Journal of Phytology 2022, 14: 08-16
doi: 10.25081/jp.2022.v14.7377
https://updatepublishing.com/journal/index.php/jp

Research Article

ISSN: 2075-6240

Vegetation analysis and species diversity of the invasive plant *Heliotropium curassavicum* growing naturally in heterogeneous habitats

Marium Hamdy, El-Sayed F. El-Halawany, Ashraf Elsayed, Yasser A. El-Amier*

Botany Department, Faculty of Science, Mansoura University, 35516, Mansoura, Egypt

ABSTRACT

Heliotropium curassavicum is an invasive annual weed plant that spreads quickly, especially on disturbed saline soils and coastal locations in arid and semiarid habitats. This study aimed to assess the vegetation composition of the invasive plant *H. curassavicum*. The soil factors and associated species of this plant were studied in natural coastal desert habitats (northern Nile delta coast) and inland habitats (farrow land and canal bank habitats). The floristic composition revealed the occurrence of 109 species (67 annuals, 2 biennials and 40 perennials) belonging to 86 genera and related to 29 families. Asteraceae, Poaceae, Chenopodiaceae, and Fabaceae (53.21 % of all species reported) are the most abundant families. Therophytes and cryptophytes are the mainly abundant life forms and the Mediterranean chorotype is the most representative. The cluster analysis of stands expressed four vegetational groups (A, B, C and D). The most dominant species with group A was *Polypogon viridis*, with group B was *H. curassavicum*, with group C (the largest one) was *Cynodon dactylon* and *H. curassavicum* and with group D was *Phragmites australis*. Diversity indices expressed more richness and evenness of vegetation group B (*H. curassavicum* communities). The major soil factors influencing the studied invasive species are soil texture, WHC, organic carbon, cations (Na^+, K^+, Ca^{++}, and Mg^{++}), and SAR.

KEYWORDS: *Heliotropium curassavicum*, Invasiveness, Biodiversity, Ecology, Edaphic factor

Received: November 9, 2021
Revised: February 6, 2022
Accepted: February 17, 2022
Published: March 1, 2022

***Corresponding Author:**
Yasser Ahmed El-Amier
E-mail: yasran@mans.edu.eg

INTRODUCTION

Invasive plants have been identified as one of the most severe environmental issues globally (Barney *et al*., 2013). In Egypt, the growing population necessitates the expansion of agricultural land. This has been accomplished in recent decades by the reclamation of arid regions (Hegazy *et al*., 2004). Human intervention enforces weedy plants to displace native plants in the reclaimed regions, that are considered as transitional habitats between old cultivated lands and deserts (Baessler & Klotz, 2006). The involvement of bioactive phytochemical constituents (allelochemicals) into chemical weapons of invasion is one of the processes of plant invasion (Zheng *et al*., 2015). Allelochemicals are a class of beneficial secondary metabolites that includes phenolic acids, glucosinolates, flavonoids, and essential oils (Einhellig, 1995; El-Amier *et al*., 2014b).

The major element influencing the quantity of natural vegetation in deserts is anthropogenic activity (El-Amier & Abd El-Gawad, 2017). Roads and railways construction are examples of activities that have a direct influence on existing habitats, such as deterioration and/or fragmentation, as well as an indirect influence on vegetation (Spellerberg, 1998; Jackson, 2000). Many researchers described plants communities and vegetation-environment interactions in Egypt's Nile Delta (El-Amier *et al*., 2014a; El-Amier & El Hayyany, 2020).

Egypt possesses more than 3500 kilometers of coasts on the Mediterranean and Red Seas. Egypt's Mediterranean coastline area stretches for roughly 970 km from Sallum eastward to Rafah, with mean width of 20- 25 kilometers in the northern-southern direction (Zahran & Willis 2009). Higher erosion, water logging and soil salinization are all major concerns in Egypt's coastal areas, as are anthropogenic activities such as unplanned village building and ecosystem deterioration (El-Amier & Abd El-Gawad, 2017). Moreover, the Nile Delta occupies 2% of its geographical areas and 63% of all agricultural lands (~29,600 km^2) is Egypt's most heavily used region, with 41% of the population (Negm *et al*., 2016).

Heliotropium curassavicum (salt heliotrope) is an annual plant of the family Boraginaceae that is native to India, America, Hawaii, and Argentina, but considered as invasive plant in Africa, Europe, and Asia (Al-Shehbaz, 1991). It is an invasive species in Egypt's northern Mediterranean coastal area (Hegazy *et al*., 2008; Abd-ElGawad *et al*., 2019), and it has recently been discovered colonizing damaged habitats into the Nile Delta (Note from the author). This plant possesses the capability to reproduce vegetatively and sexually, allowing its colonization to a variety of environments (Hegazy, 1994). Plant bioactive components vary in response to changes in environmental circumstances (Elshamy *et al*., 2019; Abd-ElGawad *et al*., 2020), which is thought to be an adaptation mechanism since these bioactive chemicals allow plants to invade and colonize new environments (Zheng *et al*., 2015).

Invasive species continue to pose a significant threat to a variety of biological systems and species diversity across the world. Therefore, vegetation studies on invasive weed offer the quantitative data needed to design comprehensive weed community management plans, as well as the baseline data needed to track any changes in the weed flora (Frick & Thomas, 1992; Gadallah *et al*., 2019). However, the vegetation composition and available data on invasive species in Egypt are still insufficient. The current study looks at the vegetation in the Nile Delta that is dominated by *Heliotropium curassavicum*. The major goal is to investigate the variety of vegetation and species in invasive plant communities in relation to habitats types.

MATERIALS AND METHODS

Study Area

The studied area was separated into two groups: coastal desert (represented by Delta Coast) and inland habitat (represented by farrow land and canal bank) (Figure 1). The Egyptian Mediterranean coastal desert is divided into three regions: western, delta, and eastern. The Deltaic Coast is defined by the occurrence of three shallow lakes that receive most of the Nile Delta's drainage water. This section stretches for roughly 200 km from Abu-Quir (31°19′27.5″N 30°04′00.6″E) to Port-Said (31°16′09″N 32°18′19.1″E). The Nile Delta's coastal zone featured new cities construction, desert reclamation, and agricultural activities, among other things. In numerous sites, the growth of the invasive plant *H. curassavicum* is associated with cultivated lands (such as Barley, maize, tomato, sesame, and watermelons).

On the other hand, the Mediterranean Sea's impact modifies the climate along Egypt's north coast. Despite the fact that the climate of the Nile delta shore is comparable to that of the western and eastern Mediterranean, there is a distinction in vegetation composition. In addition to seawater, it is impacted by leakage water from the Damietta and Rosetta River Nile branches in addition to the northern lakes (Zahran & Willis, 2009).

