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The Impact of climate change on the endemic flora of Wadi Al Arbaein, South Sinai, Egypt: A unique ecosystem

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This study aimed to investigate the change in the vegetation composition because of climate change and its effect on natural heritage. Wadi Al Arbaein is one of the most important wadis in the flora and vegetation composition. Wadi Al Arbaein is another narrow steep wadi, on its bed are scattered boulders and large stones. There are successive broad terraces reducing to a deep narrow channel flooded by spring water. The climate of the study area is extremely arid, with a long hot and rainless summer and mild winter. During the study, vegetation survey for the Al Arbaein in south Sinai was done including vegetation parameters such as total plant cover, physical and chemical soil analysis, temperature and moisture were the main factors controlling the floristic and structural distribution of vegetation in the study area. The variation in vegetation is highly influenced by diversity and is susceptible to climatic change. Endemic species are consistently more adversely impacted, endemics are considered as indicators for assessment and conservation of bio geographical regions and biodiversity hotspots. Climate change may cause rare and threatened endemic species to experience changes in their distribution range, perhaps leading to their extinction. The study conducted in Wadi Al Arbaein recorded 125 plant species, detailing their life forms and conservation statuses according to the IUCN 2024 criteria. Asteraceae emerged as the most abundant plant family, followed by Lamiaceae, with therophytes predominating among the recorded species. Wadi Al Arbaein harbors 16 endemic plant species, including seven critically endangered, six endangered, one near threatened, and one vulnerable. Preserving these botanical treasures is crucial for biodiversity conservation. The study identified ten distinct plant communities, in addition to five pure plant communities, likely characterized by distinct species compositions.

Keywords: Climate change; Endemic species; Flora; Medicinal plants; Plant communities; Saint Catherine; Wadi Al Arbaein

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INTRODUCTION

Wadi Al Arbaein, nestled in the rugged landscapes of south Sinai, stands as a testament to the resilience and diversity of desert flora in an extreme arid environment (Moustafa and Mansour, 2020). This wadi, characterized by its narrow, steep terrain punctuated by scattered boulders and terraces, harbors a rich tapestry of plant life uniquely adapted to survive in harsh conditions (Zahran and Willis 2009). The flora of Wadi Al Arbaein showcases a remarkable array of species that have evolved specialized mechanisms to thrive amidst the region's long, scorching summers and mild winters. From drought-tolerant shrubs and succulents to hardy perennial herbs, each species plays a crucial role in maintaining soil stability, supporting local biodiversity, and providing habitats for numerous wildlife species (El-Absy and Kamel, 2019). The structural complexity of vegetation within Wadi Al Arbaein, influenced by factors such as soil characteristics, moisture availability, and microclimate variations, underscores the wadi's ecological significance and its contribution to the broader desert ecosystem, understanding the intricacies of Wadi Al Arbaein's flora and structure is essential not only for conservation efforts but also for appreciating the resilience of nature in one of Egypt's most arid regions (Dadamouny and Schnittler 2016).

Wadi Al Arbaein, situated in the arid landscapes of South Sinai, experiences a climate characterized by extreme dryness and temperature variations typical of desert environments. Summers in the wadi are long, scorching, and virtually rainless, with daytime temperatures often exceeding 40°C. The region's winter is comparatively mild, offering some relief with cooler temperature, although frost is rare. Annual precipitation is minimal and irregular, predominantly falling during the winter months in sporadic, often intense showers that contribute to the wadi's hydrological dynamics, including occasional flash floods (Fouad *et al*., 2023; Moustafa *et al*., 2023). Relative humidity remains low throughout the year, accentuating the arid conditions. Strong winds are also a notable feature, shaping the terrain and influencing the distribution of vegetation. These climatic factors collectively define Wadi Al Arbaein's harsh but resilient environment, shaping its unique flora and ecosystem dynamics (Borcard *et al.,* 2011).

The wadi experiences an arid to extremely arid climate, with rainfall irregularity influenced significantly by the orographic effect of the surrounding high mountains (El-Lamey *et al.,* 2018). These climatic conditions, exacerbated by climate change and periodic drought cycles, further compound the challenges to the survival and sustainability of the flora within Wadi Al Arbaein's.

The main aims of this study are to examine the evolution of plant communities and assess how local climate change has influenced both vegetation, the structure of plant communities.

MATERIALS and METHODS

Study area

Wadi Al Arbaein sub-basin area is considered one of the important areas of Wadi Ghreaba basin in the central part of south Sinai. It is deep, narrow, and roughly filled by huge boulders and is bounded approximately by latitudes 28.5514° N and longitudes 33.9770° E. The average width of the Wadi bed is around 50 m; the bed rocks are mostly granitic. The elevation of the studied stands ranges from 1580 to 1660 m a.s.l Fig. (1). Varieties of landforms are recorded, including Wadi bed, slopes, and terraces. Wadi Al Arbaein contains a wide range of habitats and landscapes that are a consequence of varying climatic conditions, a wide range of altitudes, and variable topography. Wadi Al Arbaein stretches from the village of Saint Catherine to the Bedouin settlement (Ramadan home), encompassing three gardens in this vicinity. The width of the wadi in this area varies between 30 to 50 meters. A significant source of fresh water in Wadi Al Arbaein is Bir Al Arbaein, located centrally within the wadi near a small church and Mousa stone. This well serves as a crucial water source for human consumption and supports the cultivation in all three gardens. The drainage of Wadi Al Arbaein is influenced by several main wadis and their smaller tributaries (Moustafa and Mansour 2020).

