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Floristic Inventory and Preliminary Diversity Assessment of the Al-Tar Caves Area, Karbala, Iraq

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ABSTRACT

Plant diversity in arid and semi-arid regions is strongly shaped by climatic and environmental conditions. This study documented and analyzed the floristic composition of Al-Tar Caves, Karbala, Iraq, and assessed the influence of climatic factors on plant distribution. Field surveys were conducted in 2024 across 17 geo-referenced stations using stratified sampling to represent major habitat types. Species were identified using standard taxonomic keys. Diversity was evaluated using three indices: species richness (S), the Shannon–Wiener index (H′), and Pielou's evenness (J). Species richness ranged from 5 at Station 16 to 12 at Station 9. H′ varied between 1.49 and 2.31, indicating moderate to relatively high diversity across the study area. J ranged from 0.88 to 0.97, suggesting a generally even distribution of individuals among species. These results reflect spatial heterogeneity in vegetation structure among the surveyed stations. Climatic data obtained from the Iraqi Meteorological Organization were compared descriptively with the observed vegetation patterns. A total of 106 plant species belonging to 34 families were recorded, including 96 species from 32 dicotyledon families. Asteraceae was the dominant family (15 species), followed by Amaranthaceae (11 species), while 15 families were represented by a single species, particularly in riparian habitats. Reduced vegetation cover was observed in sites characterized by higher temperatures and low rainfall. Despite harsh environmental conditions, the region supports notable plant diversity, with temperature and rainfall identified as key drivers of spatial variation in species distribution.

1. INTRODUCTION

Karbala is situated in central Iraq, between latitudes 32°10′15″ N and 32°50′15″ N, and longitudes 43°09′41″ E and 44°18′56″ E. The city encompasses 4,987 km². Geologically, the governorate forms part of the unstable shelf of the sedimentary plain zone and the Al-Salman zone. Additionally, it is generally characterized by a topography that gradually declines from the southwest towards the northeast [1]. Due to its strategic location, Holy Karbala is considered one of the most important regions in Iraq in terms of its historical, religious, touristic, and agricultural importance. However, the branch of the Euphrates River that flows through the governorate, together with several irrigation channels, contributes significantly to the groundwater recharge, making groundwater one of the main water resources in the area [2]. The Tar Al-Sayed area, also known as the Al-Tar Caves, is one of the important geological areas in Iraq. It is situated approximately 100 km southwest of Baghdad, in the western part of Karbala Governorate, and south of Al-Razzaza Lake. Covering an area of about one square kilometre, this location possesses unique geological and historical features, which make it a potential candidate for Geopark designation [3].

Plants are essential for land resources, as they play a crucial role in sustaining nature, wildlife, conservation, and ecological balance [4]. However, technological advancement, population growth, industrialization, and various other anthropogenic factors have strained natural resources to their limits [5]. The conservation of plant diversity has received considerably less attention than the conservation of animals, possibly because plants lack the widespread public appeal associated with many animal species [6]. As a result, plant conservation is greatly under-resourced compared with animal conservation [7]. Nevertheless, plants are much more important to humans. Also, animals can provide meat, fur, leather, and other products, but none of these are necessities of human survival and well-being. In contrast, many plant products are essential, as plants supply food for humans and livestock, as well as provide a huge diversity of other products and ecosystem services. These include timber, fibers, clean water regulation, and erosion control. Despite these varieties of products, most commercial plant products are derived from a very narrow range of plant species [8].

Floristic inventories are used to get basic information about the trends in biodiversity, ecosystem performance, and conservation effectiveness [9]. The vegetation structure in the arid and semi-arid ecosystems depends mostly on variation in precipitation, temperature extremes, salinity of soil, and composition of the substrate [10]. Limestone topography, like the Al-Tar Caves region, can tend to create microhabitats that affect species assemblages by having a greater or lesser ability to retain moisture and provide shade. Despite the botanical history of Iraq [11], new regional floristic evaluations are still scarce, especially in centrally located limestone and cave-linked habitats. It has already been mentioned that desert vegetation and riverine systems have been studied in the past [12], but no floristic inventory has been performed regarding the Al-Tar Caves.

Climate change represents a major global challenge addressed at multiple governmental and non-governmental levels. Rising greenhouse gas emissions and increasing atmospheric CO_2 concentrations (eCO_2), along with associated changes in temperature and precipitation patterns, are expected to affect plant ecophysiology, distribution, and ecological interactions. The soils of the Karbala area are characterized by sparse natural vegetation cover and a predominantly arid climate. High evaporation rates, coupled with low annual rainfall, contribute significantly to the depletion of soil organic matter, particularly in uncultivated lands. Furthermore, most soils in the region are calcareous and derived from riverine sedimentary deposits, and they are frequently affected by salinity [2]. In general, Iraq experiences hot, dry summers, during which mean maximum temperatures often exceed 48 °C in the hottest months, particularly in the central and southern regions. Winters range from cool to cold, with mean minimum temperatures dropping to near freezing in the north and to approximately 5 °C in the south. Annual rainfall varies considerably across the country, reaching up to 1000 mm in the northern mountainous areas but declining to less than 100 mm in the southern and southwestern regions. Approximately 90% of the annual rainfall occurs between November and April [13].

Overall, the Iraqi climate is characterized by two contrasting seasonal extremes. The summer season is long, intensely hot, and dry, with extremely low relative humidity and persistent dry winds that further accelerate evaporation. In contrast, winter is relatively short in the lower plains and is marked by occasional frosts and limited rainfall. These climatic conditions are particularly harsh for plant life, especially in the lowland regions. By the time winter rains arrive, temperatures are often too low to support optimal plant growth. Significant vegetative growth typically occurs only during the brief spring season, just as rainfall begins to decline. During the prolonged summer months, surface water becomes unavailable, and extreme heat combined with low humidity results in severe desiccation [14]. Consequently, only certain plant types can survive in the lower plains of Iraq, notably ephemeral annuals, which rapidly complete their life cycle during spring and remain dormant as seeds for the rest of the year, and deep-rooted, highly xerophytic perennials capable of accessing underground water reserves and withstanding the harsh summer conditions [15].

In line with this, the present study sought to compile a thorough list of the vascular plant species that are present in the Al-Tar Caves region. It also aimed to analyze the floristic structure of the vegetation in the form of family composition, dominant taxa, and to evaluate the spectrum of life forms. Besides this, the research measured the spatial change in species richness among various habitat types. Lastly, it gave an initial explanation of the observed trends in vegetation depending on the current climatic and topographical conditions.

2. MATERIALS AND METHODS

2.1 Collection of plants

The current study on plant diversity and habitat characteristics in the Al-Tar Caves region, Karbala, Iraq, was conducted through six field surveys carried out during 2024. Field visitation was arranged to coincide with the flowering and fruiting periods of the recorded plant species. A total of 17 geographical locations were surveyed and georeferenced to provide a distribution map of the collection areas. Upon completion of all research requirements, the dry specimens were deposited in the Natural History Museum's herbarium / Iraq Natural History Research Center and Museum, University of Baghdad, Baghdad, Iraq (Figure 1 and Table 1).