Vegetation Analysis

During the months of March and May in 2019 and 2020, 45 sampling stands (10 meters × 10 meters) were randomly chosen

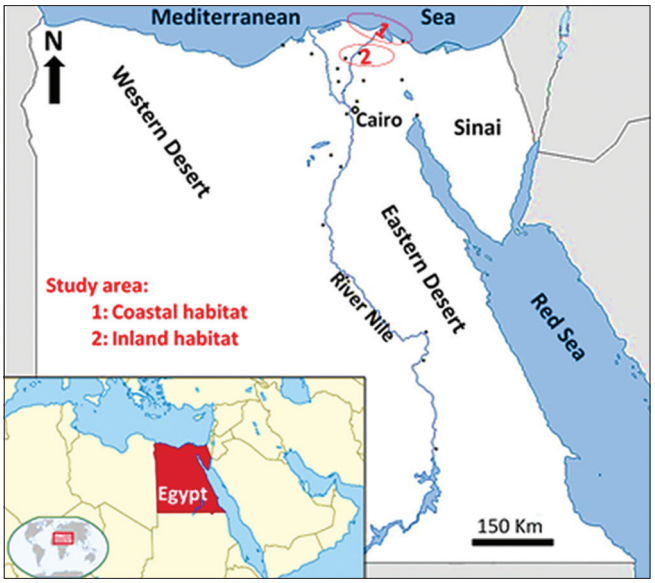

Figure 1: Map demonstrating the Nile delta and the studied area

to express a broad scale of physiographic and environmental variability in the coastal and inland environments (Nile Delta). In each plot, the density and cover of plants were recorded as adopted by Shukla and Chandel (1989). For each plant species, relative density, cover and importance values (IV) were calculated. To represent the *H. curassavicum* in the study sites, a floristic list was obtained from the 45 sites: 29 along the Deltaic Mediterranean coast and 16 from the inland habitats. Tackholm (1974) and Boulos (1999-2005) are used to identify the species reported. According to Zohary (1966 and 1972), the chorology of the plant species was localized and life forms were described in harmony with the scheme of Raunkięr (1934 - 1937).

Plants Diversity

The Shannon Wiener diversity index (H), Simpson Diversity Index (D), and Shannon evenness index (E) were determined for each community and used to compute species richness and evenness:

$$H = \sum_{i=1}^{s} P_i \ln(P_i)$$

$$D = \frac{\sum_i [n_i \times (n_i - 1)]}{[N \times (N - 1)]}$$

$$E = \frac{H}{\ln s}$$

$Pi = ni/N$, ni = the number of stands and N is the total number of species.

Soil Analysis

Three soil samples were obtained at depths of 0-20 cm from each of the 45 study sites. The samples were spread sheets of paper then air dried. For each soil sample, a soil solution (1:5) was produced.

Piper's (1947) method was used to evaluate the texture, water holding capacity (WHC), porosity, organic carbon, and sulphate content of the soil. The electrical conductivity, pH, calcium carbonate and chloride were estimated according to the assay described by Jackson (1962). Titration with 0.1N HCl was used to determine carbonate and bicarbonate (Pierce *et al*., 1958). Sodium and potassium cations were detected by a Flame Photometer (Model PHF 80 Biologie Spectrophotometer), while the levels of calcium and magnesium were measured by atomic absorption spectrometer (Perkin-Elmer, Model 2380 USA) (Allen *et al*., 1974).

Statistical Analysis

The vegetation associated with *H. curassavicum* was classified and ordinated by TWINSPAN analysis using the Community Analysis Package (CAP) software application (version 2.3) (Hill & Smilauer, 2005). The relationship between vegetation and soil gradients was examined using Canonical Correspondence Analysis (CCA) (Ter Braak, 1988). Soil analyses results were analyzed by ANOVA and Least Significant Difference (LSD) at 0.05 probability level using COSTAT 6.3 program. Using SPSS 16 for Windows, the linear correlation coefficient (r) was computed to assess the relationship between the obtained soil parameters and the community variations.

RESULTS AND DISCUSSION

Floristic Analysis

One hundred and nine plant species (67 annuals, 2 biennials and 40 perennials) from 86 genera and 29 families were listed in this study (Appendix 1). During the winter season, this region of the country received the most rain (Zahran and Willis, 2009). Annual plants possess higher reproduction capacity in addition to their morphological, ecological, and genetic plasticity (Grime, 1979; Kowarik, 1985). In accordance with the literature, Asteraceae, Poaceae, Chenopodiaceae, and Fabaceae (22, 18, 11 & 7 species, respectively), Brassicaceae and Polygonaceae (6 species each), and Euphorbiaceae (4 species) were the most numerous groups (4 species). They made up 67.89 % of all species reported and account for the majority of the floristic composition in this area; whereas the nine families contain 20.18 % of the species and 13 monospecific families. In the Mediterranean and Northern Africa flora, these are the most prevalent families (Abd El-Gawad & Shehata, 2014; El-Amier *et al*., 2014a). Together, the Asteraceae and Poaceae families are the world's biggest and most diverse flowering plant family (Walters & Keil, 1996; Christenhusz & Byng, 2016).

Taxonomic diversity in the studied area is 1.27 for species/genera ratio and 2.97 for genera/families. In general, there is a small family size: just three families contain more than ten species, while 26 have fewer than ten. Clearly, genus *Euphorbia*, *Amaranthus*, and *Cyperus* contain the highest number of species (4, 3 and 3 species, respectively), while *Launaea*, *Zygophyllum*, *Bassia*, *Carduus*, *Conyza*, *Mesembryanthemum*, *Plantago*, *Polypogon*, *Rumex* and *Senecio* genera contain only two species (Appendix 1).

Seventy eight species (32 perennials, 2 biennials and 53 annuals) were recorded in the Deltaic Mediterranean coastal desert and 58 species (20 perennials and 38 annuals) in the inland habitats (roadsides and furrow land in the Nile Delta). *Convolvulus arvensis*, *Cynanchum acutum*, *Cynodon dactylon*, *Imperata cylindrica*, *Lolium perenne*, *Phragmites australis*, *Phyla nodiflora* and *Symphyotrichum squamatum* were the most abundant perennial species associated with *H. curassavicum* in the two habitats while, *Echinopus spinosus*, *Zygophyllum aegyptium*, and *Zygophyllum albam* were the perennial species found in the coastal desert that were linked with the examined plant. Each of these species recorded higher importance values (IV) (Appendix 1). The number of invasive species in the Nile Delta is higher than in Egypt's other phytogeographical zones. This may be due to the fact that the Nile area has a long history of human civilization, and the indigenous peoples of Egypt have had the time and opportunity to alter the natural vegetation via their agricultural operations. The invasive species, on the other hand, do poorly in the Red Sea and Gebel Elba areas, owing to their distance from heavy human effect, as well as their dry habitat (Shaltout *et al*., 2016).

Therophytes made up the bulk of the species observed (60% of the total species), followed by cryptophytes (17.39 %), hemicryptophytes (10.43 %), and chamaephytes (8.70 %), with nanophanerophytes accounting for 2.61 %. Therophytes were the most dominant species among the recorded life forms (Appendix 1) and appears to be a response to hot-dry climate, topographic variability and biotic effect that distinguish the study area (Heneidy & Bidak, 2001). At the time, cryptophytes are also the most common life form (Appendix 1). This could be described in terms of plant habits, as nearly all of these plants are rhizomatous, which are thought to be more resistant to breakdown when submerged in water. The same conclusions have almost been obtained by El-Demerdash (1984), Shaltout *et al*. (1994) and El-Amier *et al*. (2021). Figure 2 depicts the life forms of the associated species with the investigated plant in the studied habitats.

