

PHYTOSOCIOLOGY AND DISTRIBUTIONS OF SPONTANEOUS PLANT SPECIES IN THE NORTHERN ZONE OF THE SOUF REGION (ALGERIA)

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Abstract. This study was conducted in the dry areas of the northern Algerian Sahara; The northwest of the El-Oued region, this northern zone of the Sahara presents a very diverse floristic procession. The study of the flora of this region, over five (5) years (2019 to 2023), allowed us to record 85 species belonging to 68 genera and 29 families. The Asteraceae family was represented by 16.47% different species followed by Amaranthaceae at 14.12%, Poaceae at 12.94%, and Brassicaceae at 7.06%. The most frequent life forms are Therophytes (42.35%) followed by Chamaephytes (30.59%), Hemicryptophytes 14.12% and Phanerophytes 7.06%. the biological forms that characterize this herbaceous and bushy desert vegetation are the ability to resist the scarcity of water, silting, higher salinity levels, and high temperatures in this area. The distribution of species is heterogeneous from one site to another due to different chemical and physical soil conditions, notably gypsum, limestone, salts, silting, and dunes. Land reclamation programs and excessive overgrazing by stray camels have put some species in danger of extinction, including Fabaceae and Apiaceae. A notable decrease in specific richness is recorded in this dry region, Shannon's index recorded a decrease from 0.266 in Still to 0.159 in Hamraia due in particular to climate change and anthropic conditions.

Keywords: *Sahara, flora, bioecology, life forms, soil conditions*

Introduction

On a global scale, arid regions constitute a reservoir of spontaneous plants and the northern Algerian Sahara is an important part of the world's arid regions. The El Oued region is part of this immense part of the world. It contains in particular very important plant species in terms of ecological, medicinal and pedological balance which belong to different genera and do not group together in nature under the sole effect of chance but obey other laws. According to Monier (2000) and Zeki Apaydin et al. (2009), who noted that among the edaphic factors which intervene on the distribution of vegetation are the texture, saltiness as well as the level of concentration of limestone. Climate plays a fundamental role in the distribution of living beings (Ozenda, 1991). Temperature controls all metabolic phenomena and conditions the distribution of all species and communities of living beings, plants and animals in the biosphere (Chehma et al., 2005).

While for Zedam et al. (2016) the two essential climatic factors, namely precipitation and temperature, constitute the decisive element for the characterization of plant formations and determine their distribution and development. While Deghiche Diab et al. (2016) add that climate plays a crucial role in the distribution and life of living beings. Therefore, we will be able to observe the same combination of species, in certain locations, and that this combination of species will locally reflect the typology of the soil, the altitude, the latitude and the climatic conditions in place. According to Halis et al. (2012) the plant cover of the El-Oued region presents low diversity and density. It is represented by spontaneous plants characterized by rapid growth, small size and adaptation to the pedoclimatic conditions of the region. The objective of this study is to determine the distribution of plant species according to phytosociological and edaphic conditions in the North-West zone of the El-Oued region. This study established an approach to groupings, which focus on the study of plants and their association at the level of the different study sites. It consists of studying soil-floristic diversity relationships and the relationships that exist between different species. Monitoring the development of the vegetation cover over a period of five years and identifying the main factors that affected it.

Materials and methods

This study was carried out in the dry areas of the northern Algerian Sahara. Our current data on the floral communities of the Lower Sahara are poor despite some studies carried out in Oued Righ (Azizi et al., 2021; Chenchouni, 2012).

Choice of study area

Delimitation of (04) four stations were delimited at the level of (04) four localities, namely (Still; Oum-Tiour; Meguibra, and Hamraia), selected for this study and which present floristic, pedological, and morphological homogeneity of the terrain and the aim of which is to demonstrate the maximum landscape and physiognomic change while taking into account the criteria of homogeneity and representativeness of the vegetation, of the North-West zone of the northern Sahara of the El-Oued region (*Fig. 2*).

Geographical location of the sites

Still site

14 km north of the town of Still, the Still Station is located at the coordinates of (34°23'11.50"N and 5°53'09.75"E) altitude of 26 meters (*Fig. 2*) the environment is more exposed to the different stages of water erosion, namely striations and channels. The soil is shallow and marly, with an average slope of 5%. Due to its low altitude and its exposure to the southeast, temperatures become very high as we approach the summer. As a consequence of very significant potential evapotranspiration, and following substantial water erosion, the soil loses fine particles and becomes rocky. An average rainfall of 49.69 mm/year. An average temperature of around 22.1°C. Sparse plant cover (*Fig. 1a*).

Oum-Tiour site

It is located 6 km northwest of the locality Oum-Tiour at the coordinates of (34°12'04.33"N and 5°48'20.59"E) altitude of 32 meters (*Fig. 2*). It features sandy-

limestone soil. At Oum-Tiour station, the average annual temperature is 22.1°C, and the mean yearly rainfall is 49.69 mm. It is distinguished by a whitish-colored gypsum soil and a sulfated water table situating well close to the surface. (Achour-Kadi Hanifi and Loisel, 1997; Bouzid et al., 2012; Merdas et al., 2021). The gypsum forms very thick slabs, favoring the installation of herbaceous and homogeneous plants (*Fig. 1b*).