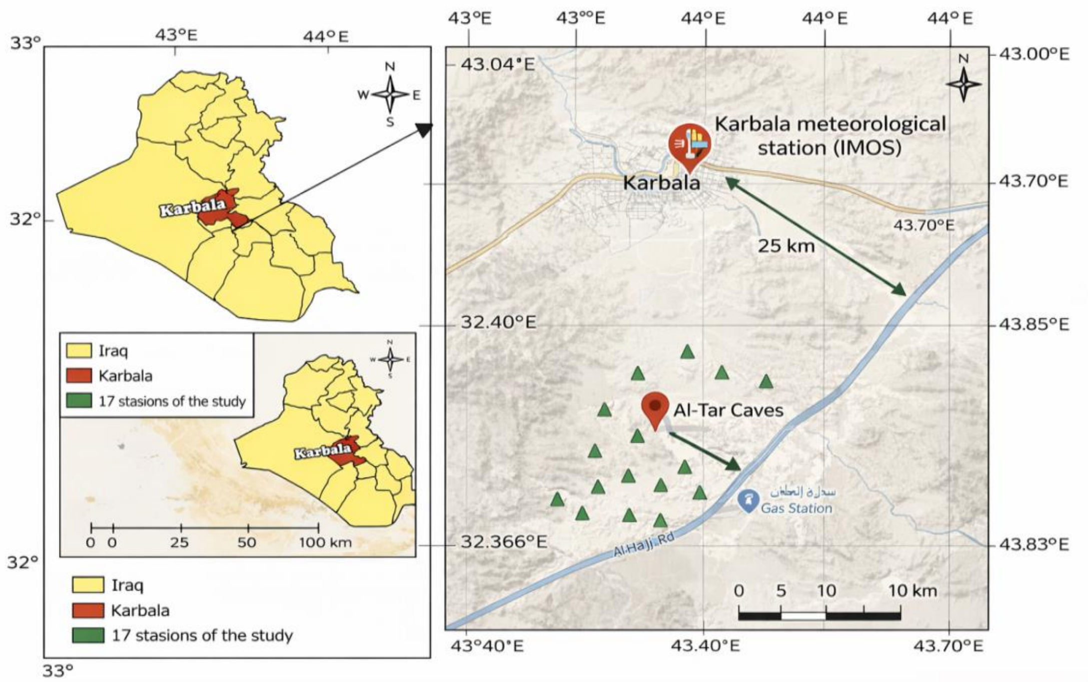

Figure 1. A map of the plant collection stations in the riparian area of the Al-Tar Caves, Karbala, Iraq

Table 1. Coordinates of the stations in the study areas

Station	Coordinate of Stations
1	32°28'53.7"N 43°46'43.1"E
2	32°28'51.7"N 43°46'39.7"E
3	32°28'49.7"N 43°46'40.8"E
4	32°28'47.3"N 43°46'48.5"E
5	32°28'50.3"N 43°46'42.5"E
6	32°28'57.9"N 43°46'49.4"E
7	32°29'06.2"N 43°46'38.3"E
8	32°29'01.6"N 43°47'11.2"E
9	32°28'41.7"N 43°46'54.3"E
10	32°28'41.3"N 43°46'43.3"E
11	32°28'56.5"N 43°45'59.5"E
12	32°28'46.8"N 43°46'17.1"E
13	32°29'22.0"N 43°46'25.7"E
14	32°29'02.6"N 43°45'49.7"E
15	32°29'29.0"N 43°45'52.4"E
16	32°29'52.9"N 43°46'34.3"E
17	32°29'42.8"N 43°47'18.6"E

2.2 Habitat classification

Four types of specimens stations were considered: (1) cave entrance/shaded calcareous slopes (Transitional microhabitats located in or near cave openings with adjacent limestone slopes which is characterized by: reduced solar radiation, higher moisture retention, thin calcareous soils and rock crevices); (2) calcareous plateau (high terrain that may be relatively flat and possibly gently undulating, dominated by exposed limestone rocks which is characterized by flat or gently undulating limestone surface, high temperature and evaporation rates, very shallow and poorly developed soils); (3) riparian margins (zones immediately adjacent to permanent and seasonal watercourses influenced with periodic water flow also higher soil moisture which is characterized by higher soil moisture and alluvial soils); (4) wadi depressions (low-lying channels and basins within ephemeral drainage systems, that water accumulates temporarily following rainfall events which is characterized by Seasonal runoff accumulation and moderate soil depth and sediment deposition).

2.3 Specimens design

The stratified specimens method was used to represent all the types of habitats. In each station, there were three quadrats that were randomly selected, since we have 17 stations, then 17 stations × 3 quadrats = 51 quadrats in total. The size of quads in open habitats was 10 by 10 m, and in cave-related microhabitats, 5 by 5 m, to consider the space limitation.

2.4 Diversity analysis

Species richness (S), the Shannon-Wiener diversity index (H′), and the evenness of Pielou (J):

$$H' = -\Sigma\ (pi\ \ln pi)$$

$$J = H' / \ln S$$

2.5 Climatic data

The data on climate (temperature, rainfall, wind speed, sunshine duration) during the years 2019-2023 in the case of Iraq was received at the Iraqi Meteorological Organization and Seismology in Karbala, located approximately 20–30 km northeast for the study area at the Al-Tar caves, so the elevation for the meteorological station (~30–40 m a.s.l.) is lower than that for the specimens stations (~70–120 m a.s.l.), resulting in an elevation difference for about 40–80 m, a descriptive comparison for mean annual values with the distribution patterns for vegetation was made.

2.6 Taxonomic keys

The collected specimens were identified at the Department of Plant and Environmental Sciences Laboratory, Iraq Natural History Research Centre and Museum, University of Baghdad. Species identification was carried out using standard taxonomic keys [16-19]. The accepted scientific names and synonyms of the recorded species were verified according to research [7], while species distribution data were compiled following the methodology described in research [18].

3. RESULTS AND DISCUSSION

3.1 Floristic composition

Plants were collected from 17 stations within the Al-Tar Caves, Karbala, Iraq. Variation was observed in the number of plant species. Several sites exhibited low plant diversity, which may be attributed to their distance from water sources and poor soil nutrient availability. A total of 106 plant species belonging to 34 families were recorded. Among these, 32 families were dicotyledons, comprising 97 species.

3.2 Dominant families

The family Asteraceae was the most species-rich, represented by 15 species, consistent with previous reports [19, 20]. Members of Asteraceae have long been utilized in traditional medicine and human diets. Despite their wide diversity, many species share similar phytochemical characteristics, which may explain their broad ethnobotanical applications. The second most represented family was Amaranthaceae, with 11 species. This family includes annual and perennial herbs, shrubs, and rarely trees. It has a cosmopolitan distribution, occurring in tropical and temperate regions worldwide. Many species within Amaranthaceae are economically important and are widely used as vegetables and in herbal medicine, in agreement with earlier studies [21, 22]. Dominance of Asteraceae and Amaranthaceae is consistent with arid floras of Southwest Asia, where C3–C4 adaptive strategies and drought tolerance enhance survival under seasonal rainfall regimes [23].

3.3 Life-form spectrum

Thirteen families were each represented by a single species in the riparian areas of Al-Tar Caves, Karbala, these families include Apiaceae, Apocynaceae, Capparaceae, Cistaceae, Cleomaceae, Frankeniaceae, Gentianaceae, Lythraceae, Malvaceae, Primulaceae, Rutaceae, Resedaceae, Oxalidaceae, Solanaceae, and Urticaceae. Regarding life-form classification, the study recorded 63 annual herbs, 25 perennial herbs, and 12 shrubs distributed across the study area, indicating the dominance of herbaceous vegetation in this arid environment. Several species were widely distributed across multiple sampling stations. For example, *Ammi majus* L. (Apiaceae) was recorded in several locations. This species has been described as a wild medicinal plant rich in bioactive compounds and has historically been used as a therapeutic alternative for various diseases [24].

The family Brassicaceae was represented by eight species that were widely distributed among the sampling stations. Brassicaceae is an ecologically and economically important angiosperm family. Previous study [25] has highlighted the taxonomic significance of morphological characteristics such as fruit, seed, and cotyledon traits in the classification of tribes within the family. In particular, seed coat texture is considered a relatively stable taxonomic character, as it is minimally influenced by environmental conditions after seed maturation.