Chorological Affinities of the Associated Vegetation

According to a chorological study, the studied habitats have the most Mediterranean elements (Deltaic coast: 53 species = 48.62%, and interior habitat: 21 species = 19.27%) (Table 1). The Mediterranean chorotype of the studied flora's wide reveals the Mediterranean climate of the study area. The obtained results are consistent with the findings of the majority of comparable investigations (Barakat *et al*., 2014; El-Amier, 2016; El-Amier & Abd El-Gawad, 2017). Cosmopolitan and Saharo-Sindian elements accounted for 11 and 7 species of the total (10.09% and 6.42%, respectively) in the Deltaic coast. While, Cosmopolitan and Pantropical have 17 and 9 species (15.60% and 8.57%, respectively) in inland habitats (Table 2). In the Deltaic coast, cosmopolitan and Saharo-Sindian elements accounted for 11 and 7 species (10.09% and 6.42% of the total species), respectively. Whereas, in inland habitat, Cosmopolitan and Pantropical had 17 and 9 species (15.60% and 8.57%, respectively) (Table 1).

Classification of the Vegetation

At the second level of classification, TWINSPAN analysis techniques identified four primary vegetational groups, with the different overall numbers of species across groups (Figure 3 and Table 2). Each detected vegetation category was given a name based on the dominant species. Two of the documented species, *C. dactylon* and *P. australis*, were found to possess a wide ecological distribution range and to be present in all of the identified vegetation types.

Group (A): *Polypogon Viridis* Group

29 species were identified in this group from 4 stands in the inland habitats (roadsides and furrow land in the Nile Delta) except site 22; it is linked to *H. curassavicum* as important species, with a mean species richness of 3.21 species/stand, Simpson index of 0.97 and Shannon diversity index of 0.87 (Table 2). These stands were in soils with higher content of silt, clay, WHC, OC and $CaCO_3$ and moderate content of cations and anions (Table 3). The other abundant species include *Amaranthus hybridus* (indicator species), *Euphorbia heterophylla*, *Bidens pilosa* and *Sonchus oleraceus*. The other indicator species in this group was *Bromus diandrus*.

Group (B): *Heliotropium Curassavicum* Group

54 species were identified in this group from 15 stands in the inland and Deltaic Mediterranean coastal strip habitat. It has a mean species richness of 3.69 species/stands, Simpson index of 0.97 and Shannon diversity index of 0.89 (Table 2). These stands present in soil with higher electrical conductivity and moderate contents of the other examined soil variables (Table 3). Sporadic species included 17 species, of *Apium leptophyllum*, *Calendula arvensis*, *Capsella bursa pastoris*, *Conyza bonariensis*, *Cornopus didymus*, *Cyperus articulates*, *Eclipta alba*, *Emex spinosa*, etc (Appendix 1). The abundant species include *Cynodon dactylon*, *S. oleraceus*, *P. nodiflora*, *Rumex dentatus* and *C. arvensis*.

Table 1: Number of species and percent of the floristic categories in the coastal and inland habitats

Floristic categories	Study area		Phytogeographical regions			
			Coastal		Inland	
	No.	%	No.	%	No.	%
Worldwide						
COSM	19	17.43	11	12.64	17	29.31
NEO	3	2.75	2	2.30	3	5.17
PAN	9	8.26	5	5.75	9	15.52
PAL	7	6.42	3	3.45	5	8.62
Pluriregional						
ME+IR-TR+ER-SR	14	12.84	12	13.79	7	12.07
ME+ER-SR+SA-SI	2	1.83	2	2.30	-	-
ME+IR-TR+SA-SI	6	5.50	6	6.90	3	5.17
Biregional						
ME+IR-TR	10	9.17	8	9.20	6	10.34
ME+SA-SI	10	9.17	10	11.49	1	1.72
ME+ER-SR	3	2.75	3	3.45	1	1.72
ME+PAL	1	0.92	1	1.15	1	1.72
IR-TR+SA-SI	3	2.75	3	3.45	1	1.72
IR-TR+S-Z	1	0.92	1	1.15	-	-
SA-SI+S-Z	2	1.83	1	1.15	2	3.45
Monoregional						
ME	11	10.09	11	12.64	2	3.45
SA-SI	7	6.42	7	8.05	-	-
AUST	1	0.92	1	1.15	-	-
Total	109	100	87	100	58	100

Group (C): *Cynodon Dactylon* and *Heliotropium Curassavicum* Group

This group showed higher diversity as it comprises 74 species identified from 23 stands, from the inland habitat and Deltaic Mediterranean coastal strip, with a mean species richness of 3.61 species/stands, Simpson index of 0.95 and

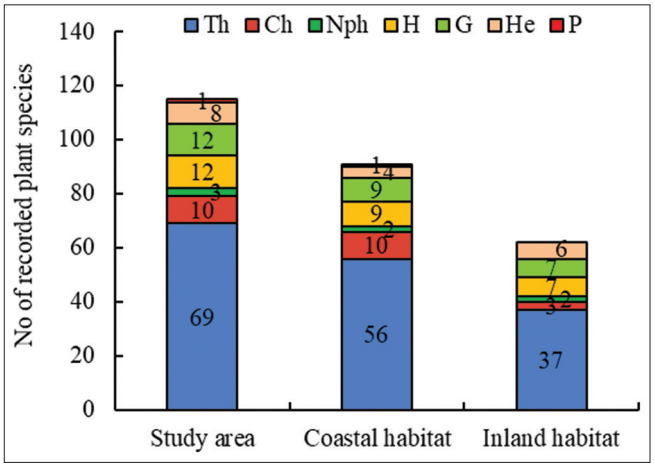

Figure 2: Plant life-form in the study area, and two habitats

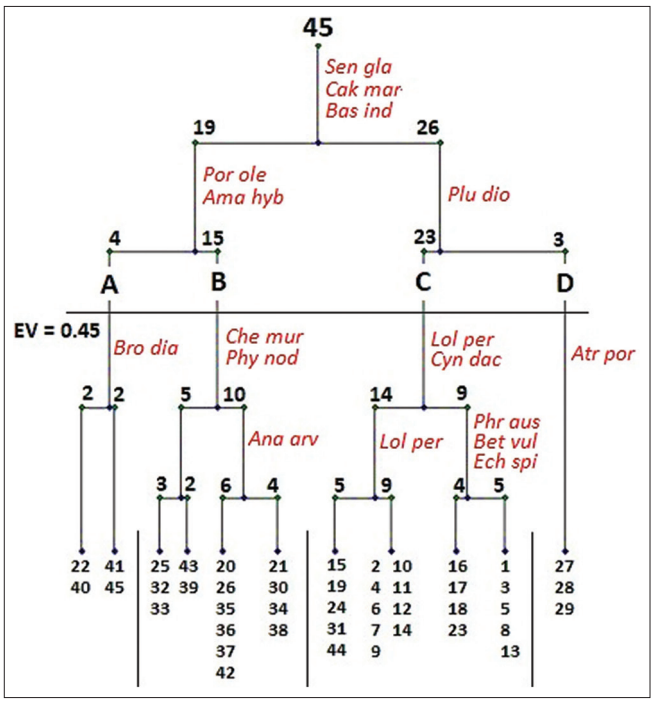

Figure 3: TWINSPAN dendrogram of 45 stands according to the importance value and the 4 vegetation groups (A-D) separated. EV: Eigen value