The study area of Wadi Al Arbaein identifies six primary landform types: slopes, terraces, gorges, wadis, fans, and plains. Slopes are formed through a combination of tectonic processes and erosion. Terraces consist of bedrock platforms covered with a layer of gravel, sand, or rocky debris. Gorges originate from natural joints or faults in the landscape photos 1, 2. Wadis refer to dry riverbeds in desert regions that intermittently fill with water after heavy rainfall. Alluvial fans form at the mouths of larger gorges or smaller wadis where they enter the main valley (El-Wahab *et al.,* 2006a). Plains are extensive flat desert expanses characterized by deep layers of alluvial deposits. These desert plains represent a late stage in the arid erosion cycle (Moustafa and Klopatek, 1995).

Hydrogeology

Most water sources in the study area appear on the fissured rocks due to the free passage of ground water through the interconnected open fissures in the granitic rocks giving rise to many small springs (El-Rayes *et al.,* 2020). The water channels coming from the mountains produce deep valleys with steep gradients. The beds were originated in lakes formed due to the damming of these water channels by strong porphyry dikes acting as barriers to the ground water flow.

Climate Change

Ecosystems and biodiversity are under constant and escalating threat from climate change. Climate change has an impact on certain species, their interactions with other living things, and their habitats, which changes how ecosystems work and what products and services are produced by natural systems for society (Moustafa and Ghowail, 2022; Moustafa *et al.,* 2023).Wadi Al Arbaein climate is characterized by extremely hot summers with temperatures often exceeding 40°C during the day, and cool to mild winters with temperatures typically ranging from 5-20°C. Rainfall in Wadi Al Arbaein is sparse and irregular, generally occurring between November and March, with annual precipitation averaging around 50-100 mm (2-4 inches). The region is known for its arid conditions, low humidity, and clear skies throughout much of the year, making it part of the larger arid and semi-arid climatic zone that spans across the Sinai Peninsula and neighboring regions.

Wadi Al Arbaein experiences a distinct rainy season that significantly impacts vegetation abundance in the region. The seasonal rainfall plays a crucial role in nourishing the plant life, leading to increased vegetation growth and diversity during favorable conditions. This phenomenon is essential for sustaining various plant species adapted to the arid or semi-arid environments characteristic of many wadis (dry riverbeds) in the region. The periodic influx of water not only supports the growth of native vegetation but also influences the ecological balance and biodiversity within Wadi Al Arbaein, highlighting the dynamic relationship between precipitation patterns and plant abundance in this unique desert landscape (El-Wahab *et al.,* 2006b).

In May 2024, Wadi Al Arbaein experienced its annual rainy season, marking a crucial period for the region's ecosystem. The season brought much-needed precipitation, rejuvenating the arid landscapes and sustaining the unique flora and fauna that thrive in this desert environment. The rains transformed the wadi, causing temporary rivers and streams to flow,

creating a vibrant contrast against the typically dry terrain. This period is not only vital for local agriculture and water resources but also for the replenishment of underground aquifers and the preservation of delicate ecosystems. As the rainwater infiltrates the soil, it supports the growth of endemic plants and provides essential habitats for various species, showcasing the resilience and beauty of nature in Wadi Al Arbaein during this rejuvenating season. Photos 3-6 shows the heavy rain occurred in Wadi Al-Arbaein in 2024.

Identification plant communities

To recognize the ten plant communities in Wadi Al Arbaein, a systematic approach was employed combining field observations and plant identification techniques. Initial surveys focused on identifying the dominant plant species in each area, noting the prevalence and distribution of key species such as *Artemisia inculta*, *Teucrium polium*, and *Fagonia mollis*. Vegetation structure was assessed by examining plant height, density, and overall coverage, which helped differentiate between shrubland and grassland communities. Soil type and moisture levels were recorded to understand the habitat preferences of each community (Barakat *et al.,* 2014). Fieldwork was conducted across different seasons to account for seasonal variations in plant presence and abundance. Detailed field guides and botanical surveys were consulted to verify species identification and community characteristics. This comprehensive approach enabled accurate classification of plant communities, including those dominated by *Achillea fragrantissima*, *Peganum harmala*, and *Centaurea scoparia,* among others. Each plant community was mapped and documented to create a reliable profile of the ecological landscape of Wadi Al Arbaein.