Comparisons and contrasts in the floristic composition recorded in this survey with the other arid and limestone-impregnated areas of Iraq are quite impressive. The national flora of Iraq has approximately 3300 species in 136 families, and the most species-rich families are represented by Asteraceae, Fabaceae, Poaceae, and Brassicaceae, which can be found in the deserts, steppes, and riverine plains [26]. On the same note, in the Western Desert District, wild flora was found to be predominantly Amaranthaceae and Asteraceae, regardless of the conditions of extreme ecological variability, and thereafter Brassicaceae and Poaceae. The patterns are congruent with the results of the present study, where drought-tolerant families were prevalent based on the general tendencies of desert vegetation in Iraq and neighbouring Saharo-Sindian and Mesopotamian shrub desert ecoregions including sparse open scrub, halophytic communities, and rapid-growing annuals in response to rain [27]. Nevertheless, the limestone and cave topography in this research site contains more microhabitat complexity than does a flat desert plain and therefore permits a higher richness of local species than would be anticipated by desert flora in the region alone.

3.4 Influence of climatic and topographical conditions on species distribution patterns

Climate is one of the most critical determinants of plant growth and spatial distribution. In the present study, climatic variables were examined to assess their influence on plant distribution within the region. It directly affects plant physiology and indirectly influences soil properties, which are fundamental for plant establishment and sustainability. The flowering periods of the recorded species varied according to environmental conditions, climatic characteristics, and species-specific adaptations, consistent with observations from similar studies [28]. The effects of climatic factors differ among plant families. For instance, rainfall may enhance growth in some species, while others are more adapted to dry conditions. Many members of Asteraceae prefer full sunlight or partial shade for at least six hours daily and thrive in well-drained, loamy soils that retain moderate moisture; excessive watering may lead to root rot. Consequently, variations in temperature and precipitation significantly influence plant diversity and distribution patterns in the study area. Among the most widespread families recorded in this study was Amaranthaceae, which is characterized in many species by efficient carbon fixation mechanisms that enhance adaptation to hot and arid environments, in agreement with previous findings [29], also species richness (S) ranged from 5 species at Station 16 to 12 species at Station 9, Shannon-Wiener index (H′) varied between 1.49 and 2.31, indicating moderate to relatively high diversity across the study area, and Pielou’s evenness (J) values (0.88-0.97) suggested a generally balanced distribution of individuals among species. These findings reflect spatial heterogeneity in vegetation structure across the surveyed stations.

Table 2 and Figure 2 which present the Shannon–Wiener diversity index (H′) also Pielou’s evenness (J) of the studied stations, are commonly used to describe the structure and distribution for biological communities, also the Shannon–Wiener index reflects the species richness and the relative abundance for species, but Pielou’s evenness measures how equally individuals are distributed in the recorded species.

Table 2. Diversity indices (species richness (S), Shannon-Wiener diversity index (H′), and evenness of Pielou (J)) of plant species recorded across the studied stations

Station	Species Richness (S)	Shannon-Wiener Diversity Index (H′)	Evenness of Pielou (J)
St 1	8	1.94	0.93
St 2	6	1.73	0.97
St 3	9	2.01	0.91
St 4	8	1.87	0.90
St 5	7	1.85	0.95
St 6	10	2.05	0.89
St 7	11	2.12	0.88
St 8	11	2.17	0.91
St 9	12	2.31	0.93
St 10	11	2.29	0.95
St 11	10	2.03	0.88
St 12	11	2.10	0.88
St 13	9	2.01	0.93
St 14	7	1.82	0.93
St 15	8	1.89	0.91
St 16	5	1.49	0.93
St 17	6	1.66	0.93

The results show noticeable variation in stations, the station 9 recorded the highest diversity (H′ = 2.31) and also high species richness, which indicating a more complex also balanced community structure that many species coexist in relatively similar abundances, also station 16 exhibited the lowest diversity (H′ = 1.49), that suggests lower species richness with the dominance for a few species, so resulting at a less diverse community, which differences may reflect local environmental conditions, and including soil characteristics, habitat heterogeneity, moisture availability, and levels for disturbance, that are known to influence species distribution also diversity patterns.

The evenness values (J) ranged from 0.88 to 0.97, indicating generally high evenness in stations, so these values explained that individuals are relatively well distributed in species, with no extreme dominance at most locations. Also, the slightly lower evenness values observed in some stations may indicate moderate dominance for certain species under specific environmental conditions.

When compared within the studies conducted at arid also semi-arid ecosystems, Shannon diversity values commonly range about 1.0 and 3.0, which depending with habitat complexity and environmental stress, because of that the diversity values recorded in the present study (H′ = 1.49–2.31) fall in the moderate diversity range typical for such environments, this is evident from the recording of 34 plant families that varied among annuals, perennials and shrubs (Table 3 and Figure 3).

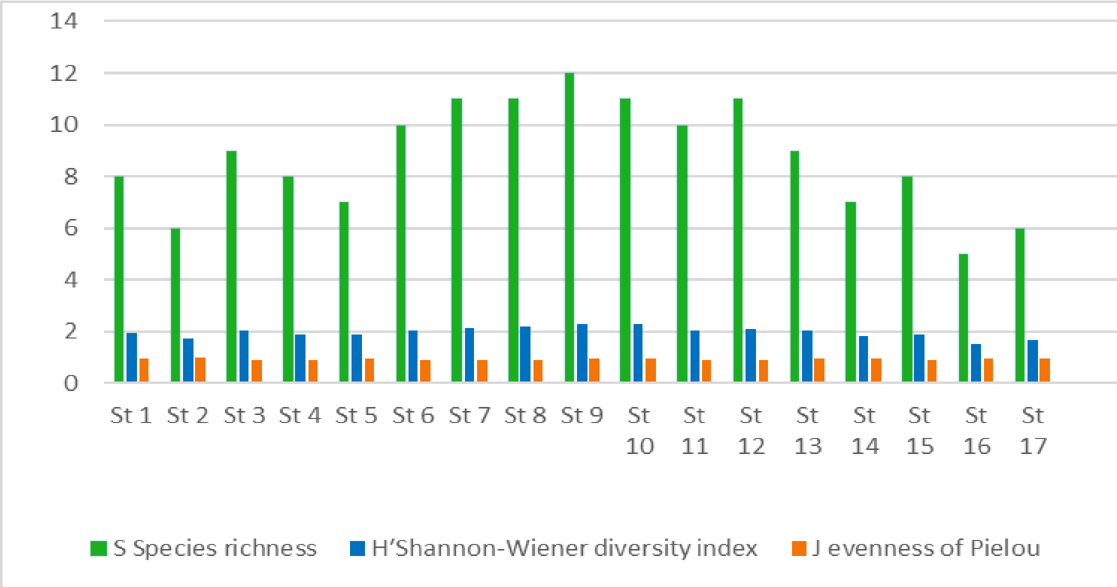

Figure 2. Species richness (S), Shannon-Wiener diversity index (H′), and Pielou's (J) across the stations
Station 9 exhibited the highest diversity, while Station 16 showed the lowest diversity among all surveyed stations.