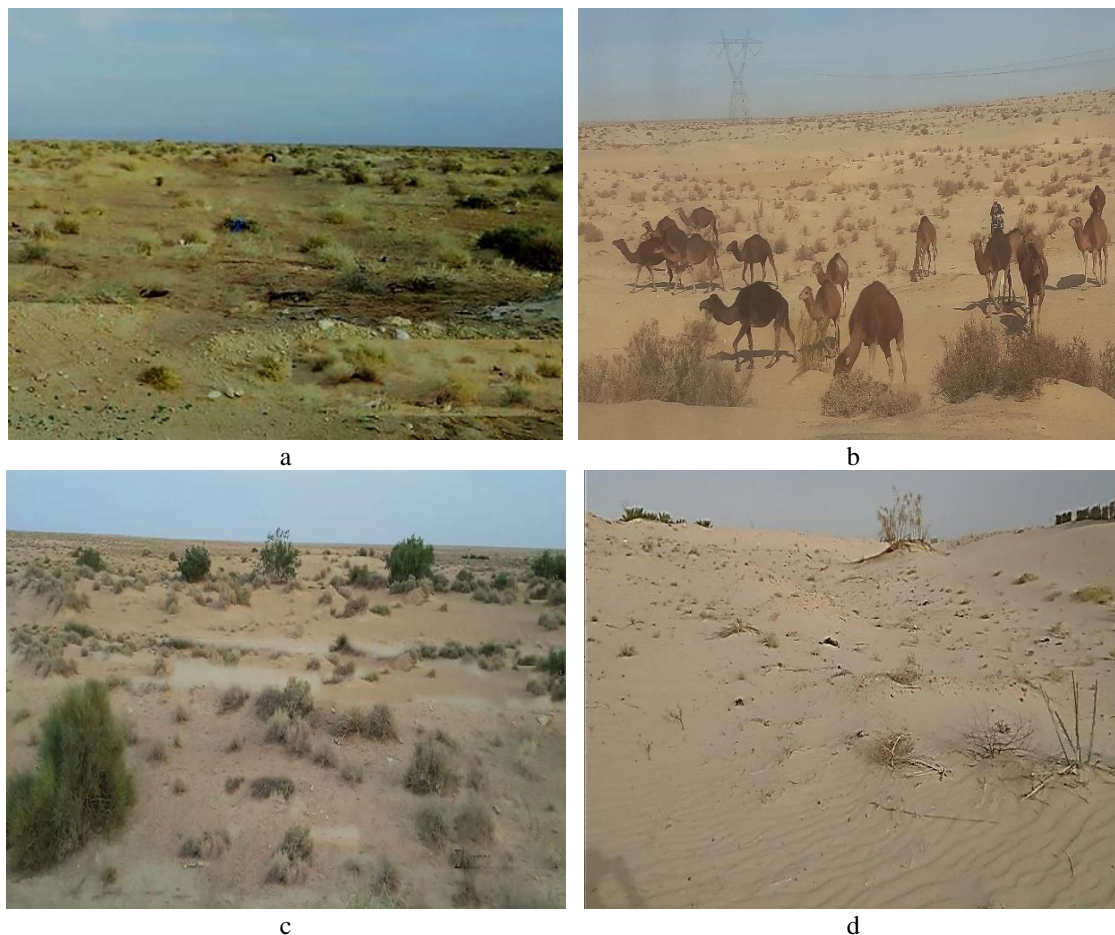


Figure 1. General view of the four ecological study sites in the north-eastern area of the El-Oued region. (a) Overview of sampling sites and habitats at Still Station. (b) Overview of sampling sites and habitats at Oum-Tiour Station. (c) Overview of sampling sites and habitats at Meguibra Station. (d) Overview of sampling sites and habitats at Hamraia Station

Meguibra site

It is situated 6.5 km south-southeast of town Meguibra, at coordinates (34°12'38.57"N and 6°03'25.47"E), and at an altitude of -21 meters (see *Fig. 2*). The area features various forms of sand deposits, including Nebkas, Rebdous, and dunes, which are stabilized and fixed by psammophilous vegetation (Bel et al., 2014). The slope gradually becomes gentler as one moves southeast. It is distinguished by a psammophilous floral assemblage, such as the Drinn. The average annual temperature is 22.1°C, and the mean yearly rainfall is 49.69 mm. The region is also influenced by wind inputs and sedimentary sand, on a deep support formed by Deb - deb (made up of gypsum-limestone accumulation) (*Fig. 1c*).

Hamraia site

The site is situated 9 km southeast of the town of Hamraia, at coordinates $34^{\circ}04'38.59''\text{N}$ and $6^{\circ}19'23.29''\text{E}$, with an altitude of -28 m (see Fig. 2). The soil in this area is sandy loam, and the terrain exhibits a very gentle slope of 0.07%. Due to its elevation below sea level, the plain is subject to salinity caused by drainage water and runoff containing sodium chloride from the north. The average annual rainfall is 49.64 mm, and the average temperature is 22.1°C . The vegetation is sparse and homogeneous (Fig. 1d).

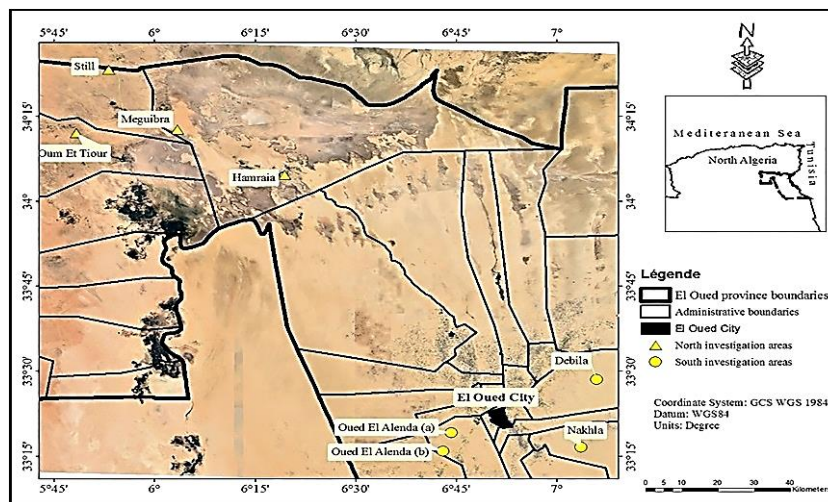


Figure 2. Location map of the study area and sampling sites

The ecological elements studied

Calculation of the minimum area of the stations. The physical and chemical state of the soil. Sand encroachment. Salinity level. The floristic, pedological, and morphological homogeneity of the terrain are the subject of the delimitation of the different stations (Ozenda, 1983).

Calculating the minimum area

The concept of “minimum area” refers to the spatial extent required to ensure that nearly all species within a plant community are represented. A traditional method used to determine this is the “nested surface method.” Given the sparse nature of the vegetation, an area of 400 m^2 per station was established as the minimum size necessary to represent the total plant diversity observed at the four study sites.

Flora analysis

At each site, four randomly selected plots, each measuring 400 m^2 , were surveyed. Surveys were conducted four times per site annually during the months of February, March, April, and May. Thus, each site was surveyed a total of 16 times per year, amounting to 80 surveys over the five-year period from 2019 to 2023. The quantitative assessment of vegetation involved analyzing quantitative coefficients related to frequency, density, and the Shannon-Weaver index concerning species richness at each site. The indices were calculated as follows:

Frequency	$F = \frac{n}{N} \times 100$	<i>F</i> : frequency <i>n</i> : number of surveys containing the species studied <i>N</i> : the sum of the surveys carried out
Specific and total density	$D_T = \sum ds$	<i>D_T</i> : total density
Shannon-Weaver index	$H = - \sum_{i=1}^s p_i \ln p_i$	<i>H</i> : Shannon-Weaver index <i>P_i</i> : proportion of individuals of a species
Species diversity number	S	S : number of species

“Vegetation surveys at each station were conducted in four randomly selected minimum areas (Deghiche-Diab et al., 2022, 2016; Diab et al., 2013; Belhadj et al., 2023; Gland et al., 2003; Larbi et al., 2021; Bouzid et Brahim, 2012; Salemkour et al., 2012). These surveys specifically targeted herbaceous and shrub species (Médail et al., 2022). According to Aboura et al. (2006) and Fetnaci et al. (2019), floristic surveys should be accompanied by comprehensive ecological and phytosociological observations. Consequently, a reconnaissance sheet was prepared for each site to collect data on location, altitude, exposure, geomorphological substrate, slope, and recovery rate.

The species encountered were identified in the field; however, unidentified specimens were collected, dried, and analyzed at the Technical Institute for the Development of Saharan Agriculture (I.T.D.A.S.). Identification was confirmed using floristic guides such as *New Flora of Algeria and the Southern Desert Regions* (Belhadj et al., 2023), *The Flora of the Sahara* (Ozenda, 1985), and *The Plant Lime Guide* (Schauer et al., 2007). Nomenclature adhered to Ozenda (1983) and was updated using the North African database (Dobignard et al., 2010-2012).

The results were analyzed using ecological and statistical indices derived from the field-based floristic surveys. The determination of the biological spectra at the stations was conducted according to the work of Kadi-Hanifi (1998), and Ecological Diversity Indices were applied following Ramade (2003). Soil sampling and climatic data collection occurred in early March, soil samples were collected from the root zone at a depth of 30 cm, with five (5) samples and soil profiles obtained from each site (Fetnaci, et al., 2019). Soil systematics were classified according to the French system of 1967. Physical analyses included measurements of particle size, texture, and humidity, while chemical analyses assessed pH, electrical conductivity (EC), total limestone, and gypsum content. Climatic data were recorded at the El-Arfiane meteorological station.