Artemisia inculta – Fagonia mollis a mix of *Artemisia inculta* (a type of sagebrush) and *Fagonia mollis* (a spiny shrub). This community present a dense, low shrubland with these characteristic plants.
Artemisia inculta – Matthiola Arabica; finding *Artemisia inculta* alongside *Matthiola arabica* (a flowering plant). The community will likely have a combination of the sagebrush and the distinctive purple or white flowers of Matthiola.
Teucrium polium – Artemisia inculta; this community features *Teucrium polium* (a small, aromatic shrub) with *Artemisia inculta*. A blend of these shrubs, with *Teucrium polium's* grayish leaves contrasting with Artemisia's greener foliage.
Teucrium polium – Galium sinaicum; Teucrium polium will be present with *Galium sinaicum* (a type of bedstraw). Teucrium's distinctive aromatic shrubs with the low-growing, creeping Galium.
Teucrium polium – Phlomis aurea; Teucrium polium is found with *Phlomis aurea* (a golden-flowered plant). This community will showcase the aromatic shrubs of Teucrium alongside the bright yellow flowers of Phlomis*.*
Achillea fragrantissima – Galium sinaicum; Achillea fragrantissima (a fragrant yarrow) will be prominent with *Galium sinaicum*. The feathery leaves and clusters of white flowers of Achillea mixed with the low, spreading Galium.
Teucrium polium – Plantago sinaica; this community features *Teucrium polium* with *Plantago sinaica* (a type of plantain). Identified it by the presence of Teucrium's aromatic shrubs and Plantago's rosette of basal leaves*.*
Centaurea scoparia – Teucrium polium; In this community, *Centaurea scoparia* (a spiny herb) is found with *Teucrium polium*. the unique spiky flowers of Centaurea combined with the aromatic shrubs of Teucrium*.*
Peganum harmala – Fagonia mollis; This association includes *Peganum harmala* (a plant with distinctive seed pods) with *Fagonia mollis*. The community will show Peganum's tall, upright growth with Fagonia's low, spiny shrubs.
Alkanna orientalis – Fagonia mollis; Alkanna orientalis (a plant with blue flowers) together with *Fagonia mollis.* Alkanna's bright blue flowers will be noticeable amidst the spiny, low-growing Fagonia.

Pure Communities

Fagonia mollis, this community is characterized by a dominance of *Fagonia mollis*, presenting a dense, spiny shrubland. *Alkanna orientalis,* recognized by the presence of *Alkanna orientalis* with its striking blue flowers. *Centaurea scoparia,* the distinct, spiny *Centaurea scoparia* without significant presence of other species. *Achillea fragrantissima,* Identified by the fragrant *Achillea fragrantissima* with its white flowering clusters. *Phlomis aurea*, characterized by the bright yellow flowers of *Phlomis aurea*, forming a distinct community (Hatim *et al.,* 2016).

Vegetation analysis and plant nomenclature

The primary objective of this study was to assess the impact of climate change by comparing the vegetation structure of Wadi Al Arbaein over the past 50 years. To achieve this, care was taken to select sampling sites that encompassed a variety of

environmental conditions within the main habitats of the wadi. A total of 75 stands were qualitatively sampled (presence/absence) during the summers of 2021, 2022, and 2023. Stands were chosen based on homogeneity in soil surface characteristics. Each stand was evaluated for slope degree, aspect, and elevation above sea level. Identification and nomenclature of the collected specimens were carried out according to Täckholm (1974), and Boulos (1999, 2000, 2002 & 2005). Additionally, the main electronic sources and online global databases were used such as: Global Biodiversity Information Facility (GBIF; http://www.gbif.org/occurrence), and Plants of the World Online (POWO; http://www.plantsoftheworldonline.org).

RESULTS

Plant communities and association

The plant diversity of Wadi Al Arbaein represents a significant aspect of its ecological landscape, yet comprehensive studies integrating family composition, life forms, and conservation statuses are limited. This study aimed to fill this gap by conducting a thorough survey of plant species across various families, assessing their life forms, and evaluating their conservation statuses according to the IUCN Red List (2024) criteria. Our objective was to provide a detailed overview of the botanical richness in this region and to identify species of conservation concern. The vegetation and plant communities of Wadi Al Arbaein plant species and identified ten distinct plant communities: *Artemisia inculta – Fagonia mollis*; *Artemisia inculta – Matthiola arabica; Teucrium polium – Artemisia inculta; Teucrium polium – Galium sinaicum; Teucrium polium – Phlomis aurea; Achillea fragrantissima - Galium sinaicum; Teucrium polium – Plantago sinaica;* and *Centaurea scoparia – Teucrium polium; Peganum harmala- Fagonia mollis;* and *Alkanna orientalis- Fagonia mollis.* In the meantime, we found a very clear pure communities represented by only one species such as *Fagonia mollis***;** *Alkanna orientalis; Centurea scoparia; Achillea fragrantissim;* and *Phlomis aurea*.

Floristic composition

The present study conducted in Wadi Al Arbaein has documented a total of 125 plant species. The floristic composition of Wadi Al Arbaein, located in the Sinai Peninsula of Egypt, reflects its unique ecological setting within a semi-arid to arid climate zone. Studies have identified a diverse array of plant species adapted to the wadi's varying elevation gradients and soil types. Dominant species include *Artemisia inculta*, which thrives in rocky and dry habitats, and *Gymnocarpos decander*, characteristic of higher elevation Irano-Turanian steppe vegetation. Other notable species such as *Zilla spinosa* and *Fagonia mollis* are well-adapted to stony alluvial ridges and contribute to the wadi's plant diversity. The flora of Wadi Al Arbaein also features species like *Stachys aegyptiaca* and *Tanacetum sinanicum*, found on terraces and exhibiting adaptations to semi-arid conditions. Additionally, endemic plants such as *Astragalus spinosus* (Forssk) Muschl v. kneuckeri (freyn) Tackh. Et Boulos and *Primula boveana* highlight the wadi's significance as a refuge for unique plant species in the Sinai region.

The species listed in Table 1 consists of various plant species from different families, each with its own life-form (such as chamaephytes, hemicryptophytes, phanerophytes, etc.) and conservation status based on the IUCN Red List criteria. Species diversity in the list includes a diverse range of plants, from Asteraceae (daisies) and Fabaceae (legumes) to Lamiaceae (mint family) and Poaceae (grass family), among others. Life-Forms plants are categorized into different life-forms based on their growth and adaptation strategies. These include chamaephytes (low-growing perennials), hemicryptophytes (perennial herbs with overwintering buds near the soil surface), phanerophytes (tall, woody plants), and therophytes (annuals completing their life cycle in one season).