Table 3. Floristic composition of the study area by family: numbers of genera and species, life-form composition, and representative species

No.	Family	No. of Genera	No. of Species	Life-Form Composition	Representative Species
1	Amaranthaceae	8	11	Annual herbs (6), Perennial herbs (2), Shrubs (3)	*Amaranthus albus*, *Suaeda aegyptiaca*, *Halothamnus iraqensis*
2	Apiaceae	1	1	Annual herb (1)	*Ammi majus*
3	Apocynaceae	1	1	Perennial herb (1)	*Apocynum venetum*
4	Asteraceae	13	15	Annual herbs (10), Perennial herbs (3), Shrubs (1), Biennial herbs (1)	Artemisia herba-alba, *Silybum marianum*, *Senecio glaucus*
5	Boraginaceae	5	5	Annual herbs (3), Perennial herbs (2)	*Arnebia decumbens*, *Heliotropium bacciferum*
6	Brassicaceae	7	8	Annual herbs (8)	*Diplotaxis harra*, *Sinapis arvensis*
7	Capparaceae	1	1	Perennial shrub (1)	*Capparis spinosa*
8	Convolvulaceae	1	2	Perennial herb (1), Shrub (1)	*Convolvulus arvensis*
9	Caryophyllaceae	4	5	Annual herbs (1), Perennial herbs/plants (4)	*Herniaria hirsuta*, *Silene succulent*
10	Cistaceae	1	1	Annual herb (1)	*Helianthemum salicifolium*
11	Cleomeaceae	1	1	Annual herb (1)	*Cleome glaucescens*
12	Euphorbiaceae	2	3	Annual herbs (2), Perennial herb (1)	*Euphorbia falcata*, *Ricinus communis*
13	Fabaceae	8	10	Annual herbs (4), Perennial herbs (3), Shrubs/subshrubs (3)	*Alhagi graecorum*, *Prosopis farcta, Trifolium resupinatum*
14	Frankeniaceae	1	1	Annual herb (1)	*Frankenia pulverulenta*
15	Gentianaceae	1	1	Annual herb (1)	*Centaurium tenuiflorum*
16	Geraniaceae	1	2	Annual herbs (2)	*Erodium glaucophyllum*
17	Primulaceae	1	1	Annual herb (1)	*Lysimachia arvensis*
18	Lamiaceae	3	3	Annual herbs (2), Subshrub (1)	Salvia spinosa, *Teucrium polium*
19	Lythraceae	1	1	Shrub/small tree (1)	*Punica granatum*
20	Plantaginaceae	1	3	Annual herbs (3)	*Plantago lagopus*, *Plantago ovata*
21	Papaveraceae	2	2	Annual herbs (2)	*Fumaria parviflora*
22	Malvaceae	1	1	Annual herb (1)	*Malva parviflora*
23	Oxalidaceae	1	1	Annual herb (1)	*Oxalis corniculata*
24	Resedaceae	1	1	Annual herb (1)	*Reseda arabica*
25	Rubiaceae	2	2	Annual herbs (2)	*Galium aparine*
26	Rutaceae	1	1	Perennial herb/subshrub (1)	*Haplophyllum tuberculatum*
27	Polygonaceae	2	3	Annual herbs (3)	*Rumex dentatus*, *Polygonum argyrocoleum*
28	Salicaceae	2	3	Perennial trees (3)	*Populus euphratica*, *Salix acmophylla*
29	Solanaceae	1	1	Annual herb (1)	*Lycium barbarum*
30	Tamaicaceae	1	3	Shrubs/small trees (3)	*Tamarix aucheriana*, *Tamarix smyrnensis*
31	Urticaceae	1	1	Annual herb (1)	*Urtica urens*
32	Zygophyllaceae	2	2	Annual herbs (2)	*Fagonia glutinosa*, *Tribulus macropterus*
33	Cyperaceae	1	2	Perennial herbs (2)	*Cyperus rotundus*
34	Poaceae	7	7	Annual grasses (6), Perennial grass (1)	*Avena fatua*, *Cynodon dactylon*, *Enneapogon persicus*

Previous studies indicate that in the lower parts of Iraq, the year is divided into two distinct seasons separated by short transitional periods: a long, hot, rainless summer (May to October) and a comparatively short, cool winter (December to February). In the lands, the summer season is shorter (June to September), while winter extends until March or April and is considerably longer than in the plains. The transitional seasons—spring (March and April) and autumn (November)—are less pronounced in the plains but remain distinguishable from the primary winter and summer seasons [30].

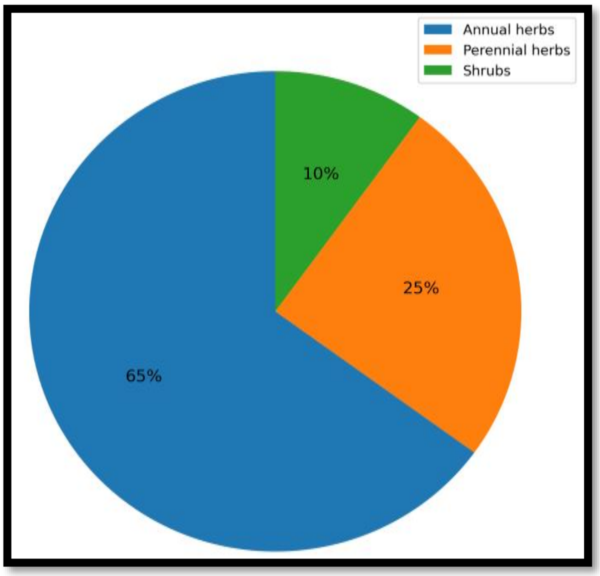

Figure 3. Life-form composition of the recorded flora in the study area

Figure 3 shows the distribution for plant types into three categories: Annual herbs: They represent the largest portion of the chart, approximately 60–65% of the total. Perennial herbs: They make up a moderate proportion, about 25–30%. And shrubs: They account for the smallest share, about 10–15%, so it indicates that annual herbs are the dominant plant type compared with perennial herbs and shrubs. This suggests that the studied area or environment favors plants that complete their life cycle within one year, but shrubs are less common.

Similarly, other studies confirm that the lower part of Iraq is characterized by two well-defined seasons with short transitional intervals: the extended hot, dry summer (May to October) and the relatively brief cool winter (December to February). In contrast, the highlands experience a shorter summer (June to September) and a longer winter lasting until March or April. The transitional seasons—spring (March and April) and autumn (November)—though less distinct in the plains, are still recognizable as intermediate periods between winter and summer [31]. This is also illustrated in Figure 4, which shows the maximum monthly temperatures from 2019 to 2023. Each group of bars represents one year (2019–2023), and within each group, twelve colored bars represent the months from January to December. Temperatures are lowest at the beginning and end of each year (winter months), rise during spring, and reach their highest levels in the middle of the year, particularly around June, July, and August (summer months). After summer, temperatures gradually decrease toward the end of the year. Overall, the chart shows a consistent seasonal pattern in all five years, with peak temperatures at summer and lower temperatures in winter.

Figure 5 shows the average minimum temperatures of each month from 2019 to 2023, The highest minimum temperatures usually occur in December and January which ranging roughly between 6–12 degrees, temperatures gradually increase winter- summer Then gradually decrease from summer-winter, also the values are relatively consistent in the five years, with slight variations 2020 and 2021 appear to have slightly higher summer minimum temperatures when compared to the other years.

The region experiences extremely high temperatures, particularly during summer, reaching up to 47 ℃, which results in elevated evaporation rates from both soil and vegetation. This is compounded by prolonged periods of low rainfall, leading to reduced groundwater levels and decreased soil moisture, thereby increasing susceptibility to erosion from seasonal winds. The Iraqi climate, especially in the southern regions, is characterized by hot summers and low winter precipitation, making it one of the driest areas in the region, Figure 6 showing sunshine levels in the month of 2019-2023, the horizontal axis (X-axis) represents the years: 2019, 2020, 2021, 2022, and 2023, while the vertical axis (Y-axis) shows the amount for sunshine (likely average hours per day or per month), so each year contains 12 colored bars, which representing the months January- December, so Sunshine is generally higher at the middle for the year (around June, July, and August), and lower sunshine levels appear in the beginning and end for the year (January, February, November, and December), some years (like 2019 and 2021) seem to have slightly higher peak sunshine which compared to 2020 and 2022, also it shows a clear seasonal pattern for sunshine, with the highest levels at summer months and the lowest at winter months, also only small differences between the years.