Statistical analyzes of data

Principal Component Analysis (PCA) and Ascending Hierarchical Classification (AHC) were performed using the software XLSTAT (2016). These analyses enabled the examination of correlations between various edaphic factors and the floristic biodiversity of the study sites through three ecological indices and nine quantitative pedological analyses. The objective was to identify homogeneous groups within the observations at the site level, thereby distinguishing between similar and divergent patterns. Duby et al. (2006) emphasized the importance of identifying variables, diversity indices, and soil analyses that exhibit high correlations with one another.

Results and discussion

We obtained climate data from the El-Afriane weather station, as it is the closest station to our study sites. We used the five-year average precipitation and temperature data (2019 to 2023) and compared them with the averages recorded by this station over the past 33 years. *Figure 3* shows that July is the hottest month, with an average maximum temperature of 40.8°C, while January has the lowest average minimum temperature at 10.4°C. The average annual temperature is approximately 22.1°C, indicating a relatively hot climate. The total annual precipitation is estimated at 49.64 mm/year, a very small and insufficient amount that results in a prolonged dry period throughout the year. From 2019 to 2023, the average annual rainfall was around 37.99 mm, which is below the long-term average. The drought period extends for nine (9) months, from April to December. The total sum of annual temperatures recorded is 31°C, representing an average increase of 1.33°C compared to the 33-year average at the El-Afriane weather station. The scarcity and irregularity of rainfall, combined with the rise in average annual temperatures, clearly demonstrate the effects of climate change on this arid region. This has led to an acceleration of desertification, increased drought conditions, and exacerbated edaphic phenomena such as erosion, in addition to anthropogenic effects like overexploitation, primarily pastoralism.

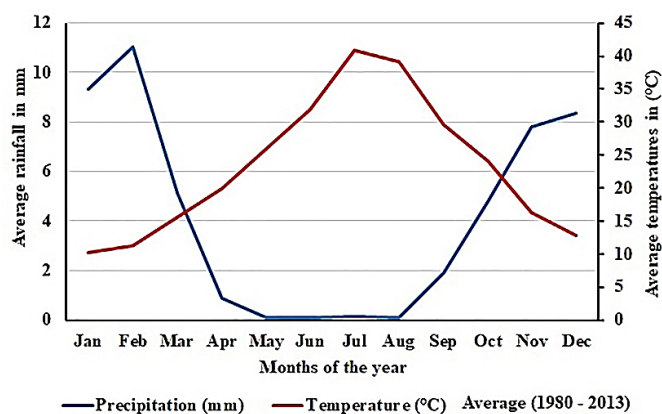


Figure 3. Bagnouls-Gaussens' Ombrothermic diagram established from a 33-year period (1980-2013) and applied to the study region. (N.M.O, of El-Arfiane 2023)

Soil analysis results

Still site is characterized by a silty-sandy structure with a high limestone content of approximately 39.97% and clay content of 18.4%. The Meguibra site exhibits a high level of gypsum and a significant presence of fine sand. In contrast, the Hamraia site is notable for its high sodium salt concentration, with a rate of 12.08 ds/m, and also has a silty-sandy structure. The pH level is alkaline across all four sites, but it is particularly pronounced at the Meguibra and Hamraia sites, with a pH of approximately 8.09. According to Dreux (1980), edaphic factors encompass all physical and chemical properties of the soil that have ecological effects on living organisms. Apaydin et al. (2009) noted that edaphic factors influence the distribution of plant species. Additionally, Halis et al. (2012) observed that the soil in the El-Oued region has characteristics typical of Saharan regions, including a lack of organic matter and a sandy texture with high water permeability (*Table 1*).

Table 1. Analyses results of soil samples from the four sites

Sites	Analyses H. cm	Cly + F. St. %	C.St. %	F.S. %	C.S. %	H. %	pH 1/5	CE 1/5 ds/m	CaSO ₄ 2H ₂ O %	CaCO ₃ %
Still sites	0 – 30	18.4	35.8	23.5	22.3	8.93	7.69	0.3	11.4	39.97
Oum-Tiour sites	0 – 30	28.1	25.4	18.10	28.4	11.7	7.86	2.9	7	18.02
Meguibra sites	0 – 30	3.2	32.9	53	10.9	4.1	8.02	10.9	14.02	4.10
Hamraia sites	0 – 30	1.1	59.3	24.4	15.2	19.33	8.09	12.08	8.6	2.47

H (cm): Height in centimeters; Cly: Clay; L.S.: Fine silt; C.St.: Coarse silt; F.S. %: Fine sand in percentage; F.St.: Fine Silt; C.S.%: Coarse sand in percentage; H%: Humidity in percentage; pH: soil acidity (hydrogen potential); E.C.: Soil Electrical conductivity; CaSO 2H O%: gypsum content in percentage; CaCO%: Limestone rate in percentage

Analysis of inventoried vegetation

Vegetation was sampled, identified, and recorded according to the International Plant Name Index (IPNI) and by the stratified method in the proximal and distal areas of the four selected stations (Table 2).

Table 2. General list of species inventoried in the four sites in the North-East zone of the El-Oued region during the 2019 to 2023 campaigns

Family	Species according to IPNI	Still site	Oum-Tiour site	Meguibra site	Hamra site	Life form	Average O. I. % 5 years
Amaranthaceae	Arthrocaulon macrostachyum (M.)				+	Cha.	15
	Atriplex cinerea (Poir.)			+	+	Cha	20
	Chenopodiastrum murale (L.)				+	The	20
	Cornulaca monacantha (Delile)		+	+		Cha	15
	Halocnemum cruciatum (Tod.)				+	Cha.	22.5
	Haloxylon salicornicum (Moq.)				+	Pha	20
	Salsola foetida (Vest)				+	Cha	17.5
	Caroxylon tetrandrum (Forssk.)				+	Cha	37.5
	Caroxylon vermiculatum (L.)				+	Cha	15
	Suaeda fruticosa (Forssk.)				+	Cha	42.5
	Suaeda vermiculata (Forssk.)				+	Cha	22.5
Traganum nudatum (Delile)				+	Cha.	42.5	
Apiaceae	Ammodaucus leucotrichus (Coss.)			+		The	40
Asclépiadacées	Pergularia tomentosa (L.)	+	+			Cha	20
Asteraceae	Anthemis stiparum (Pomel)		+			The	12.5
	Atractylis carduus (Forssk.)		+			The	20
	Atractylis serratuloides (Sieber)		+	+		The	50
	Brocchia cinerea (Delile)	+				The	50
	Koelpinia linearis (Pall.)		+			The	37.5
	Launaea capitata (Spreng.)		+	+		The	47.5
	Launaea fragilis (Asso)	+				The	47.5
	Aaronsohnia pubescens (Desf.)	+	+			The	25
	Nolletia chrysocomoides (Desf.)		+	+		Cha	47.5
	Onopordum micropterum (Pau)	+				The	22.5
	Rhanterium suaveolens (Desf.)	+	+			Cha	25
	Sonchus asper (L.)	+	+			Hem	22.5
	Sonchus maritimus (L.)			+	+	Hem	50
Picris asplenioides (L.)	+				The	12.5	
Boraginaceae	Arnebia decumbens (Vent.)	+		+		The	20
	Echiochilon fruticosum (Desf.)			+		Cha	22.5
	Echium humile (subsp.)		+	+		The	20

