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# Factors affecting the diversity and distribution of synanthropic vegetation in urban habitats of the Nile Delta, Egypt

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**Abstract** This study examined the major soil attributes that affect the plant species distribution in the urban ecosystem of the north-eastern part of Nile Delta, which represents transition between the irrigated farmlands and the adjoining desert and salt marshes. It has been under human manipulations for more than 30 years. Five major habitats (desert, reclaimed, cultivated, urban and wet) subdivided into 13 minor ones were recognized. Alterations of soil characters by anthropogenic activities of the natural environment for agriculture production have provided a favorable condition for the growth of weedy species. 231 species related to 152 genera and 45 families were recorded; of which 135 species annuals (58.4 %) and 96 perennials (41.5 %). Regarding chorological analysis, Saharo-Arabian attained the maximum value of 23.5 % in Sf, followed by Sudano-Zambezian 20.0 % in Wl, Cosmopolitan (16.6 %), Irano-Turanian 11.8 % in each of Hw and Ic, After the application of TWINSPAN classification technique, five vegetation types were identified, and well segregated along the DCA axis one; which reflects the soil moisture, fertility, biotic change, aridity and species diversity gradients. When soil moisture decreases, species diversity increase. It also represents the gradient of human interference, where the full man-made vegetation (wet lands and cultivated lands) occupied the left end of this gradient, where the less disturbed vegetation (reclaimed and urban land) was in the middle and no man-made vegetation (desert land) was in the right end. This gradient is associated with the increase of the relative presence of aridity.

**Keywords** Plant communities · Diversity · Multivariate analysis · Ruderal vegetation · Soil–environment relationships

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## 1 Introduction

The urban ecosystem contains diverse assemblages of species and habitats from the spontaneous flora of ruderal habitats to the decorative flora of managed areas. Consequently, the term “urban vegetation” refers to all types of spontaneously occurring and cultivated vegetation in cities (Sukopp and Werner 1983). As defined by Campos et al. (2004), the syanthropic plants are those linked to the voluntary and involuntary actions of man which generally modify their natural distribution by extension. Also, Lososová and Simonová (2008) defined the term synanthropic vegetation to include weed vegetation in arable fields and ruderal vegetation of human settlements and their surrounding, waste deposits railways, verges of roads and trampled habitats. Synanthropic vegetation in towns and cities is an important subject of urban ecology (Mucina 1990; Sukopp 2004). Many studies related to urban vegetation are dealing with biodiversity (e.g., McKinney 2002; Zerbe et al. 2003; Cornelis and Hermy 2004; Kühn et al. 2004), temporal changes in the plant composition (e.g., Florgård 2000; Godefroid 2001; De Candido 2004; Pyšek et al. 2004), plant distribution along urban–rural gradients (e.g., Godefroid and Koedam 2003a; Daniel and Lecamp 2004), fragmentation (e.g., Bastin and Thomas 1999; Stenhouse 2004; Guirado et al. 2006) and alien species (e.g., Pyšek 1998; Godefroid and Koedam 2003b).

Despite increased recognition of the importance of urban vegetation research (Mucina 1990), few attempts have been made to assess the relative influence of ecological variables on the distribution pattern of urban vegetation. This lack of urban ecological knowledge means that baseline information is scarce, and the possibilities of applying ecological knowledge in urban planning are limited (Niemelä 1999). Few studies have tried to relate urban vegetation to environmental factors. Amongst others, the studies of Klotz (1990) and Pyšek (1993) who found that plant species richness in cities is highly correlated to population size, can be highlighted. Effects of land use on vegetation have been investigated in the city of Plymouth (Kent et al. 1999) and in Berlin (Maurer et al. 2000). In Spain, Dana et al. (2002) studied the urban vegetation of Almería city, analyzing possible explanatory factors, such as the type of habitat or the level and frequency of disturbance.

Factors affecting the vegetation structure in cities were studied by Kowarik (1990), Wittig (2002), Pyšek et al. (2004). This interest in urban floras can be attributed to the fact that cities are remarkably rich in species because of high habitat diversity (Gilbert 1989) and enrichment by alien species (Pyšek 1998). The high diversity of urban landscapes, resulting from variable land use, creates a great variety of ecological conditions for plants (Gilbert 1989). He et al. (2007) studied the environmental factors affecting vegetation composition in the Alxa Plateau of inner Mongolia, China. Seventy species representing 46 genera and 16 families were collected. The largest families were Leguminosae, Polygonaceae, Gramineae and Compositae representing 20.0, 15.7, 14.3 and 14.3 % of the total flora, respectively.

For the authors' best knowledge, the study of the vegetation structure and floristic composition in urban environments of Egypt was poorly documented. As a recent emergent field of study and lack of information for plant species development in the urban environments of the Egyptian cities (either old or new settlements), make the classification of its synanthropic vegetation not possible as it took several years of study and calculations (e.g., in Europe for example it took many years of investigation and special projects were adopted for this task; Prof. Reinhard Bornkamm of TU Berlin, personal communications). Earlier studies on the synanthropic vegetation were carried out by Hejný and Kosinova (1978) in Cairo city, Danin et al. (1982) in the Northeastern Sinai, Shaltout and El-Sheikh (2002) in the Nile Delta, and El-Sheikh et al. (2004) in El-Qanater Public Park (south Nile Delta).

The present study aims at determining the structure of vegetation types, and assessing the environmental factors that govern the distribution and diversity of the vegetation in urban habitats in the Nile Delta region of Egypt.

## 2 Materials and methods

### 2.1 The study area

Sharkiya Governorate, east of the Nile Delta (Egypt), lies between 30° 30′ and 30° 52′ N and 30° 41′ and 31° 40′ E (Fig. 1). The total area is about 415.171 ha, of which 34.317 ha are under cultivation (Attia 1954; Khadr 1987). The study area forms a part of the Eastern Desert where extremely arid conditions prevail. It is bounded by a desert area in south and south east, salt marshes in the north and north east and old cultivated land in the west (Abd El-Salam et al. 1973).