Table 2: Plant diversity, dominant and important plant species of the tow studied habitats of *Heliotropium curassavicum*

Vegetation group	Stand No.	Total Species	Species Diversity Indices			Dominant species	Other important species
			Simposn	Shannon–Wienner	Shannon-evenness		
A	4	29	0.97	3.21	0.87	*Polypogon viridis* (29.66±0.88)	*Heliotropium curassavicum* (21.26±0.46) *Amaranthus hybridus* (18.74±0.71) *Euphorbia heterophylla* (12.92±1.44) *Bidens pilosa* (12.11±0.82) *Sonchus oleracous* (11.97±1.23)
B	15	54	0.97	3.69	0.89	*Heliotropium curassavicum* (25.02±0.33)	*Cynodon dactylon* (18.71±0.84) *Sonchus oleraceus* (8.13±0.87) *Phyla nodiflora* (7.84±1.57) *Rumex dentatus* (7.66±1.36) *Convolvulus arvensis* (7.31±1.36)
C	23	74	0.95	3.61	0.81	*Cynodon dactylon* (15.83±1.00) *Heliotropium curassavicum* (15.60±0.36)	*Zygophyllum albam* (11.33±1.69) *Hordium murinum* (11.08±1.32) *Cakile maritima* (10.09±0.98) *Phragmites australis* (9.59±0.85) *Senecio glaucus* (9.46±1.21)
D	3	11	0.91	3.07	0.85	*Phragmites australis* (45.26±0.44)	*Arthrocnemum macrostachyum* (17.30±0.87) *Atriplex portulacoides* (25.04±0.87) *Cynodon dactylon* (18.56±1.73) *Halocnemum strobilaceum* (17.86±1.04) *Heliotropium curassavicum* (25.35±0.47) *Pluchea dioscoridis* (23.48±0.24)

Table 3: Mean values, standard error (±SE) and ANOVA values of the soil parameters in the vegetation groups (A-D) of the study area

Soil variable	Vegetational group				One-way ANOVA	
	A	B	C	D	F-value	P-value
Sand (%)	51.62±7.23	58.11±5.90	86.30±4.04	39.35±0.78	10.99	0.0001***
Silt (%)	28.21±4.26	25.91±3.75	7.95±2.32	38.64±0.46	11.89	0.0000***
Clay (%)	20.18±2.99	15.99±2.27	5.75±2.03	22.01±1.03	8.98	0.0003***
Porosity (%)	32.88±0.44	30.84±0.99	39.33±1.57	30.37±0.98	17.52	0.0000***
WHC (%)	60.64±5.19	51.87±4.05	32.94±2.91	53.27±2.27	7.08	0.0011**
$CaCO_3$ (%)	7.19±0.67	5.34±0.90	3.66±0.61	5.57±0.77	5.59	0.0039**
OC (%)	4.38±0.78	4.10±0.66	1.14±0.44	4.00±0.54	5.12	0.0060**
pH	8.24±0.16	8.20±0.12	8.31±0.15	7.56±0.03	3.03	0.0461*
EC mS cm^{-1}	659.75±55.30	814.27±99.87	745.57±163.03	790.67±43.40	0.36	0.7859ns
Cl^- (%)	0.46±0.17	0.50±0.15	0.76±0.19	0.13±0.00	1.76	0.1786ns
SO^{--}_4 (%)	0.48±0.10	0.46±0.09	0.55±0.12	0.28±0.02	0.87	0.4685ns
HCO^-_3 (%)	0.26±0.02	0.21±0.01	0.48±0.38	0.21±0.01	0.86	0.4750ns
Na^+ (mg g^{-1})	77.18±7.70	101.18±14.44	256.04±33.93	41.75±2.77	19.32	0.0000***
K^+ (mg g^{-1})	54.64±9.20	38.12±5.92	75.21±5.97	25.43±2.39	5.24	0.0054**
Ca^{++} (mg g^{-1})	53.52±7.67	44.17±5.19	142.19±17.02	32.14±4.81	20.44	0.0000***
Mg^{++} (mg g^{-1})	38.09±6.73	32.42±4.68	99.85±11.59	22.34±1.28	21.37	0.0000***
SAR	11.58±0.55	15.83±1.45	22.46±2.01	8.07±0.09	15.32	0.0000***
PAR	7.98±0.91	5.88±0.59	7.44±0.82	4.84±0.18	2.06	0.1282ns

EC = Electrical conductivity, OC = Organic carbon, ns = no significance at $P < 0.05$. *: significance at $P < 0.05$, **: significance at $P < 0.01$, ***: significance at $P < 0.001$

Shannon diversity index of 0.81 (Table 2). Sand, porosity, pH, sodium, potassium, calcium, magnesium, chloride, bicarbonate and sulphate were at their highest levels in these stands (Table 3). Sporadic species comprised 47 species (or about 43.12% of the listed species in this group) that included *Aegilops bicornis*, *Alhagi graecorum*, *Amaranthus graecizans*, *Carduus getulus*, *Carduus pycnocephalus*, *Carthamus tenuis*, *Cyperus capitatus* and *Launaea nudicaulis* (Appendix 1). The abundant species in this group include *Z. albam*, *Hordium murinum*, *Cakile maritima*, *P. australis* and *Senecio glaucus*.

Group (D): *Phragmites Australis* Group

It is the smallest group, representing the Deltaic Mediterranean coastal strip habitat. It contains 11 species identified from three stands, with the lowest species richness of 3.07 species/stands, Simpson index of 0.91 and Shannon diversity index of 0.85 (Table 2). These sites were characterized by higher percentages of fine particles (silt and clay), $CaCO_3$ and organic carbon, but the majority of soil variables tested were at lower levels in these stands (Table 3). The abundant species in this group include

Arthrocnemum macrostachyum, *Atriplex portulacoides*, *Cynodon dactylon*, *Halocnemum strobilaceum*, *Heliotropium curassavicum* and *Pluchea dioscoridis* (Appendix 1).

Sampling Sites Ordination

Figure 4 depicts the DCA-generated sampled stands ordination. The TWINSPAN vegetation groups were highly distinct and had a coherent pattern of segregation on the ordination plane, meanwhile, the groups A and B split at the middle portion of the right side of the DCA diagram, that was obviously segregated along the two axes of DCA. The largest group, Group C is split on the left side. Group D stands are clearly separated on the lower side from the other groups along the two axes of the DCA diagram. It's worth noting that the strong parallels in floristic composition and natural habitats between the above-mentioned plant types may explain interspecific connections.