High summer temperatures, combined with intense solar radiation, have adversely affected plant density and distribution in the study area, which exhibits characteristics typical of desert ecosystems. Long-term climatic stress has caused a significant decline in vegetation cover, rendering the region more vulnerable to wind erosion and sandstorms originating from nearby deserts. Wind plays a critical role in soil and plant water loss, as evaporation rates increase with higher wind speeds, which in turn are often associated with elevated temperatures, consistent with observations in Figure 7 which compares the amount for rainfall (in millimeters) across different months from 2019 to 2023 and the horizontal axis (X-axis) represents the years: 2019, 2020, 2021, 2022, and 2023, while the vertical axis (Y-axis) shows rainfall amounts, ranging 0-50 mm, so the different colored bars represent the different months (January to December), also 2019 had very high rainfall, especially at one month that reached about 45 mm., that is the highest value in the Figure, 2020 also shows noticeable rainfall, in some months around 20–25 mm., and 2021 and 2022 had relatively low rainfall when compared to other years, also 2023 shows moderate to high rainfall at some months, especially early at the year, Rainfall fluctuates from year to year, and the highest rainfall appears at 2019, but 2021 and 2022 seem to be the driest years in comparison.

Recent decreases in seasonal rainfall, particularly during winter, have further contributed to a significant reduction in groundwater reserves, limiting plant growth and regeneration during spring and winter seasons. The soils in the study area exhibit considerable variability in their physical and chemical properties, reflecting differences in their general characteristics and affecting their overall composition (Figure 8). It shows the average monthly wind speeds of five years:

2019, 2020, 2021, 2022, and 2023, which each group of bars represents one year, and each colored bar in the group represents a different month (January-December), so the vertical axis shows the wind speed values (0-4), and the horizontal axis shows the years, 2019 had a very high wind speed at one month (around 3.8), that is the highest value on the chart, also 2022 and 2023 generally show moderate to high wind speeds when compared to other years, also 2021 and 2020 appear to have slightly lower wind speeds overall, and wind speed changes from month to month at every year.

Although all the specimens stations are located in a relatively small geographic area, climatic factors such as temperature, rainfall, sunshine duration, and wind speed are of great importance in determining the vegetation pattern in the region. Climatic diagrams of the region.

Under these climatic conditions, the vegetation pattern in the region is greatly influenced by environmental stress factors, especially those related to water and high solar radiation. Some of the sampling stations may have relatively favorable microhabitat conditions compared with others. These may include slightly higher soil moisture content or lower wind exposure. These factors may have influenced the relatively high species richness found in Station 9, so Tables 3A–3D provide a comprehensive botanical inventory of the study area, documenting 106 plant species across multiple taxonomic families, along with their lifespans, local names, and spatial distribution across 17 specimens stations. The data show a clear dominance of annual herbaceous species, which constitute the majority of recorded species, demonstrating their adaptation to arid and semi-arid environmental conditions characterized by seasonal rainfall and ecological instability. Perennial grasses and shrubs are relatively less common but play a crucial role in maintaining vegetation structure and long-term ecosystem stability. Families such as Asteraceae, Fabaceae, Brassicaceae, and Amaranthaceae are well represented, reflecting their ecological diversity and tolerance to harsh conditions such as salinity and drought. The inclusion of local names reinforces ethnobotanical significance, while the distribution across stations highlights each species' habitat preferences and spatial diversity within the study area. Overall, these tables illustrate a diverse but stress-adapted plant community, shaped by environmental gradients and human influences, providing a valuable basis for environmental assessment, biodiversity conservation, and future vegetation studies.

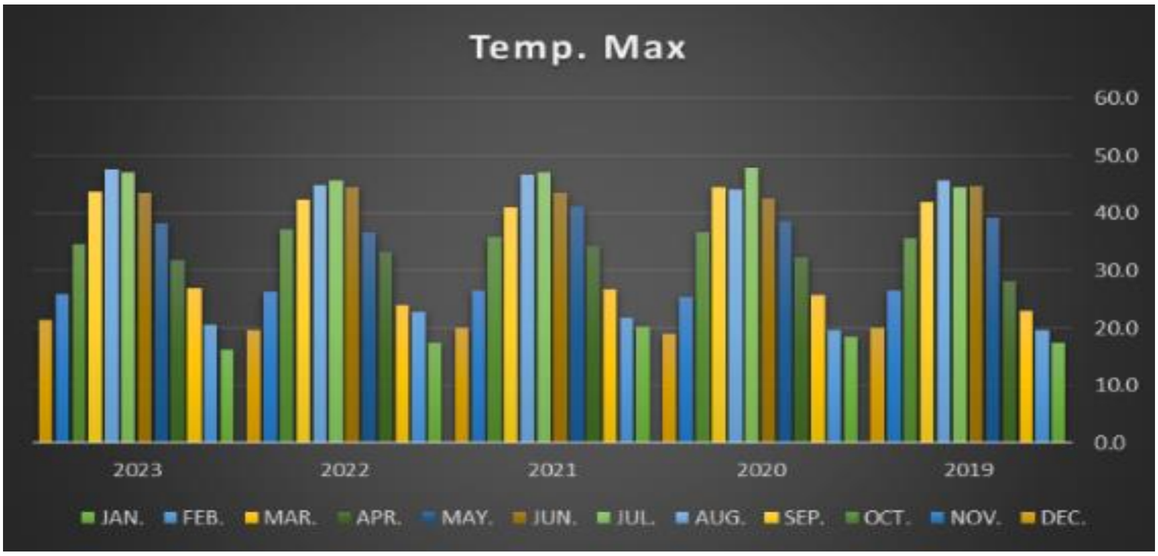

Figure 4. Mean monthly maximum temperature at Karbala 2019–2023
Iraqi Meteorological Organization and Seismology

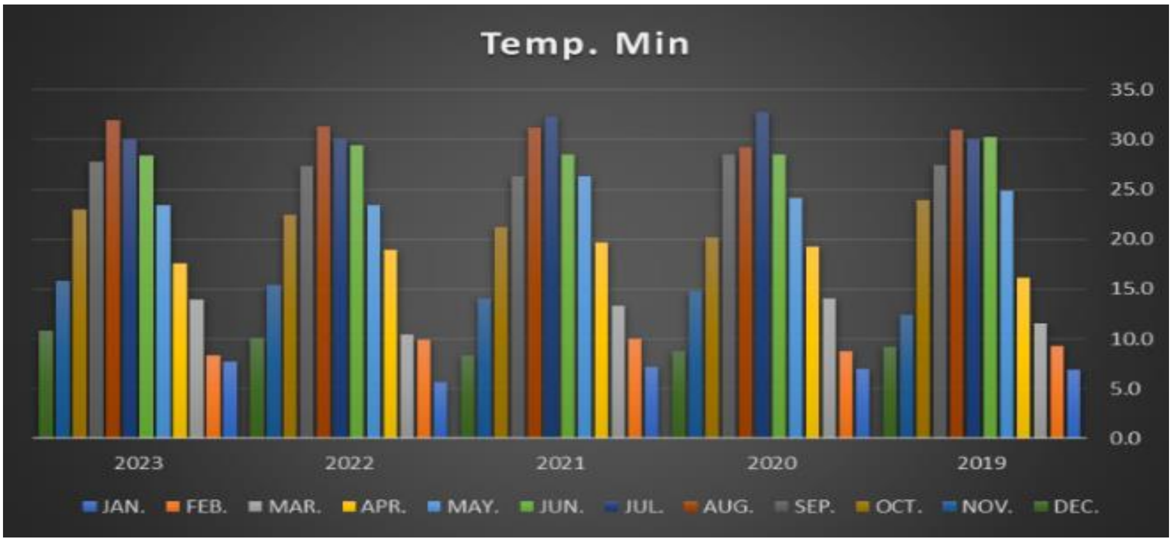

Figure 5. Average of minimum temperature in Karbala from 2019-2023
Iraqi Meteorological Organization and Seismology