The study area has an Emberger quotient of 23.5, which classified it as an arid Mediterranean type of climate (Emberger 1955). It has an aridity index (P/PET), following UNESCO (1979), of less than 0.03, where $P$ is the mean annual of precipitation, and PET is the mean annual potential evapotranspiration. The mean annual temperature increases from 14.2 °C (January) to 27.3 °C (August). The relative humidity decreases from 77.2 % in August to 56.9 % in December. Evaporation is greater during summer than in winter months, it ranges between 9.1 mm day$^{-1}$ in August to 5.2 mm day$^{-1}$ in December. About 75 % of the total amount of rain falls from November to February. The gradient in the annual rainfall ranged between 21.2 mm in October and 39.3 mm in January; the wettest months (Table 1).

Soil of this area represents a transitional zone between the irrigated farmlands in the Nile Delta and the adjoining desert and salt marshes. In the east, the soil is mostly alkaline with sandy desert deposits, and extensive salt marshes of Lake Manzala to the north. The middle part of this area is occupied by plain with landscape characterized by sand dunes of active types and sandy sheets. Soils of the sandy sheets are composed of loose very coarse sand particles. The western part is dominated by the Nile Delta alluvial deposits and sandy formation in the south (El-Fayoumy 1968; El-Shazly 1975; Ibrahim 1979).

### 2.2 Vegetation data collecting

The present study was conducted between 2003 and 2007 to several locations to cover as much as possible all major and minor habitats. According to the standard system adopted by the world Land Use Commission (Hamdan 1961) and the previous studies, the study area included 5

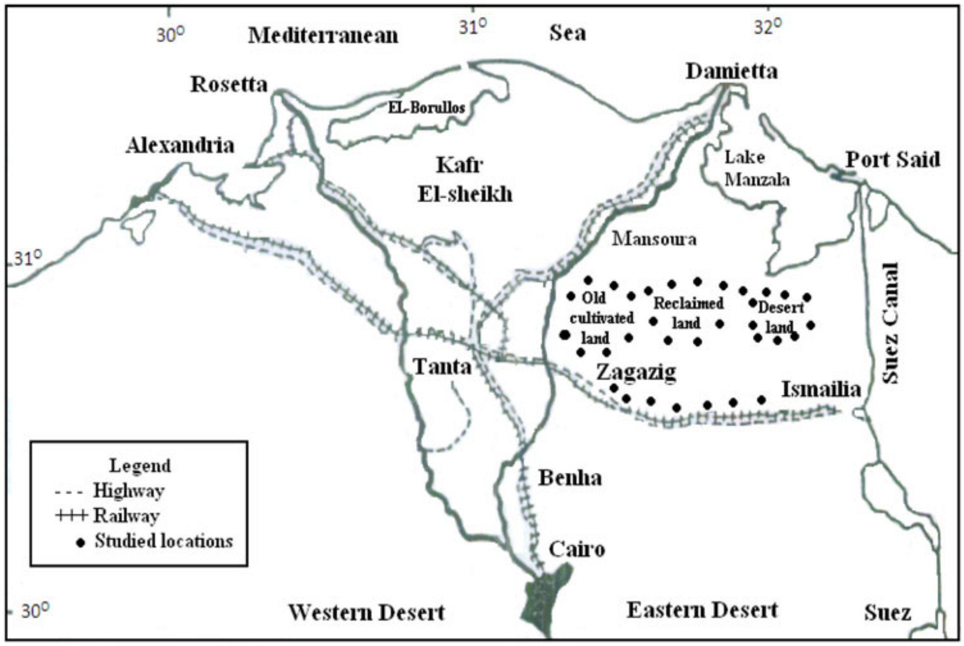


**Fig. 1** Map of the Nile Delta showing the studied locations (•)

**Table 1** Monthly mean of climatic factors at Sharkiya Governorate

| Meteorological variables | January | February | March | April | May | June | July | August | September | October | November | December |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature (°C) | 14.2 | 14.9 | 15.8 | 18.2 | 21.3 | 32.8 | 25.2 | 27.3 | 25.4 | 23.7 | 19.3 | 16.8 |
| Rainfall (mm year$^{-1}$) | 39.3 | 22.8 | 7.3 | 2.8 | 1.1 | 0.0 | 0.0 | 0.0 | 0.5 | 21.3 | 27.4 | 36.3 |
| Relative humidity (%) | 66.3 | 61.3 | 60.8 | 63.2 | 64.8 | 70.3 | 72.8 | 77.2 | 65.8 | 59.2 | 58.3 | 56.9 |
| Wind velocity (km h$^{-1}$) | 16.8 | 15.2 | 16.2 | 15.4 | 14.3 | 15.1 | 15.8 | 14.3 | 10.8 | 10.2 | 13.7 | 17.1 |
| Evaporation (mm day$^{-1}$) | 5.5 | 6.8 | 7.2 | 7.6 | 8.2 | 7.3 | 8.2 | 9.1 | 8.3 | 7.9 | 6.2 | 5.2 |

Means of 10 years from 1990 to 2000; data from Meteorological Department, Cairo

major habitats subdivided into 13 minor ones. These are distinguished into natural habitat (desert lands) included sand flats (Sf), sand dunes (Sd) and salt marshes (Sm), highly altered natural habitats: reclaimed lands (Rl) and man-made ones. The man-made habitats were distinguished into: cultivated lands; orchards (Or), summer crops (Sc) and winter crops (Wc), urban habitats (wastelands (Wl), abandoned fields (Af), railways (Rw) and highways (Hw) and wet lands irrigation canals (Ic) and drainage canals (Dc).