Soil–vegetation Relationships

Canonical Correspondence Analysis (CCA) was used for investigating the link between vegetation and soil characteristics. The CCA ordination biplot with vegetation groups (A-D) and the investigated soil parameters are shown in Figure 5. The phytodiversity of natural communities can be influenced by soil texture, salinity, and organic carbon (El-Sheikh, 1989; Pinke *et al*., 2010). In this study, soil texture, WHC, organic carbon, cations (Na^+, K^+, Ca^{++}, and Mg^{++}), and SAR were obviously the most influencing soil parameters with strong significant relationships with the first and second axis. This agrees more or less with the findings of Maswada and Elzaawely (2013), El-Amier *et al*. (2014a) and Abd-ElGawad *et al*. (2020) in the Mediterranean area of the Nile Delta.

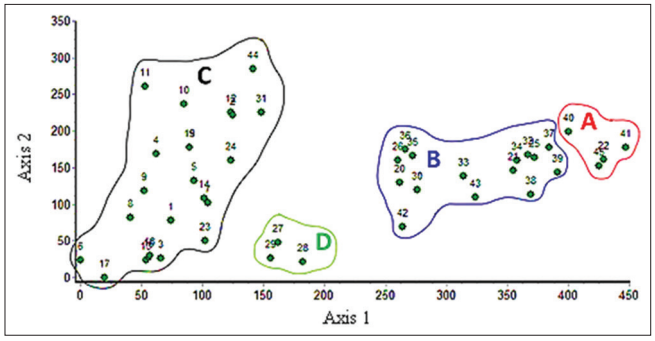

Figure 4: DCA ordination diagram of the 45 sites on axes 1 and 2 within vegetation groups (A-D)

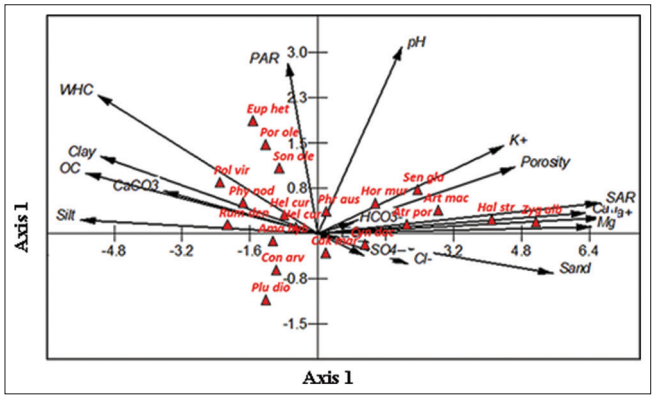

Figure 5: Canonical Correspondence Analysis (CCA) ordination diagram of plant species with soil variables represented by arrows in the study area. The dominant and important species are abbreviated to the first three letters of the genus and species respectively (See Table 2)

In the upper right side of the CCA diagram, *P. australis*, which was the dominant species in group D and important species (*A. macrostachyum*, *A. portulacoides*, *H. strobilaceum*, *Z. albam*, *H. murinum* and *S. glaucus*) in groups C and D showed close relationships with sand, pH, cations (Na^+, K^+, Ca^{++}, and Mg^{++}) and SAR. In the upper left side of the diagram, *P. viridis* was the dominant species in group A, *H. curassavicum*, which was dominant and codominant species in groups B and C, respectively, and important species (*E. heterophylla*, *P. nodiflora*, *P. olerceus*, *R. dentatus* and *S. oleracous*) in groups A and B, all expressed a close relationship with fine fractions (silt and clay), WHC, organic carbon, $CaCO_3$ and PAR. While the codominant species (*C. dactylon*) and important species (*C. maritima*) of group C are separated at the lower right side of the diagram. These species expressed a clear relationship with sand, SO_4^{2-} and Cl^-. Meanwhile, in the lower left side, *C. arvensis* and *P. dioscoridis*, which were important species in groups B and D, exhibited no relationships with soil factors.

CONCLUSIONS

Invasive plant species can obstruct native plant establishment and growth, as well as have an influence on soil cover, nutrient cycling, and hydrology. Controlling invasive species is thus vital, although sometimes costly, step toward ecosystem restoration. The current study analyzed the vegetation structure and soil properties of a single invasive plant in the Nile Delta of Egypt in order to aid in the ecological management and protection of these natural resources. More study on modifying soil biota and species diversity to improve invasion resistance is also needed.

AUTHOR'S CONTRIBUTION

All authors contributed equality in carrying out the research study and the development of this paper.

REFERENCES

Abd El-Gawad, A. M., & Shehata, H. S. (2014). Ecology and development of *Mesembryanthemum crystallinum* L. in the Deltaic Mediterranean coast of Egypt. *Egyptian Journal of Basic and Applied Sciences, 1*(1), 29-37. https://doi.org/10.1016/j.ejbas.2014.02.003

Abd-ElGawad, A. M., El-Amier, Y. A., Assaeed, A. M., & Al-Rowaily, S. L. (2020). Interspecific variations in the habitats of *Reichardia tingitana* (L.) Roth leading to changes in its bioactive constituents and allelopathic activity. *Saudi Journal of Biological Sciences, 27*(1), 489-499. https://doi.org/10.1016/j.sjbs.2019.11.015

Abd-ElGawad, A. M., Elshamy, A. I., Al-Rowaily, S. L., & El-Amier, Y. A. (2019). Habitat affects the chemical profile, allelopathy, and antioxidant properties of essential oils and phenolic enriched extracts of the invasive plant *Heliotropium curassavicum*. *Plants, 8*(11), 482. https://doi.org/10.3390/plants8110482

Allen, S. E., Grimshaw, H. M., Parkinson, J. A., & Quarmby, C. (1974). Chemical analysis of ecological materials. Blackwell Scientific Publications.

Al-Shehbaz, I. A. (1991). The genera of Boraginaceae in the southeastern United States. *Journal of the Arnold Arboretum, 1*, 1–169.

Baessler, C., & Klotz, S., (2006). Effects of changes in agricultural land-use on landscape structure and arable weed vegetation over the last 50 years. *Agriculture, Ecosystems & Environment, 115*(1-4), 43-50. https://doi.org/10.1016/j.agee.2005.12.007

Barakat, A., Mayer-Laigle, C., Solhy, A., Arancon, R. A., De Vries, H., & Luque, R. (2014). Mechanical pretreatments of lignocellulosic biomass: towards facile and environmentally sound technologies for biofuels production. *RSC Advances, 4*(89), 48109-48127. https://doi.org/10.1039/C4RA07568D

Barney, J. N., Tekiela, D. R., Dollete, E. S., & Tomasek, B. J (2013). What is the "real" impact of invasive plant species? *Frontiers in Ecology and the Environment, 11*, 322–329. https://doi.org/10.2307/23470484

Boulos, L. (1999-2005). Flora of Egypt. (Vol. 1-4). Al Hadara Publishing, Cairo.

Christenhusz, M. J., & Byng, J. W. (2016). The number of known plants species in the world and its annual increase. *Phytotaxa, 261*(3), 201-217. https://doi.org/10.11646/phytotaxa.261.3.1

Einhellig, F. A. (1995). Allelopathy: Current Status and Future Goals; ACS Publications: Washington, DC, USA.