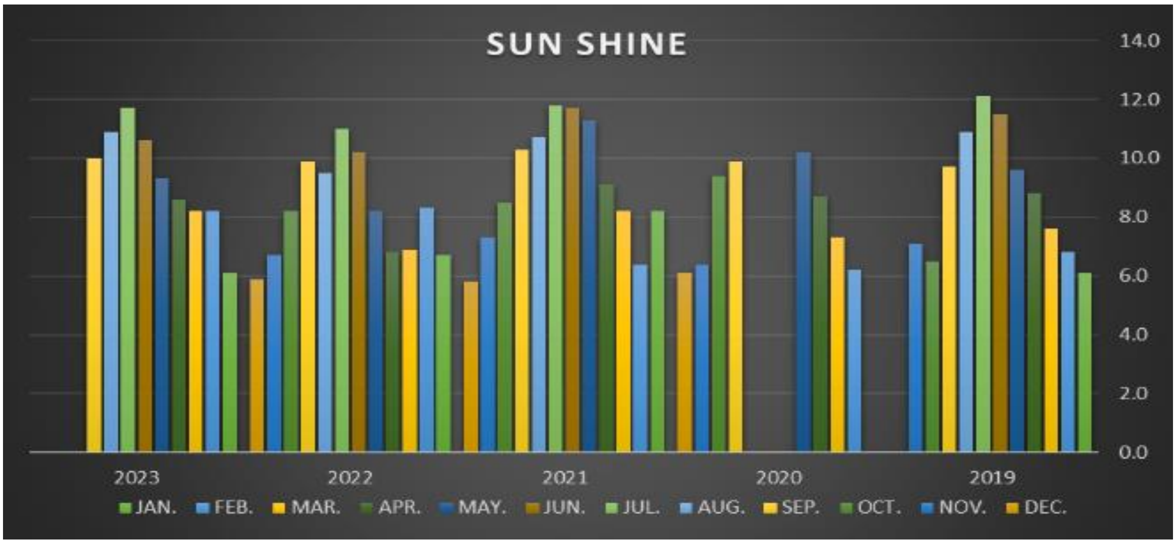

Figure 6. Average of sunshine in Karbala from 2019-2023
Iraqi Meteorological Organization and Seismology

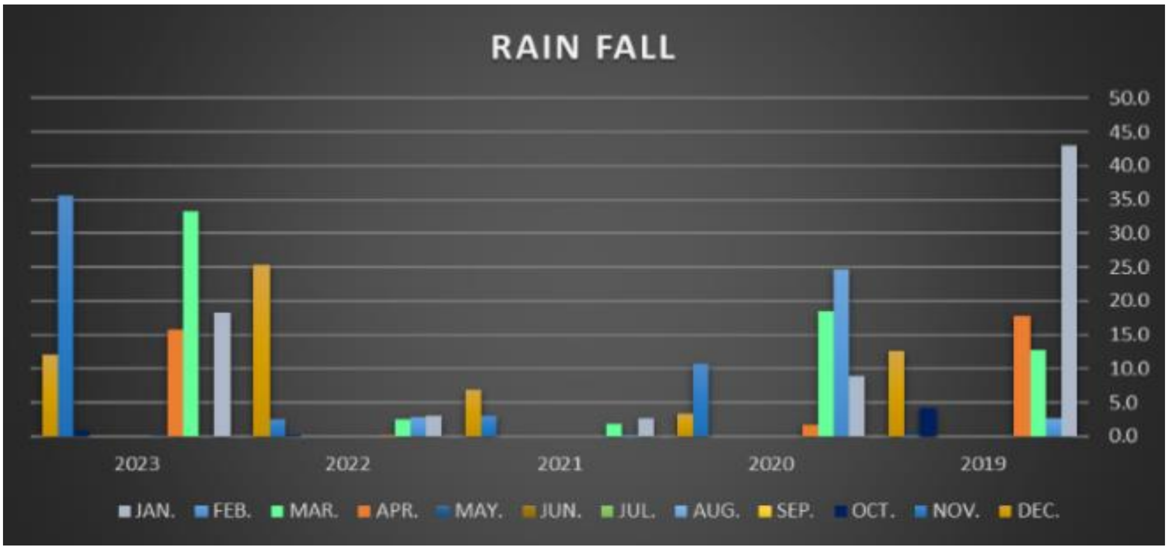

Figure 7. Average of rainfall in Karbala from 2019 to 2023
Iraqi Meteorological Organization and Seismology

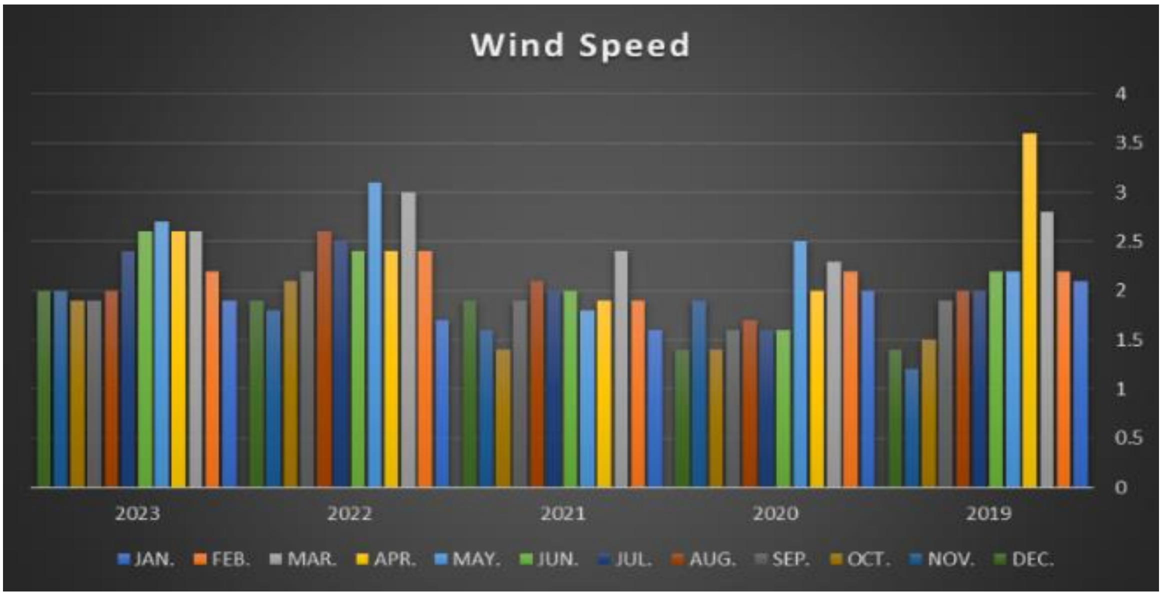

Figure 8. Average of wind speed in Karbala from 2019-2023
Iraqi Meteorological Organization and Seismology

On the other hand, some of the stations may have less favorable climatic conditions in the region. These may include high solar radiation, low soil moisture content, and high wind exposure. These factors may have influenced the relatively low species richness found in station 16.