Brassicaceae	<i>Ammosperma cinereum</i> (Desf.)			+		The	20
	<i>Diploaxis harra</i> (Forssk.)	+				The	47.5
	<i>Diploaxis pitardiana</i> (Maire)	+				The	22.5
	<i>Farsetia aegyptiaca</i> (Desv.)	+		+		Cha	22.5
	<i>Lobularia libyca</i> (Meisn.)		+	+		The	17.5
	<i>Eremobium aegyptiacum</i> (Spreng)		+	+		The	15
Capparaceae	<i>Cleome arabica</i> (L.)	+	+			The	20
Caryophyllaceae	<i>Gymnocarpos decander</i> (Forssk.)	+				Cha	20
	<i>Herniaria fontanesii</i> (J.Gay)			+		Cha	42.5
	<i>Polycarpha repens</i> (Forssk.)		+	+		The	25
	<i>Silene nicaeensis</i> (All.)	+	+			The	50
Colchicaceae	<i>Colchicum capense</i> (subsp.)	+				Geo	40
Cyperaceae	<i>Cyperus conglomeratus</i> (Rottb.)			+		Hem	45
Ephedraceae	<i>Ephedra alata</i> (Decne.)				+	Pha.	17.5
Euphorbiaceae	<i>Euphorbia guyoniana</i> (Boiss.)	+				Hem	32.5
Fabaceae	<i>Astragalus armatus</i> (Willd.)	+	+			Cha	70
	<i>Lotus halophilus</i> (Boiss.)				+	The	15
	<i>Retama raetam</i> (Forssk.)	+	+	+		Pha	40
Frankeniaceae	<i>Frankenia thymifolia</i> (Desf.)				+	Cha	40
Geraniaceae	<i>Monsonia nivea</i> (Decne.)	+				The	37.5
	<i>Erodium laciniatum</i> (Cav.)	+				The	22.5
Lamiaceae	<i>Marrubium deserti</i> (Coss.)	+				Cha	55
Liliaceae	<i>Albuca amoena</i> (Batt.)			+		Geo	45
Malvaceae	<i>Malva parviflora</i> (L.)	+	+	+		The	15
Neuradaceae	<i>Neurada procumbens</i> (L.)	+		+		The	42.5
Nitrariaceae	<i>Peganum harmala</i> (L.)	+	+	+	+	Geo	47.5
Orobanchaceae	<i>Cistanche tinctoria</i> (Forssk.)		+	+		The	50
	<i>Cistanche violacea</i> (Desf.)	+	+			The	50
Plantaginaceae	<i>Linaria peltieri</i> (Batt.)		+	+		The	47.5
	<i>Plantago albicans</i> (L.)		+	+		The	17.5
	<i>Plantago ciliata</i> (Desf.)	+	+			The	25
Plumbaginaceae	<i>Limoniastrum guyonianum</i> (Durieu)			+	+	Cha	70
Poaceae	<i>Stipagrostis obtusa</i> (Delile)			+		Hem	45
	<i>Stipagrostis plumosa</i> (L.)		+			The	20
	<i>Stipagrostis pungens</i> (Desf.)		+			Hem	20

I.P.N.I.: International Plant Names Index. L.F: Life form; Cha: Chamaephytes; Geo: Geophytes; Hel: Helophytes; Hem: Hemicryptophytes; Pha: Phanerophytes; The: Therophytes; O.I.: Occurrence index

Figure 4 shows the evolution of the Shannon-Weaver index at the four sites during the five years of monitoring and surveys, showing the evolution of species richness at each site.

The curves presented in *Figure 4* depict the evolution of species diversity at each site, as indicated by the Shannon indices, a progressive degradation and decrease in this index were observed across the sites. In 2019, the Shannon index was 1.687 at the Still site and 1.503 at the Oum-Tiour site. By 2023, the index decreased to 1.421 at the Still site and 1.192 at the Oum-Tiour site. A similar trend was noted at the other two sites, with the Meguibra site recording a Shannon index of 1.411 in 2019 and 1.421 in 2023, while the Hamraia site, which has high salinity levels, showed a decrease from 0.971 in 2019 to 0.812 in 2023 (*Fig. 4*). This decline in the Shannon index suggests an increasing threat of extinction for rare species, particularly those in the families Apiaceae, Fabaceae, Lamiaceae, and Resedaceae (*Fig. 5*). The observed decreases in diversity can be attributed to the following biotic and abiotic factors:

- Climate change
- Scarcity of rainfall
- Rising average temperatures
- Increased sodium salt levels in certain areas
- Anthropogenic effects, including grazing by wandering camel herds on endangered species
- Excessive groundwater consumption by farmers, lead to salt accumulation and deposition in surface layers of earth's crust

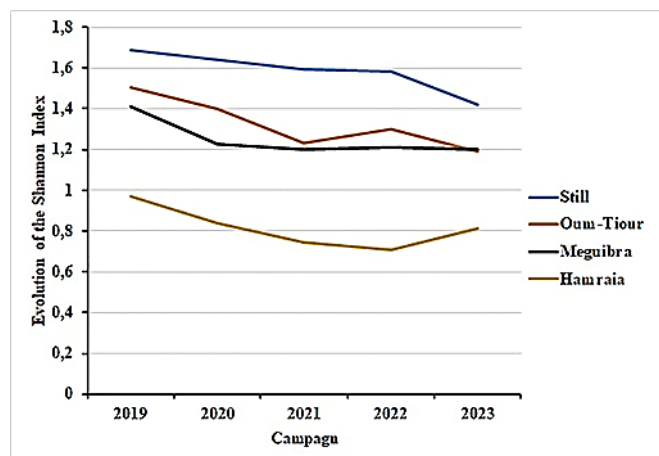


Figure 4. Evolution of the Shannon index at the level of the four sites during the five years (2019 – 2023)

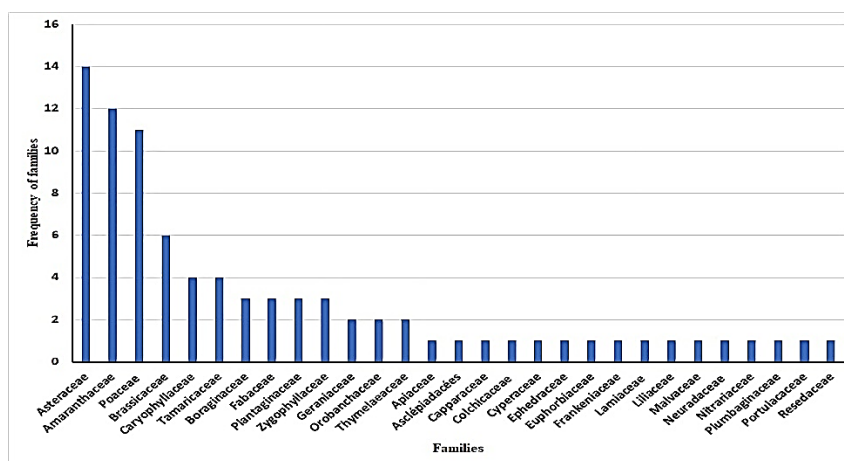


Figure 5. The average frequencies of families recorded in all study sites: (northwest zone of the El-Oued region); 2019–2023 campaigns

Species richness has been observed to be impacted by rainfall factors, which aligns with the findings of Kadi-Hanifi (1998). The Occurrence index indicates that most of the inventoried species are omnipresent, except for the dominant species in the northern zone of Souf, which exceeds 50% prevalence. These species include *Echium pycnanthum*, *Limoniastrum guyonianum*, *Malva parviflora*, *Polycarpacea repens*, *Polypogon monspeliensis*, *Retama raetam*, *Silene villosa*, and *Tamarix africana* (Dajoz,

2003). These species are well-adapted to saline, gypsum-rich, and sandy environments. However, species such as *Malva parviflora* and *Retama raetam* have occurrence indices greater than 60% and are classified as regular species, as the edaphic conditions (particularly salinity) in some environments are not always tolerable for them.