El-Amier, Y. A. (2016). Vegetation structure and soil characteristics of five common geophytes in desert of Egypt. *Egyptian Journal of Basic and Applied Sciences, 3*(2), 172-186. https://doi.org/10.1016/j.ejbas.2016.03.001

El-Amier, Y. A., & Abd El-Gawad, A. M. (2017). Plant communities along the international coastal highway of Nile delta, Egypt. *Journal of the Science of Food and Agriculture, 1*, 117-131. https://doi.org/10.25081/jsa.2017.v1.47

El-Amier, Y. A., & El Hayyany, L. Y. (2020). Floristic composition and species diversity of plant communities associated with genus *Atriplex* in Nile Delta coast, Egypt. *Asian Journal of Conservation Biology, 9*(1),11-24.

El-Amier, Y. A., El-Halawany, E. F., & Abdullah, T. J. (2014a). Composition and diversity of plant communities in sand formations along the northern coast of the Nile Delta in Egypt. *Research Journal of Pharmaceutical, Biological and Chemical Sciences, 5*(4), 826-847.

El-Amier, Y. A., Abdelghany, A. M. & Abed Zaid, A. (2014b). Green synthesis and antimicrobial activity of *Senecio glaucus*-Mediated silver nanoparticles. *Research Journal of Pharmaceutical, Biological and Chemical Sciences, 5*(5), 631-642.

El-Amier, Y. A., El-Zeiny, A., El-Halawany, E. S. F., Elsayed, A., El-Esawi, M. A., Noureldeen, A., Darwish, H., Al-Barty, A., & Elagami, S.A. (2021). Environmental and Stress Analysis of Wild Plant Habitat in River Nile Region of Dakahlia Governorate on Basis of Geospatial Techniques. *Sustainability, 13*(11), 6377. https://doi.org/10.3390/su13116377

El-Demerdash M. A. (1984). Ecological studies on Juncus plants. Unpublished Ph. D. Thesis, Mansoura University, Egypt.

Elshamy, A., Abd-ElGawad, A. M., El-Amier, Y. A., El Gendy, A., & Al-Rowaily, S. (2019). Interspecific variation, antioxidant and allelopathic activity of the essential oil from three *Launaea* species growing naturally in heterogeneous habitats in Egypt. *Flavour and Fragrance Journal, 34*, 316–328. https://doi.org/10.1002/ffj.3512

El-Sheikh, M. A. (1989). A study of the vegetation- environmental relationships of the Canal Banks of Middle Delta Region. (MSc. Thesis.) Fac. Sci., Tanta Univ., Egypt.

Frick, B., & Thomas, A. G. (1992). Weed surveys in different tillage systems in south western Ontario field crops. *Canadian Journal of Plant Science, 72*, 1337-1347. https://doi.org/10.4141/cjps92-166

Gadallah, S. M., Nasser, M. G., Farag, S. M., Elhawary, M. O., & Hossny, A. (2019). Deroplax silphoides (Thunberg, 1783) (Hemiptera: Heteroptera: Scutelleridae) Invasive Species in Egypt with additional morphological and behavioral data. *Zootaxa, 4624*(3), 387-396. https://doi.org/10.11646/zootaxa.4624.3.7

Grime, J. P. (1979). Primary strategies in plants. In Transactions of the Botanical Society of Edinburgh (Vol. 43) 2: pp. 151-160. Taylor & Francis Group.

Hegazy, A., Mussa, S., & Farrag, H. (2008). Invasive plant communities in the Nile Delta coast. *Global Journal of Environmental Research, 2*, 53–61.

Hegazy, A. K. (1994). Trade-off between sexual and vegetative reproduction of the weedy *Heliotropium curassavicum*. *Journal of Arid Environments, 27*, 209–220. https://doi.org/10.1006/jare.1994.1059

Hegazy, A. K., Fahmy, G. M., Ali, M. I., & Gomaa, N. H. (2004). Vegetation diversity in natural and agro-ecosystems of arid lands. *Community Ecology, 5*, 163-176. https://doi.org/10.1556/ComEc.5.2004.2.3

Heneidy, S. Z. & Bidak, L. M. (2001). Multipurpose plant species in Bisha, Asir region, southwestern Saudi Arabia. *Journal of King Saud University Science, 13*, 11-26.

Hill, M. O., & Šmilauer, P. (2005). Win TWINS. TWINSPAN for Windows version, 2.

Jackson, K. A. (1962). On the origin of dislocations. *Philosophical Magazine, 7*(81), 1615-1616. https://doi.org/10.1080/14786435808244398

Jackson, S. D. (2000). Overview of Transportation Impacts on Wildlife Movement and Populations. Pp. 7-20 In Messmer, T. A., & B. West, (Eds) Wildlife and Highways: Seeking Solutions to an Ecological and Socio-economic Dilemma. The Wildlife Society.

Kowarik, I. (1985). Grundlagen der Stadukologie und Forderungen Anchihrer Berucksichtigug bri der Stadgestaltung am Beispiel Berlins, Schriftenrh. DBV. *Jungend, 3*, 22-39.

Maswada, H. F., & Elzaawely, A. A. (2013). Ecological investigation of three geophytes in the Deltaic Mediterranean coast of Egypt. *Pakistan Journal of Biological Sciences, 16*, 1662–1674. https://doi.org/10.3923/pjbs.2013.1662.1674

Negm, A. M., Saavedra, O., & El-Adawy, A. (2016). Nile Delta biography: Challenges and opportunities. In The Nile Delta; Negm, A.M., Ed.; Springer: Cham, Switzerland, pp. 3–18.

Pierce, W. C., Haenisch, E. L., & Sawyer, D. T. (1958). Quantitative Analysis. Wiley Toppen, Tokyo.

Pinke, G., Pal, R., & Botta-Dukat Z. (2010). Effects of environmental factors on weed species composition of cereal and stubble fields in western Hungary. *Central European Journal of Biology, 5*, 283–292. https://doi.org/10.2478/s11535-009-0079-0

Piper, C. S. (1947). Mechanical analysis. *Soil and Plant Analysis*, 368.

Raunkięr, C. (1934-1937). Plant life forms: Clarendon Press.

Shaltout, K. H., Sharaf El-Din, A., & El-Sheikh, M. A. (1994). Species richness and phenology of vegetation along irrigation canals and drains in the Nile Delta, Egypt. *Vegetatio, 112*, 35-43. https://doi.org/10.1007/BF00045098

Shaltout, K. H., Hosni, H. A., El-Kady, H. F., El-Beheiry, M. A. & Shaltout, S. K. (2016). Composition and pattern of alien species in the Egyptian flora. *Flora-Morphology, Distribution, Functional Ecology of Plants, 222*, 104-110. https://doi.org/10.1016/j.flora.2016.04.001

Shukla, R. S., & Chandel, P. S. (1989). A Textbook of Plant Ecology including Ethobotany and Soil science. 10th edition, S. Chand & Company Ltd., New Delhi.