Altogether, 650 stands (50 in each minor habitat) were sampled to represent the apparent variation in the vegetation physiognomy and habitats. In each stand, five plots (2 $m^2$ each) were used to determine the floristic variations, and the percentage of total plant cover that was visually determined. Abundance of species was estimated according to the scheme of Braun-Blanquet (1932). The relative density and frequency of the recorded species were calculated according to Greig-Smith (1983). A list of species was made seasonally in each stand indicating the first and second dominant species. A matrix of 231 species × 650 stands was obtained. A list of species indicating the first and second dominant species was employed. Nomenclature was according to Täckholm (1974), Boulos and El Hadidi (1984), and Boulos (1999–2009). The life-form spectrum was according to Raunkiaer (1934).

### 2.3 Soil factors sampling

In each stand, five soil samples were collected from soil profile (0–40 cm), these samples were then pooled together forming one composite sample. Soil texture was determined by the hydrometer method. Soil moisture content (MC) was estimated by drying at 105 °C and then soil ignited at 600 °C for 3 h to determine organic matter (OM). Soil water extract (1:5) was prepared for the determination of electrical conductivity (EC) using conductivity meter, and soil reaction (pH) using a pH-meter. $Ca^{2+}$ and $Mg^{2+}$ were estimated with ethylene-diaminetetra-acetate (EDTA; versenate method), and $Na^+$ and $K^+$ using flame photometry. The total N was estimated by the micro-Kjeldahl method, $CaCO_3$, $CO_3$ and $HCO_3$ by acid titration, $Cl^-$ by titration with standard $AgNO_3$ solution and $SO_4$ gravimetrically by $BaSO_4$. Molybdenum blue and indophenols methods were used for the determination of P and N, respectively. These methods were outlined in Black (1965) and Allen et al. (1974).

### 2.4 Data analysis

Based on the presence/absence data matrix of 231 species in 650 stands, two-way indicator species analysis (TWINSPAN) for classification and detrended correspondence analysis (DCA) for ordination (Hill 1979a, b) were applied. Species richness (alpha-diversity) was estimated as the average number of species per stand and species turn-over (beta-diversity) as the ratio between the total numbers of species recorded in a certain cluster and its alpha-diversity. Shannon–Wiener index ($H' = -\Sigma$ P$i$ log P$i$) for the relative species evenness, and Simpson index ($C = \Sigma$ P$i^2$) for the relative concentration of species dominance were calculated for each vegetation cluster on the basis of the relative cover (P$i$) of the species (Whittaker 1972; Pielou 1975). One-way analysis of variance (ANOVA) was applied using SPSS version 10.0 for Windows (SPSS Inc., Chicago, IL, USA) to assess the significance of variation in the community and soil variables in relation to the identified vegetation types. LSD test was applied as a complementary test to the ANOVA to assess the significance of difference between each pair of means. The correlation coefficient ($r$) was applied to indicate the probable environmental significance of the ordination axes.

## 3 Results

Many localities in the study area have attracted the attention of the governmental authorities as a possible addition to the cultivated area. 231 species related to 152 genera and 45 families were recorded; of which 85 species (36.8 %) were winter active, 50 species (21.6 %) were summers active, contributing 58.4 %. *Sonchus macrocarpus* was recorded as endemic species. The most represented families were Gramineae (21.5 %), Compositae (14.7 %) and Leguminosae (9 % species) representing 45.2 % of the total recorded species.

Some species attain high presence percentage in most habitats (e.g., *Cynodon dactylon*, *Chenopodium murale*, *Cyperus rotundus*, *Phragmites australis*, *Sonchus oleraceus*, *Beta vulgaris*, *Senecio glaucus*, *Bassia indica*, *Convolvulus arvensis* and *Symphotrichum squamatum*). Many others were restricted to one habitat only such as *Adiantum capillus-veneris*, *Agathophora alopecuroides* (Ic), *Avena sterilis*, *Bacopa monnieri* (Af), *Datura innoxia* (Hw), *Centaurea pumilio* (Sf), *Cuscuta pedicellata*, *Euphorbia hirta* (Wc), *Ifloga spicata* (Sd), *Panicum coloratum*, *Myriophyllum spicatum* (Dc), *Juncus subulatus* and *Nitraria retusa* (Sm) (Table ESM1, Online Resource 1).

The species diversity of 13 habitats indicated that the irrigation canals had the maximum percentage of species (57.1 %) followed by drains (56.7 %), while drains had the maximum percentage of genus (65.7 %). Sand flats had the minimum percentage of species (16.4 %) and genus (22.4 %). Irrigation canals had the maximum value of species per genus (1.4) while sand flat (1.11) and wasteland (1.08) had the lowest one (Table 2).

Therophytes are the most represented life forms (58 %) of the total recorded species, followed by the crpytophytes (19 %) and chamaephytes (14.4 %). Therophytes are the most frequent life forms for all the habitats except the drains (16.4 %) where the cryptophytes exceeds slightly the therophytes (12.8 %). The cryptophytes are the second dominant life form in the habitat of irrigation canals (15.8 %), and highways (11.6 %). The high percentage of chamaephytes was recorded in (Dc) (10.7 %). Phanerophytes had the highest relative value (8.2 %) in the (Hw). Chorotype analysis of the study area revealed that, the Mediterranean element is represented by 120 species (51.9 % of the total species), followed by Irano-Turanian element 90 species (38.9 %), each of Cosmopolitan and Saharo-Arabian element 58 species (25.1 %), Euro-Siberian comprises 48 species (20.7 %) and Sudano-Zambezian element comprises 21 species (9.1 %). Regarding to the habitats, Saharo-Arabian attained the maximum percentage 23.5 % in Sf, followed by Sudano-Zambezian 20.0 % in Wl, Cosmopolitan (16.6 %), Irano-Turanian 11.8 % in each of Hw & Ic, Euro-Siberian 11.4 % in Dc and Mediterranean 10.7 % in Or (Table 2).