Conservation status in plant species recorded range from Least Concern to Critically Endangered, indicating the level of threat each species faces in the wild (Table 1). Species classified as vulnerable, endangered, or critically endangered are particularly at risk due to factors such as habitat loss, overexploitation, or climate change, geographical context many of these species are native to or found in regions like Sinai, indicating a specific geographical focus, taxonomic Diversity the species come from diverse taxonomic families, highlighting the richness of plant life in the regions they inhabit. The results show a summary of the distribution of plant species among different families from a compiled list (Figure 1). Asteraceae stands out with the highest representation, comprising twenty species, followed by lamiaceae with fifteen species, and poaceae with twelve species. On the other hand, several families are represented by a single species, indicating more specialized or less diverse plant groups in the list. This diversity across families underscores the varied botanical composition and ecological roles these plants play within their respective habitats.

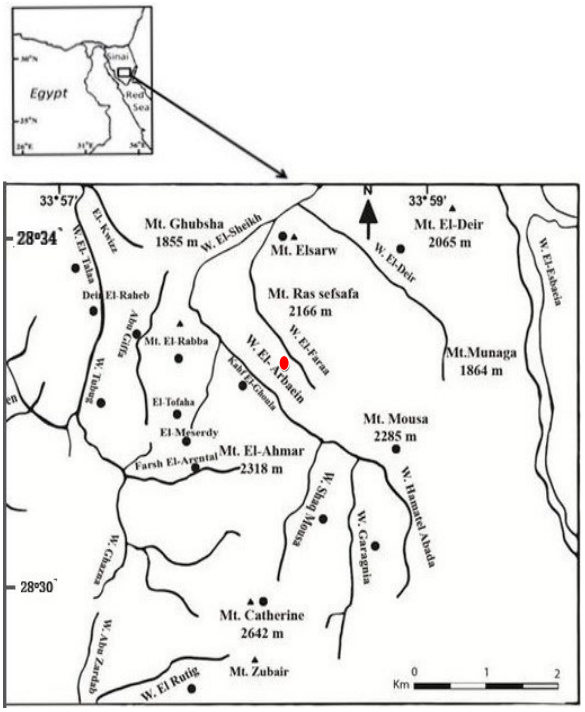

Figure 1. Location map of the study area (Saint Catherine Protectorate) in the southern part of Sinai.

Photos 1, 2. Beauty view of cultivation and outcrops of pink granites meets rugged mountains in Wadi Al Arbaein.

Photo 3, 4. Witnessing the dramatic drainage of water after an hour of heavy rain in Wadi Al Arbaein during May, 2024.

Photos 5, 6. Cloudy skies over Wadi Al Arbaein followed by a flood of heavy rain in May, 2024.

Table 1. The plant diversity, families, life forms, and conservation status in Wadi Al Arbaein. The conservation status of each species, was assessed by the IUCN Red List 2024 https://www.iucnredlist.org. , The asterisk preceeds each species refers to endemic species.

