{3-} (2.44 mg g^{-1}). The soil of cluster (VIII) contained the highest percent of coarse sand (48.64%) and the lowest percent of silt (10.41%). Calcium carbonate was 13.45% and estimated Mg^{2+} about 5.45 mg g^{-1}.

Table 3. Correlations coefficients (r) between the estimated soil variables and DCA axes 1, axes 2 and axes 3. * Correlation is significant at $p<0.05$. ** Correlation is significant at $p<0.01$.

Soil variables	AX1	AX2	AX3
WC, %	0.484	-0.310	0.619
pH	**0.779***	0.551	-0.570
EC(mS cm^{-1})	0.642	-0.095	0.388
TDS (g L^{-1})	0.528	-0.292	0.261
Coarse Sand, %	0.121	**0.849****	-0.307
Fine Sand, %	0.007	0.388	-0.159
Silt, %	-0.203	-0.521	-0.087
Clay, %	-0.040	**-0.697***	0.343
OM, %	0.640	-0.333	0.424
HCO_3 mg g^{-1}	**0.807****	0.157	-0.194
$CaCO_3$,%	0.424	0.544	0.097
Cl (mg g^{-1})	0.593	-0.090	0.304
SO_4 (mg g^{-1})	**0.672***	0.487	0.045
PO_4 (mg g^{-1})	-0.408	**-0.909****	0.477
NO_3 (mg g^{-1})	-0.410	-0.394	**0.720***
Na (mg g^{-1})	0.646	-0.204	0.485
K (mg g^{-1})	0.416	-0.168	0.519
Ca (mg g^{-1})	0.406	-0.231	0.620
Mg (mg g^{-1})	0.515	-0.055	0.339

The soil of cluster (IX) had the highest value of pH (8.72), HCO_3^- (1.18 mg g^{-1}), SO_4^{2-} (1.45 mg g^{-1}) and the lowest values of both PO_4^{3-} (1.46 mg g^{-1}) and NO_3^- (0.12 mg g^{-1}).

The correlation between the resulted vegetation groups and the soil characteristics is indicated on the ordination diagram (Fig. 7) produced by the canonical correspondence analysis (CCA). The arrows represent the environmental variables and indicate the direction of maximum change of that variable across the diagram. The length of the arrow is proportional to the rate of change.

As shown in Fig. 7, CCA axis 1 correlated positively with SO_4^{2-}, pH, Mg^{2+}, Ca^{2+}, K^+, Na^+, Cl^-, HCO_3^- and OM, while correlated negatively with NO_3^-, PO_4 and coarse sand. CCA axis 2 correlates positively with coarse sand and CO_3 and negatively with PO_4 and clay. Axis 1 clearly represents the salinity gradient. On the other hand, axis 2 correlated strongly and positively with coarse sand. In the same time there is weak positive with fine sand. Axis 2 correlated negatively with clay, silt and phosphate. It is clear that axis 2 is correlated with the soil structure. Group A that represent the desert ecosystem (true xerophytic plants) were affected by soil content of nitrate strongly. Group B in the ecotone affected by the percent of clay and silt in addition to the soil content of phosphate. Finally, group C that represents the coastal ecosystem (halophytic plants) was affected strongly by the in organic osmolytes.

Discussion

It known that ecotone is an area of tension between two interfered ecosystems (CADENASSO *et al.*, 2003a,b). The ecotones may form due to an environmental gradient or competition between the species of the interfered ecosystems. The ecotone can be created by man-made or natural factors, especially the abiotic factor gradients in soils composition, pH, soil salinity, soil mineral content as well as topography (WIENS *et al.*, 1985; VAN DER MAAREL, 1990; KENT *et al.*, 1997; EGGEMEYER & SCHWINNING, 2009). These gradients have specific attributes, creating "hydro-ecotones" or "chemo-ecotones", and so forth (KAMEL, 2003; DE ANGELIS, 2012).

The Red Sea coast represents an ecotone between Red Sea and Eastern desert. ZAHRAN (2010) divided the Red Sea coastal lands into two main habitats: saline (mangrove swamps and the littoral salt marshes) and non-saline (coastal desert plains and coastal mountains). The Red Sea-Eastern Desert ecotone is controlled by soil salinity. Therefore, it identified as chemo-ecotone according the KAMEL (2003).

The current work is carried out to understand the impact of environmental gradient on the species distribution, vegetation structure and to detect the ecotonal area between the coastal halophytic ecosystem and the desert ecosystem.