The application of TWINSPAN technique led to distinguish 30 vegetation groups at level 6 of the classification (Table 3). This is consistent with the results of DCA (Fig. 2a, b). These groups could be categorized at level 3 according to their habitat preferability into five vegetation types. These vegetation types were named after the first and occasionally the second dominant species as follows: group (I) that characterized the water zone of the drainage and irrigation canals and could be classified into open water, emergent and arid sub-associations based on the hydric adaptation. Open water was dominated by *Potamogeton pectinatus*, *Ceratophyllum demersum* and *Eichhornia crassipes*. *Phragmites australis*, *Echinochloa stagnina*, *Persicaria salicifolia* and *Typha domingensis* inhabit the slopes and terraces of the irrigation and drainage canals. *Imperata cylindrica*, and *Desmostachya bipinnata* dominated the terraces of canal banks. Vegetation type (II) characterizes the cultivated lands; orchards, winter

**Table 2** Floristic diversity, structural and chorological criteria in relation to the 13 habitats identified in the study area

| Habitats criterion | Sf | Sd | Sm | Rw | Hw | Wl | Af | Or | Sc | Wc | Rl | Ic | Dc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total species (S) | 38 | 54 | 48 | 73 | 116 | 63 | 84 | 100 | 50 | 85 | 77 | 132 | 131 |
| | *16.4* | 23.3 | 20.8 | 31.6 | 50.2 | 27.3 | 36.4 | 43.3 | 21.6 | 36.8 | 33.3 | *57.1* | 56.7 |
| Genus (G) | 34 | 40 | 38 | 63 | 92 | 58 | 68 | 78 | 42 | 63 | 58 | 94 | 100 |
| | *22.4* | 26.3 | 25.0 | 41.4 | 60.5 | 38.1 | 44.7 | 51.3 | 27.6 | 41.4 | 38.1 | 61.8 | *65.7* |
| Species/genus (S/G) | 1.11 | 1.35 | 1.76 | 1.2 | 1.26 | *1.08* | 1.23 | 1.28 | 1.19 | 1.34 | 1.3 | *1.4* | 1.3 |
| Species/stand | 20 | 22 | *15* | 17 | 15 | 20 | 23 | *35* | 25 | 30 | 23 | 29 | 25 |
| Therophytes | 19 | 33 | 25 | 35 | 66 | 35 | 45 | 69 | 30 | 66 | 47 | 80 | 44 |
| | 3.1 | 5.2 | 4.1 | 5.6 | 10.5 | 5.6 | 7.2 | 11.1 | 4.8 | 10.5 | 7.5 | *12.8* | 7.1 |
| Cryptophytes | 4 | 7 | 9 | 17 | 22 | 8 | 18 | 13 | 11 | 5 | 14 | 30 | 31 |
| | 2.1 | 3.7 | 4.7 | 6.2 | 11.6 | 4.2 | 9.5 | 6.8 | 5.8 | 2.6 | 7.4 | 15.8 | *16.4* |
| Hemicryptophytes | 6 | 8 | 4 | 10 | 10 | 8 | 11 | 9 | 5 | 6 | 8 | 9 | 8 |
| | 5.8 | 7.8 | 3.9 | 9.8 | 9.8 | 7.8 | *10.7* | 8.8 | 4.9 | 5.8 | 7.8 | 8.8 | 7.8 |
| Chamaephytes | 7 | 5 | 8 | 5 | 10 | 7 | 6 | 5 | 3 | 3 | 4 | 7 | 12 |
| | 8.5 | 6.1 | 9.7 | 6.1 | 12.2 | 8.5 | 7.3 | 6.1 | 3.6 | 3.6 | 4.8 | 8.5 | *14.6* |
| Phanerophytes | 1 | 1 | 2 | 6 | 8 | 5 | 4 | 3 | 1 | 1 | 1 | 5 | 5 |
| | 2.3 | 2.3 | 4.6 | 13.9 | *18.6* | 11.6 | 9.3 | 6.9 | 2.3 | 2.3 | 2.3 | 11.6 | 11.6 |
| Chorotypes | | | | | | | | | | | | | |
| ME | 14 | 18 | 21 | 27 | 34 | 16 | 30 | 36 | 12 | 29 | 32 | 34 | 32 |
| | 4.2 | 5.3 | 6.2 | 8.01 | 10.1 | 4.7 | 8.9 | *10.7* | 3.5 | 8.6 | 9.5 | 10.1 | 9.5 |
| IR-TR | 6 | 7 | 15 | 18 | 25 | 9 | 21 | 20 | 8 | 23 | 15 | 25 | 20 |
| | 2.8 | 3.3 | 7.1 | 8.5 | *11.8* | 4.2 | 9.9 | 9.4 | 3.7 | 10.8 | 7.1 | *11.8* | 9.4 |
| ER-SR | 4 | 6 | 5 | 9 | 8 | 6 | 8 | 8 | 4 | 5 | 6 | 9 | 10 |
| | 4.5 | 6.8 | 5.6 | 10.2 | 9.0 | 6.8 | 9.0 | 9.0 | 4.5 | 5.6 | 6.8 | 10.2 | *11.4* |
| Cosmopolitan | 2 | 1 | 1 | 2 | 7 | 5 | 5 | 6 | 6 | 5 | 5 | 10 | 11 |
| | 3.1 | 1.5 | 1.5 | 3.1 | 10.6 | 7.6 | 7.6 | 9.1 | 9.1 | 7.8 | 7.8 | 15.2 | *16.6* |
| SA–AR | 8 | 6 | 5 | 1 | 3 | 3 | 3 | 2 | – | 1 | 1 | – | 1 |
| | *23.5* | 17.6 | 14.7 | 2.9 | 8.8 | 8.8 | 8.8 | 5.8 | | 2.9 | 2.9 | | 2.9 |
| SU–ZA | – | – | – | 2 | 2 | 4 | – | 2 | 1 | 1 | 2 | 3 | 3 |
| | | | | 10.0 | 10.0 | *20.0* | | 10.0 | 5 | 5 | 10.0 | 15.0 | 15.0 |