No.	Species	Family	Life-form	Conservation status
1	*Achillea fragrantissima* (Forssk.) Sch.Bip.	Asteraceae	Chamaephyte	Vulnerable
2	*Adiantum capillus-veneris* L.	Pteridaceae	Hemicryptophyte	Endangered
3	*Ajuga chamaepitys* (L.) Schreb.	Lamiaceae	Hemicryptophyte	Endangered
4	*Alkanna orientalis* (L.) Boiss.	Boraginaceae	Chamaephyte	Not threatened
5	*Anagallis arvensis* L.	Primulaceae	Therophyte	Least Concern
6	**Anarrhinum pubescens* Loudon.	Plantaginaceae	Therophyte	Near Threatened
7	*Andrachne aspera* Spreng.	Euphorbiaceae	Chamaephyte	Vulnerable
8	*Andrachne telephioides* L.	Euphorbiaceae	Hemicryptophyte	Critically Endangered
9	*Arenaria deflexa* Decne	Caryophyllaceae	Chamaephyte	Critically Endangered
10	*Aristida coerulescens* Desf.	Poaceae	Hemicryptophyte	Least Concern
11	*Artemisia inculta* Delile.	Asteraceae	Chamaephyte	Not Threatened
12	*Artemisia judaica* L.	Asteraceae	Chamaephyte	Critically Endangered
13	*Asparagus stipularis* Forssk.	Liliaceae	Helophyte	Endangered
14	*Astragalus spinosus* (Forssk) Muschl. *v. kneuckeri (freyn) Täckh. Et Boulos	Fabaceae	Chamaephyte	Not Evaluated
15	*Astragalus vogelii* (Webb) Bornm.	Fabaceae	Phanerophyte	Not Threatened
16	*Atraphaxis spinosa* L. *var. sinaica* Boiss.	Polygonaceae	Phanerophyte	Endangered
17	*Avena sativa* L.	Poaceae	Therophyte	Data Deficient.
18	**Ballota kaiseri* Täckh.	Lamiaceae	Therophyte	Critically Endangered
19	*Ballota undulata* (Fresen.) Benth.	Lamiaceae	Therophyte	Vulnerable
20	*Bidens pilosa* L.	Asteraceae	Therophyte	Not Applicable
21	*Bromus catharticus* Vahl	Poaceae	Therophyte	Not applicable
22	*Bromus diandrus* Roth	Poaceae	Therophyte	Least Concern
23	**Bufonia multiceps* Decne	Caryophyllaceae	Chamaephyte	Critically Endangered
24	*Capparis sinaica* Veill	Capparaceae	Phanerophyte	Least Concern
25	*Capparis spinosa* L.	Capparaceae	Therophyte	Not Evaluated
26	*Caylusea hexagyna* (Forssk.)	Resedaceae	Therophyte	Vulnerable
27	*Centaurea erygnioides* Lam.	Asteraceae	Hemicryptophyte	Endangered
28	*Centaurea scoparia* Sieber	Asteraceae	Phanerophyte	Vulnerable
29	*Chiliadenus montanus* (Vahl) Brullo.	Asteraceae	Phanerophyte	Not Threatened
30	*Conyza triloba* Decne.	Asteraceae	Chamaephyte	Least Concern
31	*Cotoneaster orbicularis* Schltdl.	Rosaceae	Phanerophyte	Endangered
32	*Crateagus x sinaica* Boiss.	Rosaceae	Phanerophyte	Endangered
33	*Crepis sancta* (L.) Bornm.	Asteraceae	Therophyte	Not threatened
34	*Cynodon dactylon* Pers.	Poaceae	Hemicryptophyte	Least Concern
35	*Cyperus capitatus* Vand.	Cyperaceae	Hemicryptophyte	Least Concern
36	*Diplotaxis acris* (Forssk.) Boiss.	Brassicaceae	Therophyte	Vulnerable
37	*Diplotaxis harra* (Forssk.) Boiss.	Brassicaceae	Therophytes	Vulnerable
38	*Echinops spinosus* L.	Asteraceae	Hemicryptophyte	Endangered
39	*Echinops glaberrimus* DC.	Asteraceae	Hemicryptophyte	Not Evaluated
40	*Ephedra alata* Decne.	Ephedraceae	Phanerophyte	Least Concern
41	*Equisetum ramosissimum* Desf.	Equisetaceae	Phanerophyte	Least Concern
42	*Erodium laciniatum* (Cav.) Wild.	Geraniaceae	Therophyte	Not Evaluated
43	*Euphorbia obovata* Decne.	Euphorbiaceae	Hemicryptophyte	Endangered
44	*Eruca sativa* Mill.	Brassicaceae	Therophyte	Not applicable
45	*Fagonia arabica* L.	Zygophyllaceae	Chamaephyte	Least Concern
46	*Fagonia mollis* Delile	Zygophyllaceae	Chamaephyte	Least Concern
47	*Farsetia aegyptia* Turra.	Brassicaceae	Phanerophyte	Vulnerable
48	*Ficus pseudo-sycomorus* Decne	Moraceae	Phanerophyte	Vulnerable
49	*Francoeuria crispa* (Forssk.)	Asteraceae	Therophyte	Vulnerable
50	*Galium sinaicum* (Delile ex Decne)	Rubiaceae	Therophyte	Least Concern
51	*Galium parisiense* L. (Medit.)	Rubiaceae	Therophyte	Endangered
52	**Glaucium arabicum* Fresen.	Papaveraceae	Chamaephyte	Endangered
53	*Gomphocarpus arabicum* Fresen.	Asclepiadaceae	Chamaephyte	Vulnerable
54	*Gymnocarpos decandrum* Forssk.	Caryophyllaceae	Chamaephyte	Vulnerable
55	*Gypsophilla capillaris* (Forssk.)	Caryophyllaceae	Therophyte	Vulnerable
56	*Heliotropium arbainense* Fresen.	Boraginaceae	Chamaephyte	Vulnerable
57	*Hyoscyamus muticus* L.	Clusiaceae	Chamaephyte	Not Evaluated
58	**Hypericum sinaicum* Hochst. & Steud.ex Boiss.	Solanaceae	Chamaephyte	Vulnerable
59	*Iflago spicata* (Forssk.) Sch.Bip.	Asteraceae	Therophyte	Vulnerable
60	*Juncus acutus* L.	Juncaceae	Hemicryptophyte	Least Concern
61	*Juncus rigidus* Desf.	Juncaceae	Hemicryptophyte	Least Concern
62	**Kickxia macilenta* (Decne.) Danin	Scrophulariaceae	Chamaephyte	Endangered