Equitability (E) varies between 0 and 1; it tends towards 0 when the population is dominated by a single species and towards 1 when each species is represented by a similar number of individuals (Ramade, 2003). Vegetation sampling revealed 85 taxa belonging to 29 families. The highest plant diversity was observed at Station Still (average richness = 38), while the lowest was at Station 4 (average richness = 26). Most of the halophytes belong to the genera *Suaeda*, *Atriplex*, and *Salicornia*. The dominant families, respectively, are Asteraceae, Amaranthaceae, Poaceae, and Brassicaceae (Fig. 5). Notably, 15 recorded families are represented by only a single species (mono-specific). Conversely, four families—Asteraceae, Amaranthaceae, Poaceae, and Brassicaceae—comprise more than 50% of the species due to their significant adaptation to sandy and saline soils (Fig. 5).

Analysis of the flora of the northern zone of El Oued

According to Figure 5, a total of twenty-nine (29) families were recorded across the four sites. The family Asteraceae, known for its deep root system that can extend up to 4 meters deep and its reduced leaf surface, is the most dominant, representing 16.47% of the recorded species. This dominance is attributed to their adaptation to pedoclimatic and environmental conditions. The second most prevalent family is Amaranthaceae, accounting for 14.12% of species, followed by Poaceae, which represents 12.94% of species. The Poaceae family includes psammophilous species, particularly *Aristida pungens*, which stabilize sand dunes (Deghiche Diab et al., 2016). The Brassicaceae family follows with 7.05% of species, while Caryophyllaceae, Plumbaginaceae, and Tamaricaceae each account for 4.7% of the species

Total biological spectrum of the northern zone of El-Oued region

The structure of the flora at a station can be characterized by its biological spectrum, which indicates the proportion of each biological type. These spectra reflect the adaptation strategies of different plant species to harsh environmental conditions (Raunkiaer, 1905). The conservation of biodiversity is achieved not only through the protection of individual species but also by conserving biodiversity-rich sites. Effective preservation results in the establishment of protected areas with well-maintained and unmodified environments (Sergio et al., 2007).

The biological spectrum (Fig. 6) shows the dominance of Therophytes over other biological forms in the northern zone of the El-Oued region, with Therophytes comprising 42.35% of the flora. Chamaephytes account for 30.59%, Hemicryptophytes for 14.12%, and Phanerophytes for 7.06%. Chamaephytes, which include bushes adapted to withstand dry conditions through specialized leaf and root systems, are notably prevalent.

Analysis of vegetation at site level

At the Still site, 31.76% of the recorded species are represented, with 27 different species belonging to 21 families. The dominant families are Asteraceae, comprising 25.92% of the species, and Poaceae, comprising 18.52% (Fig. 8a). The dominant biological types are Therophytes at 50%, followed by Chamaephytes at 23.68% (Fig. 7a).

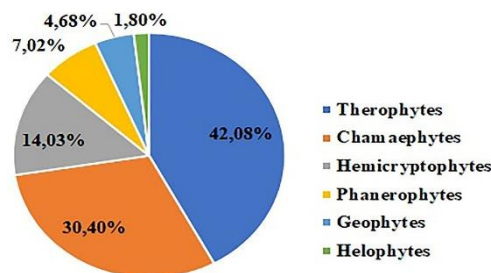


Figure 6. Represents the means of the percentage distributions of life forms of the North-West zone of the El-Oued region (Campaigns 2019-2023). Cha: Chamaephytes; Geo: Geophytes; Hel: Helophytes; Hem: Hemicryptophytes; Pha: Phanerophytes; The: Therophytes

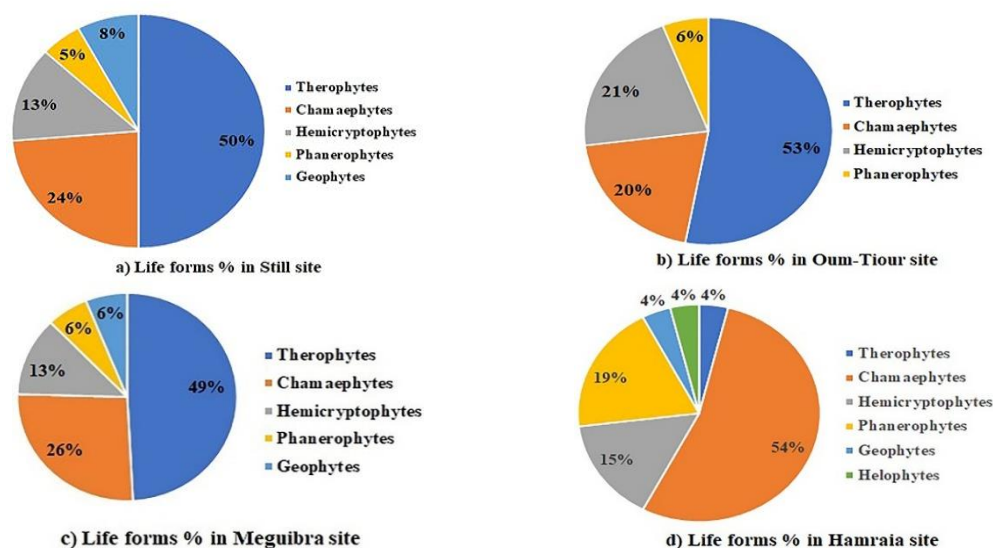


Figure 7. Represents the percentages of life forms from the four study sites in the north-eastern area of El-Oued region; 2019-2023 campaigns

At the Oum-Tiour site, 30.58% of the recorded species include 26 species from 15 families. Asteraceae is the most dominant family at 34.62%, followed by Poaceae at 19.23% (Fig. 8b). The dominant biological types are Therophytes at 52.94%, followed by Chamaephytes and Hemicryptophytes, each at 20.59% (Fig. 7b).

At the Meguibra site, 29.41% of the recorded species include 25 different species from 18 families. Asteraceae and Brassicaceae are the most dominant families, each comprising 16% of the species, followed by Boraginaceae and Poaceae, each at 12% (Fig. 8c). The dominant biological types are Therophytes at 51.61%, followed by Chamaephytes at 27.58%, and Hemicryptophytes at 12.90%. Phanerophytes and Geophytes each constitute 6.45% (Fig. 7c).

At the Hamraia site, 29.41% of the recorded species include 25 random species from 9 families. The dominant family is Tamaricaceae at 42%, followed by Asteraceae at 16% (Fig. 8d). The dominant biological types are Chamaephytes at 53.85%, followed by Phanerophytes at 19.23%, and Hemicryptophytes at 15.38% (Fig. 7d).