The first line is the actual value and the second line is the relative value (%). The maximum relative values are in italics

*Ic* irrigation canals, *Dc* drainage canals, *Or* Orchard fields, *Sc* summer crops, *Wc* winter crops, *Ri* reclaimed lands, *Rw* railways, *Hw* high ways, *Wl* waste lands, *Af* abandoned fields

and summer crops. C*ynodon dactylon and Oxalis corniculata* dominated the orchards; while *Vicia sativa*, *Beta vulgaris*, and *Amaranthus viridis* dominated the winter crops and *Cynodon dactylon*, *Sida alba* and *Polypogon monspeliensis* dominated the summer crops. Vegetation type (III) characterizes the reclaimed lands which dominated by *Launaea nudicaulis*, *Imperata cylinderica*, *Marsilea aegyptiaca* and *Dicanthium annulatum*. Vegetation type (IV) occupies a wide environmental gradient (railways, abandoned fields, highways and waste lands) dominated by *Cynodon dactylon*, *Phragmites australis* and *Desmostachya bipinnata* in railways and abandoned fields; and *Pluchea dioscoridis*, *Bassia indica* in the highways and waste lands. Vegetation type (V) characterizes the desert habitats (sand flats, sand dunes and salt marshes), where *Paronychia arabica* in the sand dunes; *Mesembryanthemum nodiflorum*, *Halocnemum strobilaceum* and *Tamarix nilotica* in the salt marshes; and *Lactuca saligna* and *Zygophyllum album* in the sand flats.

Almost all the community and soil variables associated with the five vegetation types differed significantly between each type. Vegetation type (II) which dominated in cultivated land had the highest value of alpha diversity (10.7 species stand -1) and Shannon–Wiener index ($H' = 1.74$). Vegetation type (I) which dominated in wet land had the lowest alpha diversity (0.6 species/stand) and Shannon–Wiener index ($H' = 0.23$).Soils of vegetation type (V) which dominated in desert habitat had the highest values of coarse sand (33.7 %), fine sand (56.2 %) and $SO_4$ (18.4 %) while the vegetation type (II) had the highest

**Table 3** Characteristic of the vegetation groups derived after the application of TWINSPAN

| VT | No. of stands | No. of species | Minor habitats | First dominant species | *P* (%) | Second dominant species | *P* (%) |
|---|---|---|---|---|---|---|---|
| I | 42 | 3 | Ic | *Ceratophyllum demersum* | 100 | *Potamogeton nodosus* | 55 |
| | | | | | | *Eichhornia crassipes* | 75 |
| I | 25 | 2 | Ic, Dc | *Eichhornia crassipes* | 100 | *Phragmites australis* | 25 |
| | | | | | | *Azolla filiculoides* | 100 |
| | | | | | | *Ceratophyllum demersum* | 100 |
| | | | | | | *Echinochloa stagnina* | 100 |
| I | 6 | 3 | Ic, Dc | *Potamogeton pectinatus* | 100 | *Eichhornia crassipes* | 75 |
| | | | | | | *Spirodela polyrhiza* | 20 |
| I | 23 | 10 | Ic, Dc | *Echinochloa stagnina* | 100 | *Eichhornia crassipes* | 83 |
| | | | | | | *Panicum repens* | 66 |
| | | | | | | *Cyperus alopecuroides* | 44 |
| | | | | | | *Phragmites australis* | 44 |
| I | 5 | 2 | Ic, Dc | *Phragmites australis* | 100 | *Typha domingensis* | 25 |
| | | | | | | *Scirpus litoralis* | 20 |
| | | | | | | *Echinochloa stagnina* | 43 |
| I | 42 | 10 | Ic, Dc | *Persicaria salicifolia* | 90 | *Polypogon monspeliensis* | 15 |
| | | | | | | *Echinochloa stagnina* | 20 |
| I | 3 | 2 | Dc | *Typha domingensis* | 100 | *Phragmites australis* | 100 |
| | | | | | | *Symphyotrichum squamatum* | 40 |
| I | 19 | 6 | Ic, Dc | *Imperata cylindrica* | 100 | *Alhagi graecorum* | 67 |
| | | | | | | *Phragmites australis* | 40 |
| I | 60 | 7 | Dc | *Desmostachya bipinnata* | 100 | *Imperata cylindrica* | 75 |
| II | 69 | 6 | Or | *Cynodon dactylon* | 76 | *Chenopodium murale* | 30 |
| | | | | | | *Stellaria pallida* | 40 |
| | | | | | | *Melilotus indicus* | 52 |
| II | 81 | 10 | Or | *Oxalis corniculata* | 100 | *Anagallis arvensis* | 70 |
| II | 75 | 10 | Wc | *Polypogon monspeliensis* | 85 | *Medicago polymorpha* | 20 |
| | | | | | | *Vicia sativa* | 15 |
| II | 65 | 9 | Wc | *Beta vulgaris* | 100 | *Trifolium resupinatum* | 100 |
| II | 65 | 8 | Wc | *Amaranthus viridis* | 75 | *Cichorium endivia* | 75 |
| II | 20 | 6 | Sc | *Sida alba* | 75 | *Sesbania sesban* | 50 |
| III | 25 | 6 | RI | *Launaea nudicaulis* | 100 | *Cyperus rotundus* | 25 |
| III | 8 | 6 | RI | *Imperata cylinderica* | 100 | *Paspalum distichum* | 70 |
| | | | | | | *Sida alba* | 50 |
| III | 11 | 2 | RI | *Marsilea aegyptiaca* | 83 | *Dactyloctenium aegyptium* | 100 |
| III | 60 | 3 | RI | *Dicanthium annulatum* | | *Digitaria sanguinalis* | 66 |
| IV | 19 | 10 | Rw, Af | *Cynodon dactylon* | 100 | *Imperata cylindrica* | 100 |
| | | | | | | *Panicum repens* | 50 |
| IV | 8 | 4 | Rw, Af | *Desmostachya bipinnata* | 100 | *Bassia indica* | 65 |
| | | | | | | *Phragmites australis* | 70 |
| IV | 39 | 10 | Hw, Rw | *Pluchea dioscoridis* | 86 | *Arundo donax* | 65 |
| | | | | | | *Chenopodium murale* | 50 |
| IV | 99 | 11 | Rw, Hw, Wl, Af | *Bassia indica* | 95 | *Chenopodium murale* | 86 |
| IV | 77 | 13 | Wl, Af, Rw | *Phragmites australis* | 83 | *Chenopodium murale* | 76 |
| V | 21 | 9 | Sd | *Paronychia arabica* | 100 | *Plantago amplexicaulis* | 70 |
| | | | | | | *Launaea fragilis* | 80 |
| V | 15 | 4 | Sf | *Lactuce saligna* | 65 | *Calendula arvensis* | 59 |
| V | 13 | 4 | Sf | *Zygophyllum album* | 70 | *Salsola kali* | 70 |