The results have shown that climatic factors may have an indirect effect on the species richness in the region through factors related to soil moisture content and environmental stress factors. On the other hand, microhabitat factors may have an additional role in determining the pattern of species distribution in the sampling station [32].

There is an emphasis on annual herbs and stress-tolerant shrubs, which evidences obvious adaptation to arid conditions. The rapid completion of the life cycle of the annual forms of life in short favourable regimes is a typical survival strategy in the extremely seasonal rainfall regime and in the extreme heat of Iraq, and structural adaptations to save water during drought can be seen in perennial shrubs and deep-rooted taxa [26]. Localized damp microhabitats comprising woody riparian communities, including *Populus euphratica* and *Salix acmophylla*, also highlight the importance of the water availability and edaphic variation on community structure, a pattern also evident in riparian surveys in other parts of Iraq that possess the same taxa along water courses [32]. The special geology of the limestone and cave systems forms microhabitats that lack isolation and have high moisture retention in comparison with those of exposed plateaus. Most shade-tolerant and moisture-related species tend to be concentrated around the cave entrances and shady cliff bottoms, where the rate of evapotranspiration is reduced, whereas the annuals that are drought-tolerant can prevail in the exposed limestone scree and desert plains. This microtopographic effect on species turnover can be seen to be consistent with the larger vegetation patterns in semiarid landscapes where local refugia are higher than the surrounding harsh terrain.

Even though this study has made its contributions, it has some limitations. The survey was done in one year, and interannual weather variation can affect species occurrence and their abundance. Diversity measurement was based more on species richness and simple indices and did not quantitatively measure vegetation cover and biomass. Physicochemical properties of soil were not studied thoroughly at each station, but were only described, which made it difficult to directly relate the distribution of species to the parameters of the edaphic variable. The future studies must involve multi-year observations, the physical analysis of the soil, and the functional characteristics studies, as well as the remote images of the vegetation in response to climate change. Phytochemical and ecological research on significant and dominating species would further develop the ideas of adaptive and protective mechanisms of these species and their conservation importance.

4. CONCLUSION

The present study, based on plant collections from various sites around the Al-Tar Caves in Karbala, revealed significant variation in plant diversity across the area. Some locations exhibited high species richness, while others showed sparse vegetation. This variation is attributed to several factors, including harsh environmental conditions and the differential ability of certain plants to tolerate and adapt, enabling their survival and proliferation. A total of 106 plant species, representing 34 families, were documented. Among these, 97 species belonged to 32 dicotyledon families, with Asteraceae being the most diverse family in the study area. Additionally, 15 families were represented by only a single species in the riparian zones of Al-Tar Caves, including Apiaceae, Apocynaceae, Capparaceae, Cistaceae, Cleomaceae, Frankeniaceae, Gentianaceae, Lythraceae, Malvaceae, Primulaceae, Rutaceae, Resedaceae, Oxalidaceae, Solanaceae, and Urticaceae. The survey addresses a research gap in knowledge, which is that no previous specific floristic examination had been carried out in this limestone and cave-related scenery. A number of ecologically and medicinally important species were documented, which emphasized conservation importance. The findings highlight the necessity of preserving the habitat, conducting ecological studies over an extended period, and conducting additional taxonomic and phytochemical studies in the area.

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APPENDIX

Table 3A. Floristic composition of the study area: Families, species, life duration, local names, and sampling stations (1-33)

No.	Family	Species	Duration	Local Names	Station
1	Amaranthaceae	*Amaranthus albus* L.	Annual herb	White pigweed	St 2, St 10
2		*Atriplex hastata* Geners. ex Steud	Annual herb	Hastate orache	St 4, St 2
3		*Anabasis setifera* Moq.	Perennial herb	Anabasis	St 3
4		*Beta maritima* L.	Perennial herb	Sea Beet	St 6
5		*Halothamnus iraqensis* var. *hispidulus* Botsch	Perennial shrub	Saltbush	St 11, St 15, St 17
6		*Caroxylon jordanicola* (Eig) Akhani & Roalson	Perennial shrub	Kanna bush	St 15
7		*Cornulaca monacantha* Delile	Perennial shrub	Had a djouri	St 10, St 16
8		*Salsola kali* L.	Annual herb	Windwitch	St12, St13
9		*Soda inermis* (Moench) Fourr.	Annual herb	almyra	St 5
10		*Suaeda aegyptiaca* (Hasselq.) Zohary	Annual herb	Tartai, Shuatan	St 1, St 5
11		*Suaeda vermiculata* Forssk. ex J.F.Gmel.	Annual herb	Juliman	St 3, St 12, St 14
12	Apiaceae	*Ammi majus* L.	Annual herb	Bishop's Weed	St 2, St 9, St10, St 11, St 14
13	Apocynaceae	*Apoacynum venetum* (L.) Mavrodiev, Laktionov & Yu.E.Alexeev	Perennial herb	Sword-leaf dogbane	St 1, St 7,
14	Asteraceae	*Artemisia herba-alba* Asso	Shrub	White wormwood	St 14
15		*Calendula tripterocarpa* Rupr.	Annual herb	Winged-fruited marigold	St13, St16
16		*Carduus getulus* Pomel	Annual herb	Western Negev	St 5, St9,
17		*Centaurea sinaica* DC.	Perennial herb	murrar	St 2, St 17
18		*Hedypnois cretica* (L.) Dum.Cours	Annual herb	Scaly hawkbit	St 4
19		*Launaea angustifolia* (Desf.) Kuntze	Annual herb	Bitter Lettuce	St 6
20		*Launaea nudicaulis* (L.) Hook.fil.	Perennial herb	bold-leaf launaea	St 8
21		*Leontodon laciniatus* (Bertol.) Widder	Annual herb	hawkbits	St 3
22		*Picris babylonica* Hand-Mazz.	Annual herb	Rough Hawkbit	St 17
23		*Reichardia picroides* (L.) Roth	Perennial herb	Coustelline	St15
24		*Senecio glaucus* L.	Annual herb	Jaffa groundsel	St 8, St 13
25		*Silybum marianum* (L.) Gaertn.	Biennial herb	blessed milkthistle	St1, St8
26		*Taraxacum monochlamydeum* Hand-Mazz.	Perennial herb	Ingle-flowered dandelion	St10, St11
27		*Sonchus tenerrimus* L.	Annual herb	Slender sow thistle	St 2, St 3, St 12
28		*Xanthium strumarium* L.	Annual herb	Hasach, lizzaij	St 3
29	Boraginaceae	*Arnebia decumbens* (Vent.) Coss. & Kralik	Annual herb	Shajaret el arneb	St 13
30		*Arnebia hispidissima* (Lehm.) DC., b	Perennial herb	Hasheshat al arnab	St16
31		*Gastrocotyle hispida* (Forssk.) Bunge	Annual herb	Hairy Bugloss	St 4
32		*Heliotropium bacciferum* Forssk.	Perennial herb	Monkey tail	St 6
33		*Lappula spinocarpos* (Forssk.) Asch.	Annual herb	Bluebur	St 9, St 15

St: Station

Table 3B. Floristic composition of the study area: Families, species, life duration, local names, and sampling stations (34-64)