Forty-five species (38 perennials, 7 annuals) belonging to 38 genera and 24 families were recorded. *Z. coccineum, T. nilotica, Z. spinosa* and *N. retusa* had the highest presence values within the study area. The most frequent life forms are chamaephytes (35.6%). The chorological analysis showed that the Saharo-Sindian chorotypes are the dominant members in the study area. This agreed with the results obtained by HASSAN (1987), SHEDED (1992) and EL-DEMERDASH *et al.* (1994). The ecotone was dominated by Saharo-Sindian chorotype. This reflects the high diversity in the ecotone compared with the desert and coastal ecosystems. This agrees with the result obtained by CARTER *et al.* (1994) and KIRKMAN *et al.* (1998).

The soil texture of clusters I and II (group A) characterized by a high percent of coarse and fine sands compared with the soil of other clusters. The high percentage of coarse sand in the soil decreased the water capacity (ARCHER & SMITH, 1972) and consequently the salinity decreased. This can be considered as a helpful advantage to the growth of xerophytes. Other estimated physical and chemical soil characteristics were lower than that of other clusters.

In addition to that, topography played an important role to disperse the xerophytic plants toward the seacoast especially in the deltas of wadi Sherm El-Qibli, and Abu Shiqili El-Qibli. All the recorded species in

Table 4. Number of stands in each cluster, no.of species/cluster, species richness, species turnover, mean ± standerd deviation of soil variables for stands of the nine vegetation clusters in the study area. The F-value and its probability. *. P < 0.05.

Cluster	I	II	III	IV	V	VI	VII	VIII	IX	F-value
No of stands	9	4	14	12	12	19	15	5	8	
Sp./cluster	18	8	29	15	10	11	8	5	5	
Species richness	10.67	5.25	10.60	5.75	3.58	3.95	2.86	3.20	2.50	
Species turnover	1.69	1.52	2.74	2.61	2.79	2.78	2.80	1.56	2.00	
WC, %	0.32±0.49	0.24±0.11	0.83±0.86	1.62±1.90	3.25±2.82	3.68±6.15	8.57±10.76	1.18±0.91	3.47±4.98	1.949
pH	7.93±0.50	7.64±0.25	8.20±0.42	8.00±0.40	7.83±0.56	8.20±0.52	7.98±0.55	8.19±0.61	8.72±0.58	1.748
EC, mS cm^{-1}	1.47±1.61	2.44±1.64	2.35±3.74	6.37±13.42	47.64±59.74	32.06±33.56	29.54±36.15	36.23±36.02	24.50±17.23	2.305*
Coarse sand, %	45.94±27.29	38.05±15.37	30.17±24.21	16.04±19.72	14.38±22.26	37.26±25.48	25.44±23.27	48.64±23.98	41.18±32.12	1.851
Fine sand, %	24.03±9.63	37.50±9.59	22.89±14.72	26.21±13.53	12.99±16.14	24.30±15.74	28.64±20.12	30.90±14.53	27.00±15.11	1.053
Silt, %	14.36±11.56	12.50±6.44	17.20±14.30	25.67±13.58	11.90±9.50	14.83±12.32	17.99±8.07	10.41±8.35	12.64±14.16	1.248
Clay, %	15.67±11.93	11.95±9.16	29.75±25.38	32.08±21.12	60.74±37.97	23.61±26.16	27.92±26.57	10.05±15.78	19.18±27.41	2.406*
OM, %	2.30±1.45	2.32±0.41	3.48±1.90	5.66±5.13	8.55±5.88	7.67±5.38	8.82±6.03	7.74±4.71	5.37±2.94	2.173*
HCO_3, mg g^{-1}	0.91±0.24	0.92±0.15	0.97±0.20	1.08±0.27	1.05±0.15	1.00±0.21	1.04±0.27	1.02±0.33	1.18±0.40	1.200
$CaCO_3$, %	11.42±3.62	13.35±0.69	9.62±3.40	11.97±1.89	11.63±3.57	11.58±2.86	12.33±1.23	13.45±1.68	13.40±1.49	1.781
Cl^-, mg g^{-1}	1.61±2.71	1.67±0.31	3.50±5.23	3.24±4.36	18.25±22.5	7.77±6.47	9.02±12.97	12.21±10.91	10.03±4.47	1.954
SO_4^{2-}, mg g^{-1}	0.66±0.56	1.28±0.31	0.62±0.54	0.75±0.66	1.08±0.48	1.05±0.63	1.10±0.53	1.43±0.14	1.45±0.21	2.389*
PO_4^{3-}, mg g^{-1}	1.92±0.33	1.84±0.20	2.29±2.11	2.21±0.48	2.27±0.87	1.81±0.88	2.44±1.00	1.69±0.32	1.46±0.32	0.542
NO_3^-, mg g^{-1}	0.16±0.03	0.16±0.06	0.12±0.09	0.14±0.05	0.18±0.11	0.17±0.05	0.15±0.05	0.13±0.03	0.12±0.05	1.034
Na^+, mg g^{-1}	0.98±0.84	1.25±1.47	1.44±1.78	1.41±2.04	4.48±4.82	3.81±4.35	4.00±4.23	2.79±2.26	3.18±1.45	1.313
K^+, mg g^{-1}	1.69±2.01	0.77±0.89	1.16±1.56	1.12±1.05	6.51±8.39	2.65±5.21	3.97±6.47	1.97±1.52	4.01±5.29	1.133
Ca^{2+}, mg g^{-1}	1.74±2.30	2.58±2.23	1.46±0.95	1.17±1.11	6.04±5.01	4.96±4.56	5.12±5.20	4.84±4.90	2.44±2.23	1.951
Mg^{2+}, mg g^{-1}	0.89±1.05	0.51±0.81	1.01±1.87	0.73±1.24	3.29±2.86	2.88±3.00	3.66±5.36	5.45±8.19	1.15±0.80	1.468