**Table 3** continued

| VT | No. of stands | No. of species | Minor habitats | First dominant species | *P* (%) | Second dominant species | *P* (%) |
|---|---|---|---|---|---|---|---|
| V | 22 | 5 | Sm | *Mesembryanthemum nodiflorum* | 100 | *Salsola kali* | 69 |
| | | | | | | *Alhagi graecroum* | 30 |
| V | 10 | 4 | Sm | *Halocnemum strobilaceum* | 75 | *Arthrocnemum macrostachyum* | 75 |
| V | 22 | 7 | Sm | *Tamarix nilotica* | 100 | *Juncus acutus* | 10 |

*VT* vegetation types, *P* presence percentages (%). The habitats are: *Ic* irrigation canals, *Dc* drainage canals, *Or* Orchard fields, *Sc* summer crops, *Wc* winter crops, *Ri* reclaimed lands, *Rw* railways, *Hw* high ways, *Wl* waste lands, *Af* abandoned fields

values of silt and clay (45.5 %), OM (3.5 %), Mg (4.5 %), K (3.4 %) and P (3.6 %). The vegetation type (I) had the lowest value of coarse sand (6.6 %), fine sand (38.2 %), HCO3 (1.4 %), Cl (2.8 %) but has a highest value of MC (29.6 %) (Table ESM2, Online Resource 2).

Regarding variables, the DCA axis 1 correlates positively with the Shannon–Wiener index ($r = 0.59$), alpha diversity ($r = 0.74$) and total species ($r = 0.62$). The soil variables that correlate positively with axis **1** are OM ($r = 0.25$), pH ($r = 0.55$), EC ($r = 0.73$), $HCO_3$ ($r = 0.82$), P ($r = 0.87$) and Cl ($r = 0.64$); and those that correlate negatively are fine fractions ($r = 0.72$), MC ($r = 0.89$), $SO_4$ ($r = 0.78$) and Ca ($r = 0.67$). On the other hand, axis 2 correlates positively with coarse sand ($r = 0.57$), Mg ($r = 0.57$) and Na ($r = 0.53$), and negatively with Ca ($r = 0.55$) and $SO_4$ ($r = 0.44$) (Table ESM2, Online Resource 2).

## 4 Discussion

On the national scale, the flora of Egypt comprised of 2,121 species, related to 742 genera and 121 families (Boulos 1997). In the present study, 231 species belonging to 152 genera and 45 families were recorded. This contributes 10.9 % of the total flora of Egypt, 20.5 % of the total genera and 37.2 % of the total families. Zohary (1973) reported that the Egyptian flora is the large number of genera in proportion to that of species about 2.1 species per genus (Boulos 1997). On the other hand, Hawksworth (1995) demonstrated that the region had a certain number of species each of which belonged to a different genus is relatively more diverse than a region with the same number of species, but belonged to a few number of genera. The study area goes below the average level of the Egyptian flora where the number of species to genus was 1.5. This is a very low figure compared to the average global average of 13.6 (Good 1947).

Comparing the previous studies on Sharkiya Governorate during the last three decades (Table ESM3, Online Resource 3), Abd El-Fattah (1986) recorded 47 species related to 45 genera (S/G = 1.04), Khadr (1987) recorded 109 species related to 91 genera (S/G = 1.2), Shehata and El-Fahar (2000) recorded 107 species related to 85 genera (S/G = 1.3) in Salhiya region outskirts of Sharkiya Governorate, El Hady (2002) recorded 34 species related to 30 genera (S/G = 1.1) in San El-Hagar area and Baraka and Al-Sodany (2003) recorded 90 species related to 75 genera (S/G = 1.2) in Sharkiya which is close to 1.9 recorded by Abd Al-Azeem (2003) for the flora of Nile Delta. Some species were collected in certain studies, and not repeatedly recorded since then. Ninety-one species from different habitats were confined to this study. The floristic composition alteration in the study area may be attributed to the rapid and continuous change in the area, as several natural habitats were destroyed either by constructing new roads, establishment of new settlements and/or the expansion of building up brick factories on the expense of the cultivated areas (El-Kady et al. 2000). Seven species were constantly recorded in all studies such as *Bassia indica*, *Chenopodium murale*, *Sonchus oleraceus* and *Cynodon dactylon* which were considered among the common weeds of arable lands in Egypt (El Hadidi and Kosinová 1971). Ten species, mostly of desert (e.g., *Thymelaea hirsuta*, *Moltkiopsis ciliata*, *Asteriscus graveolens*, *Heliotropium bacciferum*, *Gymnocarpos decander*) and salt-tolerant species (e.g., *Aeluropus lagopoides*, *Scirpus tuberosus*, *Centaurium spicatum*) were only recorded by Abd El-Fattah (1986). Among the 10 species reported by Khadr (1987), certain water (e.g., *Elodea canadensis, Nymphaea lotus*) and moist-loving species (e.g., *Alternanthera sessilis*, *Verbena officinalis*, *Veronica beccabunga*) were documented. Disappearance of certain macrophytic species from the fresh water channels of the Nile Delta region was reported by Abd El-Ghani et al. (2010), who attributed this disappearance to the pollution of Nile water by heavy metals such as Hg, Pb and Cu, OM of plant and animal origin and the discharge of industrial and sewage effluents.