63	*Lactuca spinosa* Lam.	Asteraceae	Therophyte	Vulnerable
64	*Launaea spinosa* (Forssk.) Sch.Bip. ex Kuntze	Asteraceae	Chamaephyte	Least Concern
65	*Lavandula coronopifolia* Poir.	Lamiaceae	Chamaephyte	Not Evaluated
66	*Lavandula pubescens* Decne.	Lamiaceae	Chamaephyte	Not Evaluated
67	*Lotononis platycarpa (*Viv.) Pic. Serm.	Fabaceae	Therophyte	Vulnerable
68	*Lotus corniculatus* L.	Fabaceae	Therophyte	Least Concern
69	*Lotus ovetious* L.	Fabaceae	Therophyte	Least Concern
70	*Lycium shawii* Roem.	Solanaceae	Phanerophyte	Endangered
71	*Malva parviflora* L.	Malvaceae	Therophyte	Least Concern
72	*Malva sylvestris* L.	Malvaceae	Therophyte	Least Concern
73	*Matthiola arabica* Bioss.	Brassicaceae	Hemicryptophyte	Not Evaluated
74	*Medicago laciniata* (L.) Mill.	Fabaceae	Therophyte	Least Concern
75	*Mentha longifolia* (L.) Huds.	Lamiaceae	Hemicryptophyte	Endangered
76	**Nepeta septemcrenata* Benth.	Lamiaceae	Chamaephyte	Endangered
77	*Nicotiana glauca* Graham.	Solanaceae	Therophyte	Not Applicable
78	*Ochradenus baccatus* Delile.	Resedaceae	Phanerophyte	Least Concern
79	*Onopordum ambiguum* Fresen	Asteraceae	Hemicryptophyte	Vulnerable
80	**Origanum syriacum* L.	Lamiaceae	Chamaephyte	Critically Endangered
81	*Paracaryum rugulosum* (DC.) Boiss.	Boraginaceae	Hemicryptophyte	Vulnerable
82	*Paronchyia sinaica* (Barn.) Decne.	Caryophyllaceae	Hemicryptophyte	Vulnerable
83	*Peganum harmala* L.	Zygophyllaceae	Hemicryptophyte	Endangered
84	**Phlomis aurea* Decne.	Lamiaceae	Chamaephyte	Endangered
85	*Phragmites australis* (Cav.) Trin. ex Steud.	Poaceae	Helophyte	Least Concern
86	*Piptatherum miliaceum* (L.) Coss.	Poaceae	Chamaephyte	Least Concern
87	*Pituranthus triradiatus* (Forssk)	Caryophyllaceae	Therophyte	Vulnerable
88	*Plantago sinaica* (Barn.) Decne.	Plantaginaceae	Chamaephyte	Vulnerable
89	*Poa annua* L.	Poaceae	Therophyte	Least Concern
90	*Poa Sinaica* Steud.	Poaceae	Therophyte	Vulnerable
91	*Polycarpon tetraphyllum* L.	Caryophyllaceae	Therophyte	Not Evaluated
92	**Polygala sinaica* Botsch.	Polygalaceae	Chamaephyte	Critically Endangered
93	*Polypogon semiverticillata* (Forssk.) Hyl.	Poaceae	Therophyte	Least Concern
94	*Portulaca oleracea* L.	Portulacaceae	Therophyte	Least Concern
95	**Primula boveana* Decne.	Primulaceae	Hemicryptophyte	Critically Endangered
96	**Pterocephalus sanctus* Decne.	Dipsacaceae	Chamaephyte	Critically Endangered
97	*Pulicaria crispa* (Forssk.) Oliv.	Asteraceae	Therophyte	Least Concern
98	*Reseda arabica* Boiss.	Resedaceae	Therophyte	Least Concern
99	*Reseda stenostachya* Boiss.	Resedaceae	Therophyte	Vulnerable
100	*Retama raetam* (Forssk).	Fabaceae	Phanerophyte	Not Evaluated
101	**Rosa arabica* Crep.	Rosaceae	Phanerophyte	Critically Endangered
102	*Rumex cyprius* Murb.	Polygonaceae	Therophyte	Least Concern
103	*Salvia palaestina* Benth.	Lamiaceae	Hemicryptophyte	Not Evaluated
104	*Schismus barbatus* (L.) Thell.	Poaceae	Therophyte	Least Concern
105	*Scrophularia deserti* Delile	Scrophulariaceae	Therophyte	Endangered
106	*Scrophularia sinaica* Benth.	Scrophulariaceae	Therophyte	Vulnerable
107	*Silene arabica* Boiss.	Caryophyllaceae	Therophyte	Endangered
108	**Silene leucophylla* Boiss.	Caryophyllaceae	Therophyte	Endangered
109	*Silene linearis* Decne	Caryophyllaceae	Therophyte	Data Deficient
110	**Silene schimperiana* Boiss.	Caryophyllaceae	Therophyte	Endangered
111	*Solanum nigrum* L.	Solanaceae	Therophyte	Least Concern
112	*Sonchus macrocarpus* Boulos & C. Jeffrey	Asteraceae	Therophyte	Data Deficient
113	*Spergula fallax* (Lowe) E. H. L. Krause	Caryophyllaceae	Therophyte	Endangered
114	*Stachys aegyptiaca* Pers.	Lamiaceae	Chamaephyte	Near Threatened
115	*Stipagrostis raddiana* (Savi) de Winter	Poaceae	Therophyte	Not Evaluated
116	*Tanacetum sinaicum* (Fresen.) Delile ex Bremer & Humphries	Asteraceae	Phanerophyte	Vulnerable
117	*Teucrium leucocladum* Boiss.	Lamiaceae	Phanerophyte	Not Evaluated
118	*Teucrium pilosum* (Decne.) Asch & schweinf.	Lamiaceae	Phanerophyte	Vulnerable
119	*Teucrium polium* L.	Lamiaceae	Chamaephyte	Endangered
120	*Thymus decussatus* Benth.	Lamiaceae	Chamaephyte	Endangered
121	*Trigonella stellata* Forssk.	Fabaceae	Therophyte	Not Threatened
122	*Verbascum decaisneanum* kuntze	Scrophulariaceae	Chamaephyte	Endangered
123	*Verbascum sinaiticum* Benth.	Scrophulariaceae	Hemicryptophyte	Endangered
124	*Veronica biloba* L.	Scrophulariaceae	Therophyte	Endangered
125	*Zilla spinosa* (L.) Prantl.	Asteraceae	Phanerophyte	Least Concern