No.	Families	Species	Duration	Local Names	Stations
34	Brassicaceae	*Alyssum linifolium* Stephan	Annual herb	Flaxleaf Alyssum	St 7
35		*Cardaria draba* (L.) Desv.	Annual herb	Whitetop	St 10, St 12
36		*Carrichtera annua* (L.) DC.	Annual herb	Ward's weed	St 7
37		*Diplotaxis acris* (Forssk.) Boiss.	Annual herb	White rocket	St 6, St 8
38		*Diplotaxis harra* (Forssk.) Boiss.	Annual herb	Sand Rocket,	St 2, St 5, St 11
39		*Farsetia aegyptiaca* Turra	Annual herb	Shiqara, Shikara	St 15
40		*Sinapis arvensis* L.	Annual herb	Wild mustard	St 7
41		*Sisymbrium irio* L.	Annual herb	London Rockets	St 1, St 4, St 7, St 15
42	Capparaceae	*Capparis spinose* L.	Perennial plant	Caper bush	St 7, St 8
43	Convolvulaceae	*Convolvulus arvensis* L.	Perennial herb	Morning glory,	St 4, St 6, St 10
44		*Convolvulus oxyphyllus* Boiss.	shrub	Bindweed	St 12
45	Caryophyllaceae	*Herniaria hemistemon* J.Gay	Perennial plant	Half-leaved Rock-rose	St 8
46		*Gypsophila heteropoda* Freyn & Sint.	Perennial plant	Baby's Breath	St 15
47		Herniaria hirsuta L.	Perennial herb	Hairy rupturewort.	St 7
48		*Paronychia arabica* (L.) DC.	Annual herb	Whitlow	St 9
49		*Silene succulenta* Forssk.	Perennial plant	Silène charnue - Succulent catchfly	St 11
50	Cistaceae	*Helianthemum salicifolium* (L.) Mill.	Annual herb	Willowleaf Frostweed	St 14
51	Cleomaceae	*Cleome glaucescens* DC.	Annual herb	Spider Flower	St 13

52	Euphorbiaceae	*Euphorbia falcata* L.	Annual herb	Spurge	St 5, St 13
53		*Euphorbia peplus* L.	Annual plant	Radium weed	St 3, St 8, St 16
54		*Ricinus communis* L.	Perennial herb	Castor oil plant	St 17
55	Fabaceae	*Alhagi graecorum* Boiss.	Perennial shrub	Manna tree	St 1, St 3, St 12, St 16
56		*Astragalus spinosus* (Forssk.) Muschl.	Shrub	Shadad	St 12
57		*Hippocrepis areolata* Desv.	Perennial plant	Horseshoe Vetch	St 6
58		*Lathyrus odoratus* L.	Annual herb	Sweet pea	St 14
59		*Onobrychis ptolemaica* (Delile) DC.	Perennial herb	Single-cut Sainfoin.	St 12, St 15
60		Prosopis farcta (Banks & Sol.) J. F.Macbr.	Subshrub or shrub	Syrian mesquite	St 1, St 5, St 12
61		*Trifolium resupinatum* L.	Annual herb	Reversed clover	St 11, St 16
62		*Lotus corniculatus* L.	Annual herb	bird's-foot trefoil	St 11
63		*Medicago laciniata* (L.) Mill.	Perennial herb	Cut leaf medick	St 6
64		*Melilotus indicus* (L.) All.	Annual herb	Sweet clover	St 5, St 6

Table 3C. Floristic composition of the study area: Families, species, life duration, local names, and sampling stations (65-87)

No.	Families	Species	Duration	Local Names	Stations
65	*Frankeniaceae*	*Frankenia pulverulenta* L.	Annual herb	European sea-heath wisp-weed.	St 9
66	*Gentianaceae*	*Centaurium tenuiflorum* (Hoffmanns. & Link) Fritsch	Annual herb	Slender centaury	St 10
67	Geraniaceae	*Erodium glaucophyllum* (L.) L'Hér.	Annual herb	Stork's-bill,	St 3
68		*Erodium laciniatum* (Cav.) Willd.	Annual herb	Cutleaf stork's bill	St 6
69	Primulaceae	*Lysimachia arvensis* subsp. *arvensis*	Annual herb	Scarlet pimpernel	St 9
70	Lamiaceae	*Mentha longifolia* (L.) L.	Annual herb	Horse mint	St 4
71		*Salvia spinosa* L.	Annual herb	Spiny-calyxed Sage	St 3, St 7
72		*Teucrium polium* L.	Sub-shrub	Felty germander	St 9
73	Lythraceae	*Punica granatum* L.	Shrub or small tree	Pomegranate	St 8
74	Plantaginaceae	*Plantago lagopus* L.	Annual herb	Hare-foot plantain	St 9, St 10
75		*Plantago afra* L.	Annual herb	Glandular plantain	St 4, St 10
76		*Plantago ovata* Forssk.	Annual herb	Blond plantain	St 5
77	Papaveraceae	*Fumaria parviflora* Lam.	Annual herb	Fine-leaf fumitory	St 9
78		*Hypecoum pendulum* L.	Annual herb	Hypécoum pendant	St 11
79	Malvaceae	*Malva parviflora* L.	Annual herb	cheeseweed,	St 13
80	Oxalidaceae	*Oxalis corniculata* L.	Annual herb	Yellow Wood Sorrel,	St 12
81	Resedaceae	*Reseda arabica* Boiss.	Annual herb	Love flower,	St 7
82	Rubiaceae	*Crucianella membranacea* Boiss.	Annual herb	Crossworts	St 8
83		*Galium aparine* L.	Annual herb	Bedstraw	St 9
84	Rutaceae	*Haplophyllum tuberculatum* (Forssk.) A.Juss.	Perennial or subshrub	Oblongleaf Rock-rose	St 17
85	Polygonaceae	*Rumex spinosus* L.	Annual herb	Devil's thorn	St10
86		*Polygonum argyrocoleum* Steud. ex-Kunze	Annual herb	Silver-sheath knotweed	St 13
87		*Rumex dentatus* L.	Annual herb	Toothed dock	St 5, St 7

Table 3D. Floristic composition of the study area: Families, species, life duration, local names, and sampling stations (88-106)

No.	Families	Species	Duration	Local Names	Stations
88	Salicaceae	*Populus alba* L.	Perennial tree	White poplar	St 15
89		*Populus euphratica* Olivier.	Perennial tree	Desert poplar,	St 9
90		*Salix acmophylla* Boiss.	Perennial tree	Brook willow	St 8
91	Solanaceae	*Lycium barbarum* L.	Annual herb	Matrimony vine	St 6, St 9
92	Tamaricaceae	*Tamarix aucheriana* (Decne. ex Walp.) B.R.Baum.	Shrub or a small tree	Salt Cedar	St 3, St 14
93		*Tamarix brachystachys* Bunge.	Shrub or a small tree	Athel tamarisk	St 8, St 9
94		*Tamarix smyrnensis* Bunge.	Shrub or a small tree	Tarfa	St 10, St 11
95	Urticaceae	*Urtica urens* L.	Annual herb	Annual nettle,	St 1, St 13
96	Zygophyllaceae	*Fagonia glutinosa* Delile	Annual herb	Dereima	St 15
97		*Tribulus macropterus* Boiss.	Annual herb	Bullhead	St 4
98	Cyperaceae	*Cyperus rotundus* L.	Perennial herb	Nut Grass,	St 7
99		*Cyperus corymbosus* Rottb	Perennial herb	Kok san suea	St 8
100	Poaceae	*Eremopyrum bonaepartis* (Spreng.) Nevski	Annual herb	Taper-tipped wheat	St 1
101		*Avena fatua* L.	Annual herb	Wild oat	St 6
102		*Cynodon dactylon* (L.) Pers.	Annual herb	Bermuda Grass	St 17
103		*Dactyloctenium aegyptium* (L.) Willd.	Annual herb	Crowfootgrass,	St 14
104		*Poa annua* L.	Annual grass	Simply poa	St 13
105		*Digitaria sanguinalis* (L.) Scop.	Annual grass	Hairy crabgrass	St 12

106	*Enneapogon persicus* Boiss.	Perennial grass	Persian Pappus-Grass	St 11