The biological spectrum indicates that Therophytes dominate at more than 50% in the Still, Oum-Tiour, and Meguibra sites. These species are adapted to survive periods

of drought by remaining in seed form. They are herbaceous plants that typically appear shortly after rain, completing their biological cycle before the soil dries out. In contrast, at the Hamraia site, Chamaephytes are the most dominant at 53.85%. Hemicryptophytes occupy third place at the Hamraia site, with percentages ranging from 12.90% to 20.59%.

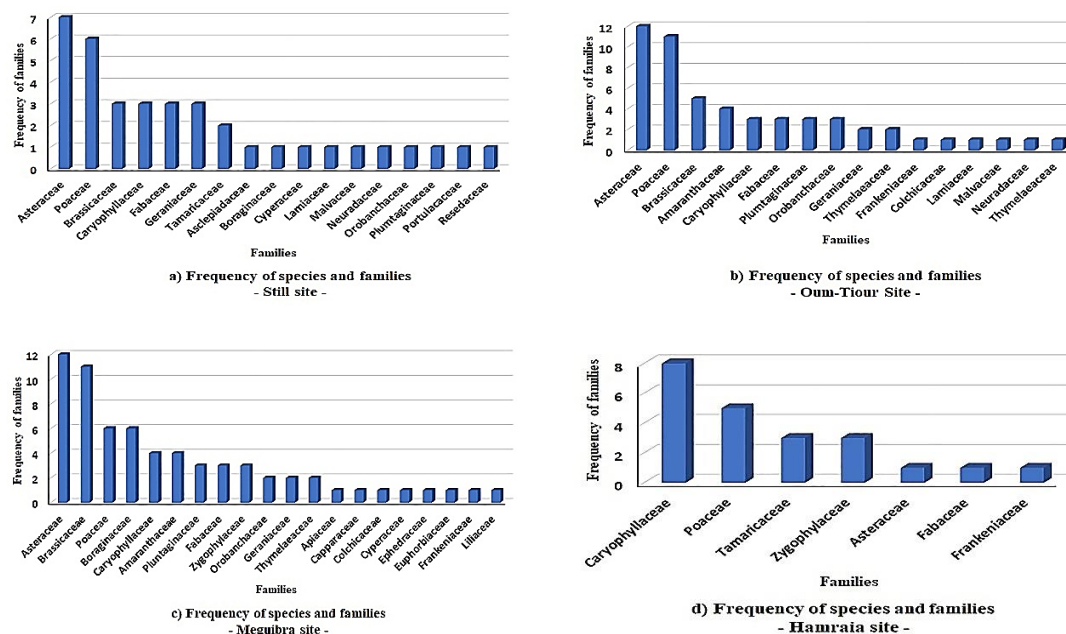


Figure 8. Shows the average frequency of families at the four sites during the 2019-2023 campaigns

Statistical analyses of correlations

To study the correlations between different quantitative variables, a mixed Principal Component Analysis (PCA) table was constructed. This table comprised 94 columns representing quantitative variables and four rows representing the sites. The scatter plots (Fig. 9) and the plots after rotation (Fig. 10) illustrate the grouping of random species according to substrate types (Deghiche Diab et al., 2016), and reveal the phytosociological relationships among different species and their environments, as well as interspecific relationships. The recorded results indicate that the horizontal axis F1 accounts for 39.99% of the initial information, while axis F2 represents 35.32% of the information before rotation, together totaling 75.31% of the information. The vectors on the scatter plots represent the variables under study, with their sizes reflecting their importance and significance (Fig. 9). After rotation, axis D1 accounts for 33.66% of the information, and axis D2 represents 37.56%, resulting in a total of 71.22% of the information (Fig. 10). PCA, conducted using Xlstat 16 software, facilitated the identification of various pedoclimatic, ecological, and phytosociological gradients that influence floristic composition and distribution (Figs. 9, 10, and 11). Additionally, similar phyto-ecological studies by Benabadji et al. (2002) on steppe environments dominated by *Stipa tenacissima* and *Artemisia herba-alba* underscore the significance of incorporating edaphic variables in multivariate analyses of floristic composition.

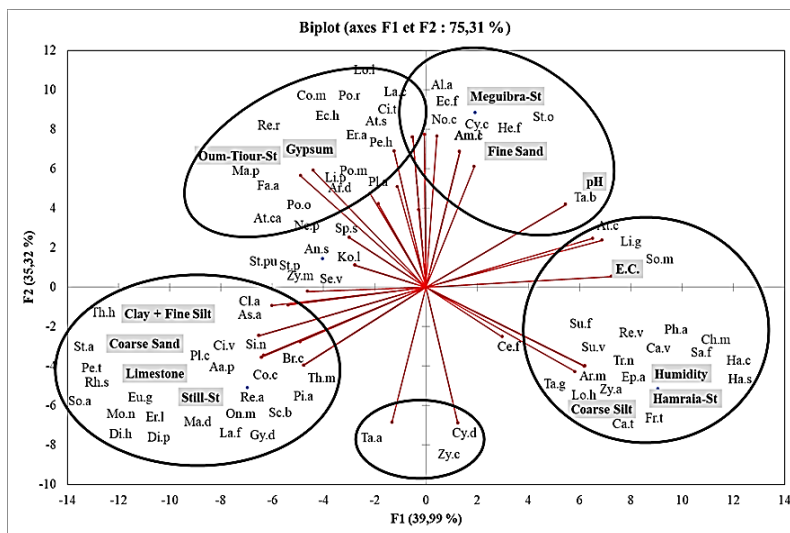


Figure 9. Circle of correlations and projection of variables on the plane of axes F1 and F2 of the Principal Component Analysis of plants and their distributions in the northern zone of the El-Oued region; 2019-2023 campaigns

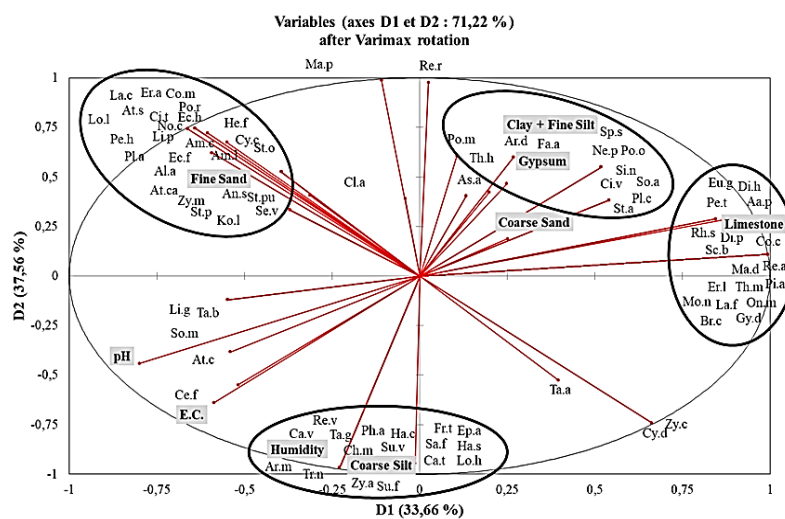


Figure 10. Circle of correlations and projection of variables on the plane of axes D1 and D2 of the Principal Component Analysis of plants; after rotation

Hierarchical clustering results

To classify all random plant species into similar groups, a dendrogram for an Ascending Hierarchical Classification (AHC) was created, identifying four groups of similar species (Fig. 11). This classification aligns with the findings of Abdel Khalik et al. (2017), Abdulkader (2015), and Médail and Quezel (2022), who emphasized that the spatial distribution of plant species and communities within small geographic areas in desert ecosystems is primarily influenced by topography and landform patterns. Furthermore, in arid steppe rangelands, severe climatic conditions have led to the formation of specialized plant communities (Merdas et al., 2021; Quezel et al., 1963; Slimani et al., 2010).