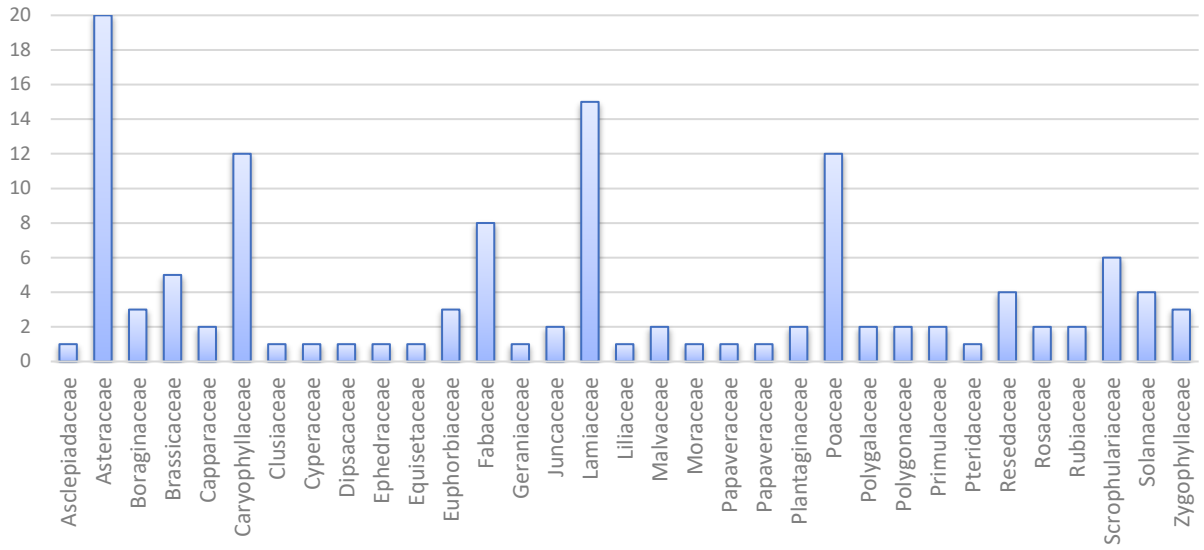

Figure 1. Histogram showing the distribution of plant species across families in Wadi Al Arbaein. Each bar represents the number of species recorded within a specific plant family, based on the 2021-2023 vegetation survey. The families are categorized along the x-axis, while the y-axis denotes the count of plant species. The histogram highlights the diversity and distribution of plant species within different botanical families in the region.

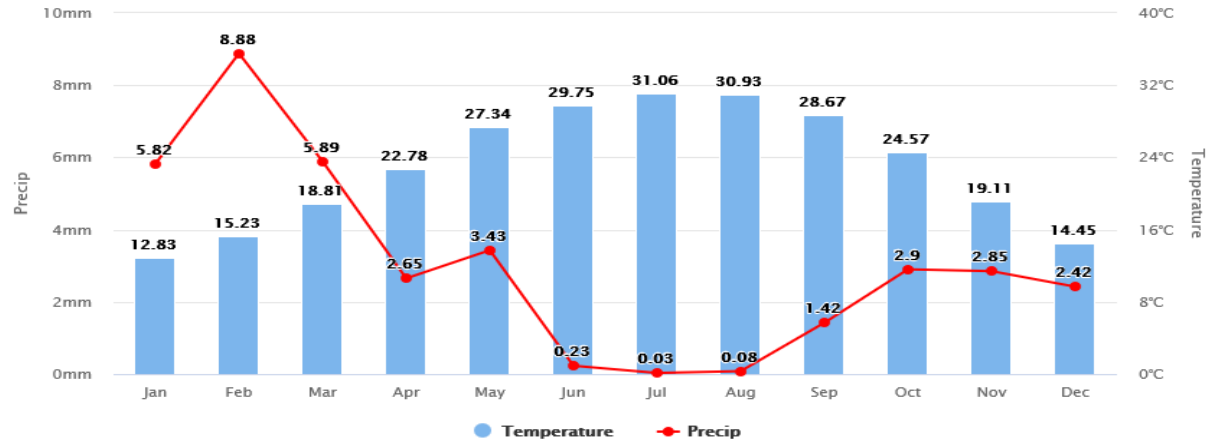

Figure 2. Mean monthly temperature and precipitation of South Sinai in recent years. Source by https://tcktcktck.org/egypt/south-sinai

The life forms are categorized based on their ecological adaptations. Chamaephytes low-growing plants with buds near the soil surface comprise twenty-four species, adapting well to rocky and arid conditions prevalent in the wadi. Hemicryptophytes represented by twenty-one species, these plants have buds near the soil surface and are adapted to withstand periodic droughts and varying climatic conditions typical of semi-arid environments. Phanerophytes, with eighteen species, these are tall woody plants that dominate the canopy layer, often found in more stable and less harsh habitats within Wadi Al Arbaein (Figure 2).

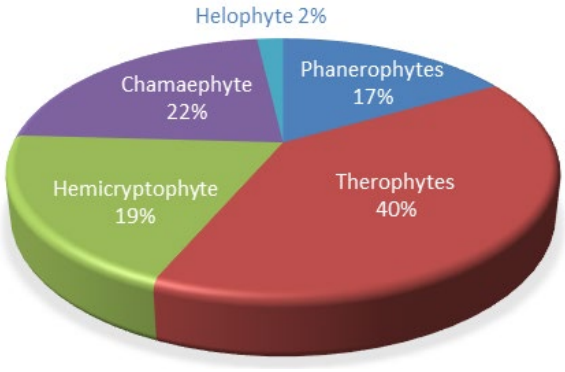

Figure 2. The pie chart presents the distribution of plant life forms observed in Wadi Al Arbaein, a region situated in the Sinai Peninsula of Egypt.