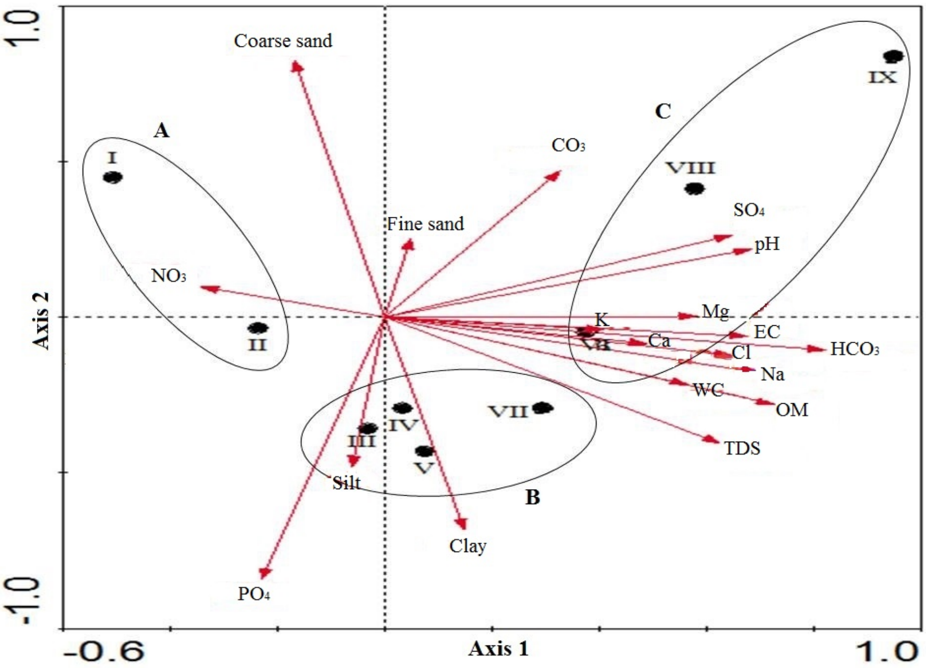

Fig. 7. CCA ordination of the first two axes showing the distribution of the 9 TWINSPAN clusters encircled in three vegetation groups (A, B & C) and different soil variables.

these locations were xerophytic plants. These variations in the elevation lead to form a fragmented ecotone (GOSZ & SHARPE, 1989).

On the other hand, the soil of the coastal ecosystem (group C) was characterized by high content of saline water. The soil texture in group A (desert ecosystem) and group C (coastal ecosystem) was approximately similar. The limiting factor in this case was the salinity and ionic content where the electrical conductivity (EC) increased up to 47.64 mS cm^{-1} in the soil of group B. The maximum EC value in group A reached 2.44 mS cm^{-1}. All the estimated cations and anions were higher in group C. These conditions were encouraging to the growth of halophytes in the coastal zones. In coastal zones as well as inland areas where salt pans exist, sharp ecotones may be maintained between halophytic (salinity-tolerant) and glycophytic (salinity-intolerant) vegetation (BURCHILL & KENKEL, 1991; GROSSHANS & KENKEL, 1997; STERNBERG *et al.*, 2007; TEH *et al.*, 2008; JIANG *et al.*, 2012a,b,c). The computed soil sodicity indicated that the halophytes survived in sodicity range between 2.25 – 3.21 while xerophytes between 0.18 – 1.86 (KAMEL *et al.*, 2013).