Hierarchical cluster analysis

Hierarchical clustering results at 75.31% of information.

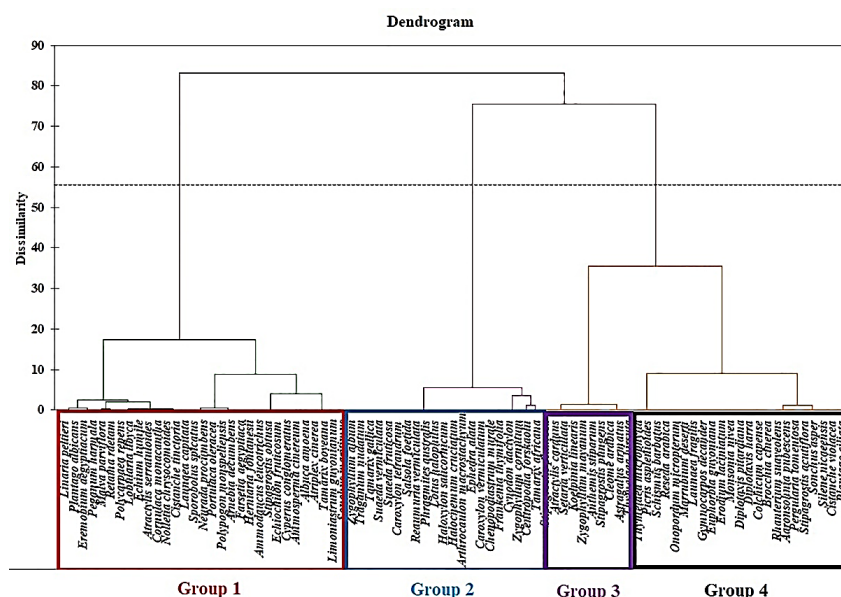


Figure 11. Dendrogram obtained by Hierarchical Cluster Analysis (HCA) of plants species

Association between species (Jaccard similarity index)

The similarity between species, as illustrated by the Jaccard index and depicted in the dendrogram (Fig. 11), reveals the presence of four main groups of species associations. The first group comprises 27 calcicole species characteristic of the Still study site. The second group consists of 26 gypsum-related species, specific to the Oum-Tiour site (Fig. 11). The third group includes 25 species that tolerate fine sand and high pH levels (Fig. 11). The fourth group is made up of 21 halophyte species, which are adapted to high electrical conductivity and elevated soil moisture due to the proximity of the water table (Fig. 11).

Discussion

The Still site is characterized by predominantly limestone soil, with the presence of clay, fine silt, and coarse sand. It supports 27 different species and is noted for its calcicole plants. Among the recorded calcicole species is *Astragalus armatus* (Willd.). Results from the Principal Component Analysis (PCA) indicate that the species at this site exhibit a negative correlation with those at the Hamraia site, where halophytes prevail due to elevated sodium levels in the soil. Species that show a negative correlation with *Atriplex cinerea* group are adapted to limestone, clay, and fine silt (Fig. 9). This group of calcicole plants, illustrated in Figure 11, includes species detailed in Table 3. This observation supports the findings of Bouzid et Brahim (2012) and Le Houérou (1995), who highlighted the significance of edaphic factors—particularly soil texture, salinity, and limestone content—in shaping plant communities.

The soils at the Oum-Tiour site, characterized by dominance of gypsum, clay, and fine silt, support a significant number of random species, totaling 26 species

(Table 3). Results from the Principal Component Analysis (PCA) indicate that the species recorded at this site (Table 3) are distinct from those at the Hamraia site, where halophyte species prevail due to high sodium levels in the soil (Figs. 9 and 11). These findings align with those of Khechekhouche et al. (2020), who identified *Zygophyllum* and *Limoniastrum* as halo-gypsophilous plants. Deghiche Diab et al. (2016) noted that gypsum soils are typically occupied by gypsum-adapted plants such as *Frankenia thymifolia*, *Limoniastrum guyonianum*, *Zygophyllum cornutum*, and *Astragalus armatus*. This observation is consistent with the work of Bouzid et Brahim (2012) and Mashaly (2006), who reported that gypsum soil vegetation includes species such as *Peganum harmala*, *Retama raetam*, *Thymelaea hirsuta*, and *Erodium glaucophyllum*.

Table 3. Species recorded in site of Still, and site of Oum-Tiour; their characteristics and the soil conditions favouring their installation

Still site		Oum-Tiour site	
Group characteristics * Limestone * Coarse Sand * Clay + Fine Silt		Group characteristics * Gypsum * Clay + Fine Silt	
N°	Registered species	N°	Registered species
10	<i>Astragalus armatus</i> (Willd.)	13	<i>Atractylis carduus</i> (Forssk.)
49	<i>Aaronsohnia pubescens</i> (Desf.)	12	<i>Atractylis serratuloides</i> (Sieber)
15	<i>Brocchia cinerea</i> (Delile)	8	<i>Arnebia decumbens</i> (Vent.)
19	<i>Cleome arabica</i> (L.)	20	<i>Cornulaca monacantha</i> (Delile)
18	<i>Cistanche violacea</i> (Desf.)	17	<i>Cistanche tinctoria</i> (Forssk.)
3	<i>Colchicum capense</i> (subsp.)	18	<i>Cistanche violacea</i> (Desf.)
24	<i>Diplotaxis harra</i> (Forssk.)	27	<i>Echium humile</i> (subsp.)
25	<i>Diplotaxis pitardiana</i> (Maire)	46	<i>Eremobium aegyptiacum</i> (Spreng.)
31	<i>Euphorbia guyoniana</i> (Boiss. & Reut.)	33	<i>Farsetia aegyptiaca</i> (Desv.)
30	<i>Erodium laciniatum</i> (Cav.)	44	<i>Lobularia libyca</i> (Meisn.)
35	<i>Gymnocarpus decander</i> (Forssk.)	40	<i>Launaea capitata</i> (Spreng.)
41	<i>Launaea fragilis</i> (Asso)	43	<i>Linaria peltieri</i> (Batt.)
48	<i>Marrubium deserti</i> (de Noé)	47	<i>Malva parviflora</i> (L.)
29	<i>Monsonia nivea</i> (Decne.)	50	<i>Neurada procumbens</i> (L.)
52	<i>Onopordum micropterum</i> (Pau)	58	<i>Polycarpaea repens</i> (Forssk.)
54	<i>Pergularia tomentosa</i> (L.)	59	<i>Polypogon monspeliensis</i> (L.)
73	<i>Picris asplenioides</i> (L.)	53	<i>Peganum harmala</i> (L.)
57	<i>Plantago ciliata</i> (Desf.)	60	<i>Portulaca oleracea</i> (L.)
62	<i>Reseda arabica</i> (Boiss.)	57	<i>Plantago ciliata</i> (Desf.)
64	<i>Rhanterium suaveolens</i> (Desf.)	56	<i>Plantago albicans</i> (L.)
70	<i>Silene nicaeensis</i> (All.)	63	<i>Retama raetam</i> (Forssk.)
75	<i>Stipagrostis acutiflora</i> (Trin. & Rupr.)	75	<i>Stipagrostis acutiflora</i> (Trin. & Rupr.)
71	<i>Sonchus asper</i> (L.)	71	<i>Sonchus asper</i> (L.)
69	<i>Setaria verticillata</i> (L.)	74	<i>Sporobolus spicatus</i> (Vahl)
68	<i>Schismus barbatus</i> (L.)	70	<i>Silene nicaeensis</i> (All.)
82	<i>Thymelaea microphylla</i> (Coss.)	81	<i>Thymelaea hirsuta</i> (L.)
81	<i>Thymelaea hirsuta</i> (L.)		