The abundance of therophytes in most of the habitats over the other life forms may be due to: In (Sf) may reflect their soil aridity, the hot-dry climate, moisture deficiency and topographic variation (Heneidy and Bidak 2001). The short life cycles of field crops and biotic influence (the most prominent land use in the study area), and substrate instability as in (Sc, Wc) probably lead to the frequent

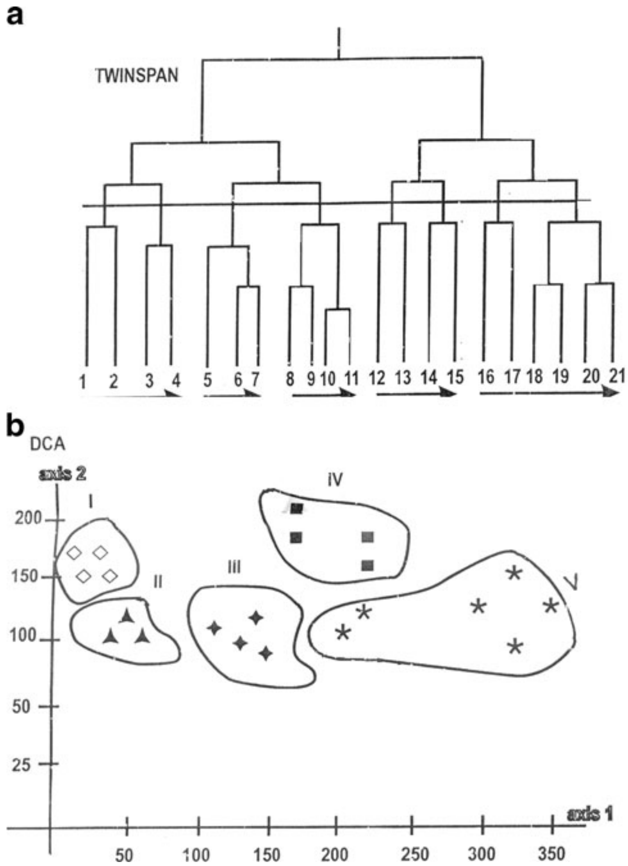


**Fig. 2** The relationship between the five vegetation types generated after the application of TWINSPAN classification technique (**a**) and their clusters along the DCA axes 1 and 2 (**b**). The indicator species are abbreviated on the head of groups. *I* water zone, *II* cultivated lands, *III* reclaimed lands, *IV* urbanized areas and *V* desert habitats

occurrence of therophytes during the favorable seasons (Shehata 2004). Irrigation and drainage canals in the study area were under many of large scale anthropogenic activities, viz: mechanical eroding of aquatic plants, new canal constructions, sediments movement or removal, waterway engineering, and alteration of the chemical composition of water, e.g., organic pollution. These endangered elements alter aquatic community structure in ways to reduce the abundance of native species and enhance the ability of non-indigenous species to become established, persist and spread (Qian 1994; McCully 1996). On the other hand, the abundance of the cryptophytes along canals and drains may relate to their growth habitats. Most of these cryptophytes were rhizomatous plants (e.g., *Cynodon dactylon*, *Cyperus rotundus*, *Phragmites australis*, and *Typha domingensis*, etc.) which believed to be more resistant to decomposition under water submergence. Similar conclusion was reported by El-Demerdash (1984); Shaltout and Sharaf El-Din, (1988); Shehata and El-Galay (2003).

The Mediterranean areas are defined according to temperature conditions (mean annual range is 10–25 °C), but the precipitation regime is the most distinctive (275–900 mm year$^{-1}$ with at least 65 % falling during winter). It might be expected that the Mediterranean species would occur mainly close to the Mediterranean coast including the coast of Nile Delta. According to Hurst (as quoted by Kassas 1955) Mediterranean species range corresponds to two climatic belts, viz. the Mediterranean costal belt and Middle Egypt. Thus, Mediterranean species occurs along North Africa, Egypt and most parts of Libya are too dry to support Mediterranean vegetation (Dallmen 1998) and in the middle and south Nile Delta, and Faiyum depression (Kosinová 1972). The mean annual temperature in the study area is in the same range, this may indicate that the relatively large percentage of Mediterranean plants, particularly the annuals, is embodied in the ruderal and segetal vegetation. The variation in relation to habitat types indicated that the Mediterranean elements are most represented in orchard fields where Shehata (2004) stated that these fields provides favorable conditions for its growth, e.g., shading, high moisture in air and soil, low temperature and evaporation. Dominant of Saharo-Arabian in sand flats seems to be able to response to the adverse of climatic conditions, which characterize in Sharkiya. Presence of mixture of different chorotype elements such as Cosmopolitan, Pantropical, Palaeotropical, Sudano-Zambezian, Irano-Turanian and Euro-Siberian elements are represented by variable numbers of species. This can be attributed to human impact, history of agriculture and capability of certain chorotype elements to penetrate the study area from several adjacent phytogeographical regions (Quézel 1978; Mashaly 1987; Shalaby 1995).