Spellerberg, I. A. N. (1998). Ecological effects of roads and traffic: a literature review. *Global Ecology & Biogeography Letters, 7*(5), 317-333. https://doi.org/10.1046/j.1466-822x.1998.00308.x

Tackholm, V. (1974). Student's Flora of Egypt, (2nd ed.). Cairo, Egypt: Cairo University Press.

Ter Braak, C. J. F. (1988). Partial canonical correspondence analysis. In Classification and related methods of data analysis: proceedings of the first conference of the International Federation of Classification Societies (IFCS), Technical University of Aachen, FRG, 29 June-1 July 1987, pp. 551-558. North-Holland.

Walters, D. R., & Keil, D. J. (1996). Vascular plant taxonomy. Kendall Hunt.

Zahran, M.A. & Willis, A.J. (2009). The Vegetation of Egypt. Springer. Netherlands.

Zheng, Y. L., Feng, Y. L., Zhang, L. K., Callaway, R. M., Valiente-Banuet, A., Luo, D. Q., Liao, Z. Y., Lei, Y. B., Barclay, G. F., & Silva-Pereyra, C. (2015). Integrating novel chemical weapons and evolutionarily increased competitive ability in success of a tropical invader. *The New phytologist, 205*(3), 1350–1359. https://doi.org/10.1111/nph.13135

Zohary, D. (1972). The wild progenitor and the place of origin of the cultivated lentil: Lens culinaris. *Economic Botany, 26*(4), 326-332. https://doi.org/10.1007/BF02860702

Zohary, M. (1966). Flora Palaestina, part 1. Israel Academy of Sciences and Humanities, Jerusalem: 76.

APPENDIX

Appendix 1: Floristic composition of the plant species of the different habitats in the study area

Species	Family	Life form	Chorotype	Phytogeographical regions		P%
				Coastal	Inland	
Perennials						
Alhagi graecorum Boiss.	Fabaceae	H	PAL	+	-	4.44
Arthrocnemum macrostachyum (Morocco.) K.koch	Chenopodiaceae	Ch	ME+SA-SI	+	-	8.89
Atriplex portulacoides L.	Chenopodiaceae	Ch	ME+IR-TR+ER-SR	+	-	8.89
Atriplex semibaccata R.Br.	Chenopodiaceae	H	AUST	+	-	6.67
Calligonum comosum (L, Her.) Soskov.	Polygonaceae	Nph	SA-SI+IR-TR	+	-	6.67
Cistanche phelypaea (L.) Cout.	Orobanchaceae	G, P	ME+SA-SI	+	-	6.67
Convolvulus arvensis L.	Convolvulaceae	H	COSM	+	+	17.78
Cynanchum acutum L.	Asclepiadaceae	H	ME+IR-TR	+	+	15.56
Cynodon dactylon (L.) Pers.	Poaceae	G	PAN	+	+	55.56
Cyperus rotundus L.	Cyperaceae	G	PAN	+	+	11.11
Cyperus articulatus L.	Cyperaceae	G, He	PAN	-	+	2.22
Cyperus capitatus Vand.	Cyperaceae	G	ME	+	-	2.22
Echinochloa stagnina (Retz.) P.Beauv.	Poaceae	G, He	PAL	-	+	2.22
Echinopus spinosus L.	Asteraceae	H	ME+SA-SI	+	-	13.33
Halocnemum strobilaceum (Pall.) M. Bieb.	Chenopodiaceae	Ch	ME+IR-TR+SA-SI	+	-	4.44
Heliotropium curassavicum L.	Boraginaceae	Ch	NEO	+	+	100
Imperata cylindrica (L.) Raeusch	Poaceae	H	ME+PAL	+	+	11.11
Juncus acutus L.	Juncaceae	He	ME+IR-TR+ER-SR	+	-	6.67
Limbarda crithmoides (L). Dumort.	Asteraceae	Ch	ME+ER-SR+SA-SI	+	-	6.67
Launaea mucronata (Forssk.) Muschl.	Asteraceae	H	ME+SA-SI	+	-	6.67
Launaea nudicaulis (L.) Hook.f.	Asteraceae	H	SA-SI	+	-	4.44
Leptochloa fusca (L.) Kunth.	Poaceae	G, He	PAN	+	+	6.67
Lolium perenne L.	Poaceae	Th	ME+IR-TR+ER-SR	+	+	17.78
Lotus polyphllos E.D.Clarke.	Fabaceae	Th	ME	+	-	2.22
Mentha longifolia (L.) Huds.	Lamiaceae	H	PAL	-	+	2.22
Oxalis corniculata L.	Oxalidaceae	H	COSM	-	+	8.89
Paspalidium geminatum (Forssk .) Stapf	Poaceae	He	PAL	-	+	2.22
Persicaria salicifolia Brouss. ex Willd.	Polygonaceae	G	PAL	-	+	2.22
Phragmites australis (Cav.) Trin. exSteud.	Poaceae	G, He	COSM	+	+	40
Phyla nodiflora (L.) Greene	Verbenaceae	Ch	PAN	+	+	13.33
Plantago major L.	Plantaginaceae	H	COSM	-	+	4.44
Pluchea dioscoridis (L.) DC.	Asteraceae	Nph	SA-SI+S-Z	-	+	13.33
Polygonum equsetiforme Sm.	Polygonaceae	G	ME+IR-TR	+	-	2.22
Stipagrostis lanata (Forssk) De Winter	Poaceae	G	SA-SI	+	-	2.22
Suaeda pruinosa Lang	Chenopodiaceae	Ch	ME	+	-	6.67
Symphyotrichum squamatum (Asch.) Dandy	Asteraceae	Ch	NEW	+	+	11.11
Tamarix nilotica (Ehrenb). Bunge	Tamaricaceae	Nph	SA-SI+S-Z	+	+	4.44
Veronica anagallis-aquatica L.	Scrophulariaceae	He	COSM	-	+	2.22
Zygophyllum aegyptium Hosny	Zygphyllaceae	Ch	ME	+	-	11.11
Zygophyllum albam L.F	Zygphyllaceae	Ch	ME+SA-SI	+	-	17.78
Biennials						
Rorippa palustris (L.) Besser, Enum. Pl.Volhyn.	Brassicaceae	Th	ME+IR-TR+ER-SR	+	-	4.44
Spergularia marina (L.) Griseb.	Caryophyllaceae	Th	ME+IR-TR+ER-SR	+	-	4.44
Annuals						
Aegilops bicornis (Forss) Jaub&Spach	Poaceae	Th	ME+SA-SI	+	-	8.89
Amaranthus graecizans L.	Amaranthaceae	Th	ME+IR-TR	-	+	2.22
Amaranthus hybridus L.	Amaranthaceae	Th	PAL	+	+	11.11
Amaranthus lividus L.	Amaranthaceae	Th	PAL	+	-	2.22
Anagallis arvensis L. var. arvensis	Primulaceae	Th	COSM	+	+	11.11
Anchusa humilis (Desf) I.M.Johnst.	Boraginaceae	Th	ME+SA-SI	+	-	2.22
Apium leptophyllum (Pers.) F. Muell. Ex.Benth.	Primulaceae	Th	COSM	+	+	4.44
Astragalus peregrinus Vahl	Fabaceae	Th	SA-SI	+	-	2.22
Bassia indica (Wight) Scott.	Chenopodiaceae	Th	IR-TR+S-Z	+	-	33.33
Bassia muricata (L.) Asch.	Chenopodiaceae	Th	IR-TR+SA-SI	+	-	4.44
Beta vulgaris var. *cicla* L.	Chenopodiaceae	Th	ME+IR-TR+ER-SR	+	+	20
Bidens pilosa L.	Asteraceae	Th	PAN	+	+	24.44
Bromus diandrus Roth	Poaceae	Th	ME	+	-	17.78
Cakile maritima Scop. subsp. *aegyptiaca* (Willd.) Nyman	Brassicaceae	Th	ME+ER-SR	+	-	35.56
Calendula arvensis L.	Asteraceae	Th	ME+IR-TR+SA-SI	+	-	2.22

(Contd...)