The precipitation of silt and clay that carried by rains and torrents from the inland at the ecotonal area (group B) increased the percentage of both in the soil texture. In addition, dissolved potassium and calcium came with rainwaters to the ecotone. The decomposition of plant residues that came with rainwaters increased the organic matter content in the ecotonal zone. The statistical analysis using SPSS showed a significant F value with EC, clay and organic matter. K^+ and Ca^{2+} can decrease the sodium toxicity (TAIZ & ZEIGER, 2002) and lead to enrich the vegetation diversity in the ecotone (TRAUT, 2005). The other chemical and physical soil characteristics were intermediated between the soil characteristics of coastal and desert ecosystems.

These conditions encouraged the species that can tolerate a wide range of drought and salinity (halo-xerophytes) such as *Nitraria retusa, Phragmites australis, Tamarix nilotica, Tamarix aphylla* and *Zygophyllum coccineum* (SAUER, 1965; TÄCKHOLM, 1974; ARONSON *et al.*, 1988). Therefore, they were the most dominant species in the ecotone (group B). The coexistence of both halo-xerophytes with the species of the interfered ecosystems in addition to the ecotonal species enriched the vegetation in the ecotone. There were two ecotonal species, *Limonium pruinosum* (Saharo-Arabian) and *Aeluropus lagopoides*, where survived in narrower range of soil sodicity (SAR) between 1 and 1.5 (KAMEL *et al.,* 2013)**.** The species richness and species turnover in the ecotone (clusters III, IV, V and IV) were higher than that in the desert and coastal ecosystems. This agreed with SHMIDA & WILSON (1985), WOLF (1993), KERNAGHAN & HARPER (2001). CARTER *et al.* (1994) and KIRKMAN *et al.* (1998) found higher species richness in wetland/upland boundaries. BROTHERS (1993) found higher species richness at anthropogenic forest edges. Other studies looking at grassland/forest ecotones have found species diversity at ecotones to be intermediate between the two bounded communities (MESZAROS, 1990; TURTON & DUFF, 1992; HARPER, 1995, LLOYD *et al.,* 2000; MEINERS *et al.,* 2000).

Results obtained by CCA ordination (Fig. 7) showed that the plants of desert ecosystem were affected by the NO_3^- concentration in the soil. It is logical as desert plants depend on the amino acids and soluble proteins more than the other plants (MILE *et al*., 2002). Nitrogen is necessary element in protein synthesis.

On the other hand, the plants in coastal ecosystem were affected by the most of inorganic solutes. This is also may explain their ability to accumulate great amounts of inorganic solutes to readjust their internal osmotic pressure. The distribution of species in saline and marshy habitats relates to salinity in many arid regions has been discussed by several authors as KASSAS (1957), FLOWERS (1975) and MARYAM *et al.* (1995). Also ZAHRAN *et al.* (1996) demonstrate the distribution of some halophytic species is best correlated along a gradient of soil variables as salinity, moisture content, soil texture, organic matter, and calcium carbonate.

The ecotonal plants are characterized by their ability to accumulate inorganic solutes. Therefore, they were affected by the percent of clay which increases the soil field capacity at moderate soil salinity. ANDERSON *et al.* (1990) suggested that the presence and relative abundance of xerophytes may be taken as a measure of the degree of halophytism in a plant community. The high percentage of fine particles, in the soils of ecotone area together with the other factors gives a number of xerophytes a competitive advantage over halophytes, as they are tolerant to salt.

In conclusion, it turns out that although the chemo-ecotone is controlled by soil sodicity, the soil texture fractions played great role in distribution of the vegetation. Although the significant correlation with the anions concentrations in the soil; sodium sodicity was the effective factor in detecting the ecotonal species as *Aeluropus lagopoides* and *Limonium pruinosum* which grew in intermediated range (0.5-2.5) of soil sodicity between the ranges of the coastal and desert ecosystems (KAMEL *et al.,* 2013).

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Received: 19.09.2013
Accepted: 02.12.2014