The five vegetation types identified in the present study are well segregated along the DCA axis one; which reflects the soil moisture, fertility, biotic change, aridity and species diversity gradients. When soil moisture decreases, species diversity increases. It also were represented the gradient of human interference, where the full man-made vegetation (wet lands and cultivated lands) occupied the left end of this gradient, where the less disturbed vegetation (reclaimed and urban land) was in the middle and no man-made vegetation (desert land) was in the right end. This gradient is associated with the increase of the relative presence of aridity.

The present study indicated that open water communities have low species diversity, may related to that most of their species are highly specific to the aquatic habitat. Caffrey (1985) decided that alteration of the chemical composition of water, due to organic pollution, may affects the composition and abundance of macrophyte species in rivers. Also the high disturbance of substrates of this zone (e.g., mechanical cleaning of aquatic weed, excessive waste discharge and fluctuations of the water velocity) may also explain this low diversity (Grime 1973). A similar conclusion was made by Shaltout and El-Halawany (1993), Shaltout and El-Sheikh (1993), Ayyad and Fakhry (1996) and Shehata and El-Galay (2003). Presence of therophytes with high species diversity on the terraces and slopes of water courses could be related to the sudden disturbance or heterogeneity of their substrates. Disturbances modify the soil substrate by alterations of soil compaction, destruction of the soil profile, and/or soil loss by direct removal or by erosion (Prose et al. 1987), changes in population responses (Bazzaz 1983) influences the spatial distribution of the population, detrimental to the vegetation growth (Rosenberg 1964). These results create spaces for establishment of pioneers and spreading of species (Sousa 1984) and selection of a specific flora with particular kinds of dispersal mechanisms and morphological and physiological features that are adapted to the new niches available for plant life (Lausi and Nimis 1985). This supports the view that increasing habitat heterogeneity is associated with an increase in species diversity (Ricklefs 1977; Nilsson et al. 1991). Moreover, the dense canopy of tall growing species along water edge (e.g., *Phragmites australis*) makes germination and growth of other species more difficult; this often leads to reduce the species diversity (Shaltout and El-Sheikh 1993). In general, the aquatic weeds are aggressively colonizing ruderals, which tend to form dense mono-dominant stand (Holzner 1978). This increases in their competitive ability resulting in lower species richness.

In full man-made habitat (old cultivated land), the soil fertility, clay and phosphorus increases while MC decreases. The weed communities of reclaimed lands are associated with soils characterized by relatively higher values of sand and alkalinity. The communities of wetlands are associated with soils characterized by relatively lower values of salinity, OM and slit. However, any attempt to relate the distribution of weeds to soil properties must be linked with several other factors (e.g., agricultural practices and biotic interaction) not directly associated with the measured soil properties (Hass and Streibig 1982; Streibig et al. 1984; Shaltout et al. 1992; Shaltout and El-Sheikh 2002).

Comparing the soil of vegetation types at the study area, it indicates that silt and clay, OM, potassium and phosphorus increase in cultivated and reclaimed with increase urbanization, while decrease in desert habitat. Urbanization and the conversion of natural habitats to agriculture by increasing runoff of silt, fertilizers and pesticides are major changes that affect the distribution and abundance of species and that enhance the importance of non-indigenous ones (Dobson et al. 1997). This trend is associated with higher number of total species and species richness of the vegetation types at cultivated and reclaimed land than those of the desert habitat. Nilsson et al. (1991) stated that increasing habitat heterogeneity increase species diversity. Thus, the high species diversity, species richness and turnover could be related to the increase of soil fertility (OM, K and P). On the other hand, the low species richness and species turnover of the wetlands and desert habitat may due to the fact that most of its species are highly specific to these habitats. Mueller-Dombois and Ellenberg (1974) pointed out that the plants, which are under extremes of an environmental gradient, do not prefer; they survive there only because they have great ecological tolerance for these ecological conditions.

## 5 Conclusions

Plant community distributions in the study area are highly correlated by soil moisture, fertility, biotic changes, and aridity and human manipulations. Water zone dominated by *Potamogeton pectinatus*, *Ceratophyllum demersum* and *Eichhornia crassipes* in open water, *Phragmites australis*, *Echinochloa stagnina*, *Persicaria salicifolia* and *Typha domingensis* in emergent and arid sub-associations based on the hydric adaptation was dominated by inhabit, *Imperata cylindrica*, and *Desmostachya bipinnata* dominated the slopes and terraces of canal banks. Meanwhile, alterations of soil characters by anthropogenic activities of the natural environment for agriculture production have provided a favorable condition for the growth of weedy species, e.g., C*ynodon dactylon and Oxalis corniculata* in orchards; while *Vicia sativa*, *Beta vulgaris*, and *Amaranthus viridis* in winter crops and *Sida alba* and *Polypogon monspeliensis* in summer crops. Reclaimed lands dominated by *Launaea nudicaulis*, *Imperata cylinderica*, *Marsilea aegyptiaca* and *Dicanthium annulatum*. Railways and abandoned fields were dominated by *Phragmites australis* and *Desmostachya bipinnata*, while in the highways and waste lands *Pluchea dioscoridis*, *Bassia indica*. Natural or desert habitats were dominated by arid plants, e.g., *Paronychia arabica* in the sand dunes; *Mesembryanthemum nodiflorum*, *Halocnemum strobilaceum* and *Tamarix nilotica* in the salt marshes; and *Lactuca saligna* and *Zygophyllum album* in the sand flats.

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