The Meguibra site, characterized by the dominance of fine sand and high pH, supports a total of 25 different species that show an affinity for fine sand (Fig. 9; Table 4). According to the results from the Principal Component Analysis (PCA) after rotation, it has been observed that gypsiferous and calcareous species exhibit a negative correlation with species positively correlated with high electrical conductivity and high soil pH. Notable examples include *Limoniastrum guyonianum*, *Tamarix boveana*, *Sonchus maritimus*, *Atriplex cinerea*, and *Centropodia forskaoalii* (Fig. 10).

Table 4. Species recorded in site of Meguibra, and site of Hamraia; their characteristics and the soil conditions favouring their installation

Meguibra site		Hamraia site	
Group characteristics		Group characteristics	
* Fine Sand * pH. Élevé		* Coarse Silt * Humidity * E.C.	
N°	Registered Species	N°	Registered Species
14	<i>Albuca amoena</i> (Batt.)	9	<i>Arthrocaulon macrostachyum</i> (Moric.)
1	<i>Ammodaucus leucotrichus</i> (Coss.)	16	<i>Chenopodiastrum murale</i> (L.)
12	<i>Atractylis serratuloides</i> (Sieber)	67	<i>Caroxylon vermiculatum</i> (L.)
4	<i>Anthemis stiparum</i> (Pomel)	66	<i>Caroxylon tetrandrum</i> (Forssk.)
13	<i>Atractylis carduus</i> (Forssk.)	16	<i>Chenopodiastrum murale</i> (L.)
26	<i>Echiochilon fruticosum</i> (Desf.)	28	<i>Ephedra alata</i> (Decne.)
46	<i>Eremobium aegyptiacum</i> (Spreng.)	34	<i>Frankenia thymifolia</i> (Desf.)
27	<i>Echium humile</i> (Subsp.)	37	<i>Haloxylon salicornicum</i> (Moq.)
22	<i>Cyperus conglomeratus</i> (Rottb.)	36	<i>Halocnemum cruciatum</i> (Tod.)
20	<i>Cornulaca monacantha</i> (Delile)	42	<i>Limoniastrum guyonianum</i> (Durieu.)
17	<i>Cistanche tinctoria</i> (Forssk.)	45	<i>Lotus halophilus</i> (Boiss. & Spruner)
38	<i>Herniaria fontanesii</i> (J.Gay)	55	<i>Phragmites australis</i> (Cav.)
39	<i>Koelpinia linearis</i> (Pall.)	61	<i>Reaumuria vermiculata</i> (L.)
40	<i>Launaea capitata</i> (Spreng.)	83	<i>Traganum nudatum</i> (Delile)
44	<i>Lobularia libyca</i> (Meisn.)	80	<i>Tamarix gallica</i> (L.)
43	<i>Linaria peltieri</i> (Batt.)	61	<i>Reaumuria vermiculata</i> (L.)
51	<i>Nolletia chrysocomoides</i> (Desf.)	72	<i>Sonchus maritimus</i> (L.)
58	<i>Polycarpaea repens</i> (Forssk.)	76	<i>Suaeda fruticosa</i> (Forssk.)
53	<i>Peganum harmala</i> (L.)	77	<i>Suaeda vermiculata</i> (Forssk.)
56	<i>Plantago albicans</i> (L.)	65	<i>Salsola foetida</i> (Vest)
69	<i>Setaria verticillata</i> (L.)	84	<i>Zygophyllum album</i> (L.f.)
5	<i>Stipagrostis obtusa</i> (Delile)		
6	<i>Stipagrostis plumosa</i> (L.)		
7	<i>Stipagrostis pungens</i> (Desf.)		
32	<i>Zygophyllum mayanum</i> (Schltdl.)		

At the Hamraia site, distinguished by coarse silt, high soil humidity, and high electrical conductivity due to elevated sodium salt levels, a total of 25 random species were recorded (Table 4). Notably, the site shows a dominance of *Halocnemum cruciatum* (Tod.), *Limoniastrum guyonianum* (Durieu), *Phragmites australis* (Cav.), *Tamarix gallica* (L.), and *Zygophyllum album* (L.f.). These findings are consistent with

those of Khechekhouche et al. (2020). The majority of halophytic plants are grouped on both sides of the F1 axis (Fig. 9), aligning with the observations of Deghiche Diab et al. (2016) and Chenchouni (2012), who noted that the halophyte group is predominantly composed of *Salsolaceae* and *Atriplex halimus*. According to Ozenda (1983), the vegetation of salty soils is characterized by halophytic plant species such as *Salsola foetida*, *Traganum nudatum*, and *Zygophyllum album*. These results also corroborate the findings of Khechekhouche et al. (2020), who indicated that *Zygophyllum* and *Limoniastrum* are considered halo-gypsiferous. This confirms the reports of Chenchouni (2012), who noted that halophytic vegetation, represented by Chenopodiaceae species, is distributed around the edges of water bodies. The Hamraia site is regarded as a shott, where the subsoil is humid and rich in salts, as indicated by the presence of halophyte and hydrophyte species. This floristic composition suggests that the environment is both salty and humid. According to Mashaly (2006), *Limoniastrum guyonianum* is highly tolerant of chott salinity levels and has a strong correlation with *Atriplex halimus* and *Zygophyllum cornutum*.

Conclusion

The total species richness recorded in the study region amounts to 85 taxa, distributed among 68 genera and 29 families. The family *Asteraceae* is represented by 16.47% of the species, followed by *Amaranthaceae* at 14.12%, *Poaceae* at 12.94%, and *Brassicaceae* at 7.06%. The biological spectrum is dominated by Therophytes (42.35%), followed by Chamaephytes (30.59%), Hemicryptophytes (14.12%), and Phanerophytes (7.06%). *Fabaceae* and *Apiaceae* show lower diversity indices compared to previous years (2019, 2020, and 2021), reflecting a significant decline. This decrease is attributed to excessive overgrazing by stray camels and the impacts of land reclamation programs.

Statistical analysis indicates significant differences ($p < 0.05$) between the edaphic factors and the various species groups recorded at each site, with their densities and frequencies varying under different edaphic conditions. Correlation analysis revealed a strong positive correlation between species and the edaphic factors at the different sites.

At the Still site, where limestone dominates, spontaneous vegetation is predominantly calcicole, with over 61% of species belonging to this group. Conversely, at the Oum-Tiour site, characterized by gypsum dominance, gypsum-related species are prevalent. The Meguibra and Hamraia sites, which are characterized by sandy accumulations and high salt levels, present psammophyte and halophytic communities, with species dominance at 51% and 54.9%, respectively. This reflects the species' ability to tolerate water scarcity, siltation, high salinity, and elevated temperatures.

Species distribution is heterogeneous across sites due to varying edaphic conditions. Over the past five years, there has been a notable decrease in the Shannon-Weaver index at all four sites, indicating a reduction in species richness as a result of anthropogenic factors, water scarcity, and climate change.

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