Appendix 1: *(Continued)*

Species	Family	Life form	Chorotype	Phytogeographical regions		P%
				Coastal	Inland	
Capsella bursa pastoris (L.) Medk.	Brassicaceae	Th	COSM	-	+	2.22
Carduus getulus Pomel.	Asteraceae	Th	SA-SI	+	-	2.22
Carduus pycnocephalus L.	Asteraceae	Th	ME	+	-	6.67
Carthamus tenuis (Boiss & Blanche) Bornm	Asteraceae	Th	ME	+	-	2.22
Chenopodium murale L.	Chenopodiaceae	Th	COSM	+	+	44.44
Conyza aegyptiaca (L.) Dryand	Asteraceae	Th	ME	+	+	13.33
Conyza bonariensis (L.) Cronquist, Bull.	Asteraceae	Th	ME	+	+	4.44
Cornopus didymus (L.) Sm.	Brassicaceae	Th	COSM	-	+	2.22
Cutandia memphitica (Spreng.) Benth.	Poaceae	Th	ME+IR-TR+SA-SI	+	-	2.22
Echinochloa colona (L.) Link	Poaceae	Th	PAN	-	+	4.44
Eclipta alba L.	Asteraceae	Th	NEO	-	+	2.22
Emex spinosa (L.) Campd.	Polygonaceae	Th	ME+SA-SI	+	+	4.44
Erodium laciniatum (Cav.) Willd.	Geraniaceae	Th	ME	+	-	4.44
Euphorbia peplus L.	Euphorpiaceae	Th	ME+IR-TR+ER-SR	+	+	15.56
Euphorbia heliscopia L.	Euphorpiaceae	Th	ME+IR-TR+SA-SI	+	+	4.44
Euphorbia heterophylla L.	Euphorpiaceae	Th	PAN	-	+	4.44
Euphorbia prostrata Aiton, Hort. Kew, ed.	Euphorpiaceae	Th	PAN	-	+	2.22
Hordium marinum Huds.	Poaceae	Th	ME+IR-TR	+	-	24.44
Ifloga spicata (Forssk.) Sch. Bip.	Asteraceae	Th	SA-SI	+	-	2.22
Juncus rigidus L.	Juncaceae	G, He	ME+IR-TR+ER-SR	+	-	6.67
Lobularia arabica (Boiss.) Muschl.	Brassicaceae	Th	SA-SI	+	-	2.22
Lotus halophilus Boiss. & Spruner	Fabaceae	Th	ME+SA-SI	+	-	6.67
Malva parvifolra L.	Malvaceae	Th	ME+IR-TR	+	+	37.78
Medicago sativum L.	Fabaceae	Th	COSM	-	+	2.22
Melilotus indicus (L.) All.	Fabaceae	Th	ME+IR-TR+SA-SI	+	+	15.56
Mesembryanthemum crystallinum L.	Aizoaceae	Th	ME+ER-SR	+	-	31.11
Mesembryanthemum nodiflorum L.	Aizoaceae	Th	ME+SA-SI+ER-SR	+	-	15.56
Parapholis incurva (L.) C.E. Hubb	Poaceae	Th	ME+IR-TR+ER-SR	+	-	11.11
Phalaris minor Retz.	Poaceae	Th	ME+IR-TR	-	+	2.22
Plantago lagopus L.	Plantaginaceae	Th	ME+IR-TR	+	-	2.22
Plantago squarrosa Murray	Plantaginaceae	Th	ME	+	-	2.22
Poa annua L.	Poaceae	Th	COSM	+	+	13.33
Portulaca oleracea L.	Portulacaea	Th	IR-TR+SA-SI	+	+	13.33
Polypogon monspeliensis (L.) Desf.	Poaceae	Th	COSM	+	+	13.33
Polypogon viridis (Gouan) Breistr.	Poaceae	H	ME+IR-TR	+	+	22.22
Pseudognaphalium luteo-album (L.) Hlliard& B.L. Burtt.	Asteraceae	Th	COSM	-	+	2.22
Reichardia tingitana (L.) Roth	Asteraceae	Th	ME+IR-TR	+	-	17.78
Rumex dentatus L.	Polygonaceae	Th	ME+IR-TR+ER-SR	-	+	15.56
Rumex pictus Forssk.	Polygonaceae	Th	ME+SA-SI	+	-	22.22
Salsola kali L.	Chenopodiaceae	Th	COSM	+	-	20
Senecio aegyptius L.	Asteraceae	Th	ME+IR-TR+ER-SR	-	+	2.22
Senecio glaucus L.	Asteraceae	Th	ME+IR-TR+SA-SI	+	+	37.78
Setaria verticillata (L.) P. Beauv.	Asteraceae	Th	COSM	-	+	2.22
Silene vivianii Steud.	Caryophyllaceae	Th	SA-SI	+	-	2.22
Sisymbrium irio L.	Brassicaceae	Th	ME+IR-TR+ER-SR	+	+	6.67
Solanum nigrum L.	Solanaceae	Th	COSM	+	+	22.22
Sonchus oleraceus L.	Asteraceae	Th	COSM	+	+	35.56
Stellaria pallida (Dumort.) Murb.	Caryophyllaceae	Th	ME+ER-SR	+	+	6.67
Suaeda maritima (L) Dumort.	Chenopodiaceae	Th	COSM	+	-	4.44
Urospermum picroides (L.) F.W.Schmidt	Asteraceae	Th	ME+IR-TR	+	+	6.67
Urtica urens L.	Urticaceae	Th	ME+IR-TR+ER-SR	+	+	11.11
Vicia sativa L.	Fabaceae	Th	ME+IR-TR+ER-SR	+	+	8.89

P = Presence, Nph = Phanerophytes, H = Hemicryptophyte, Ch = Chemaephytes, Th = Theophytes, G = Geophytes, He = Helophytes, P = Parasites, SA-SI = Saharo-Sindian, S-Z = Sudano-Zambezian, IR-TR = Irano-Turanian, ER-SR = Euro-Siberian, ME = Mediterranean, NEO = Neotropical, PAL = Palaeotropical, PAN = Pantropical, COSM = Cosmopolitan, AUST = Australian