Therophytes the most abundant category with forty-three species, these are annual plants that complete their life cycle quickly during the brief periods of rainfall, taking advantage of favorable conditions. Helophyte represented by two species, these plants grow in aquatic or marshy habitats within the wadi, adapted to seasonal water availability and soil saturation. This distribution of life forms underscores the diverse ecological niches within Wadi Al Arbaein and highlights the adaptive strategies of plant species to survive in its unique environmental conditions. Understanding these life forms is crucial for conservation efforts aimed at preserving the rich biodiversity and ecological integrity of this important region.

Wadi Al Arbaein is home to several rare and endemic species adapted to its unique desert environment. These species have evolved specific adaptations to survive in the arid conditions prevalent in the region. Among the rare species found here are plants like the Sinai Thyme (*Thymus decussatus*), a small aromatic shrub known for its medicinal properties and resilience to drought. Additionally, endemic species such as the Sinai Agama (*Pseudotrapelus sinaitus*), a lizard species with distinctive coloration and behavior, are unique to the Sinai Peninsula, including areas like Wadi Al Arbaein. These species are not only ecologically significant but also culturally important, contributing to the biodiversity and natural heritage of the region. Efforts to conserve these rare and endemic species are crucial for maintaining the ecological balance and preserving the distinctiveness of Wadi Al Arbaein's desert ecosystem amidst ongoing environmental challenges. Photos 7-16 are representative for the vegetation of Wadi Al Arbaein.

DISCUSSION

Wadi Al Arbaein exhibits a rich diversity in its flora, characterized by numerous plant species but relatively few individuals of each species. These plants are distributed across various isolated or semi-isolated patches of habitat within different parts of the wadi (Moustafa and Mansour 2020). The wadi stands out due to its diverse landforms, geology, and geomorphology, creating distinct habitats. It features a narrow and steep configuration with a microclimate that significantly influences its flora and plant communities. Wadi Al Arbaein's channel is narrow and steep, running opposite to Wadi El-Raha. Its bed is strewn with scattered boulders and large stones, and is periodically flooded by spring water, forming deep, narrow channels. Surrounding these springs are

Photo 7. *Alkanna orientalis* (L.) Boiss.

Photo 8. *Hyoscyamus muticus* L.

Photo 9. *Fagonia mollis* Delile

Photo 10. *Capparis spinosa* L.

Photo 11. *Tanacetum sinaicum* (Fresen.) Delile ex K.Bremer & Humphries.

Photo 12. *Rosa arabica* Crép.

Photo 13. *Reseda stenostachya* Boiss.

Photo 14. *Ballota undulata* (Sieber ex Fresen.) Benth.

Photo 15. *Cupressus sempervirens L.*

Photo 16. *Nicotiana glauca* Graham.

plants adapted to moisture, including shade-loving species and those suited to aquatic and salt marsh environments, such as *Adiantum capillus-veneris*, *Equisetum ramosissimum*, *Mentha longifolia* ssp. *typhoides*, and *Origanum syriacum*. *Ficus pseudosycomorus* grows in crevices nearby. Areas with abundant water support the growth of oases, where cultivated gardens thrive with palm trees, pomegranates, almonds, plums, grapes, apples, pears, peaches, and *Cupressus sempervirens* Photo 15. Herbs like *Solanum nigrum* and *Verbascum schimperianum* flourish abundantly in these cultivated areas (Moustafa and Zaghloul 1996).

The wadi's rich flora includes a variety of plants such as *Ammi majus, Anchusa aegyptiaca, Brachypodium distachyum, Carduus arabicus, Euphorbia peplus, Lactuca orientalis, Onopordum ambiguum, Plantago ciliata, Pulicaria arabica, Sisymbrium irio, and Sonchus oleraceus.* Additionally, *Asperugo procumbens, Hypericum sinaicum,* and *Verbascum schimperianum* are documented in the southern mountains. Towards the mouth of Wadi Al Arbaein's, vegetation cover is sparse, about 10%, predominantly featuring *Peganum harmala* along with *Zilla spinosa* (abundant), *Achillea fragrantissima*, and *Stachys aegyptiaca* (common). Less frequently encountered species in this area include *Alkanna orientalis, Artemisia judaica, Ballota undulata, Origanum syriacum v. aegyptiacum, Phlomis aurea,* and *Teucrium polium*. The flora of Wadi Al Arbaein faces numerous threats, including overgrazing, excessive collection of plants, cutting for fuel, impact from feral donkeys, tourism activities, scientific research collection, as well as challenges posed by the arid and irregular rainfall patterns (Ibrahim *et al*., 2022).

Over the years 2021 to 2023, Wadi Al Arbaein experienced varied climate patterns that influenced its vegetation, rainfall, and temperatures. In the year 2021, Wadi Al Arbaein experienced below-average rainfall, receiving around 100 mm of precipitation throughout the year. This reduced rainfall adversely affected vegetation growth, putting stress on plants adapted to arid conditions. Moving into the year 2022, the region saw a significant increase in rainfall, reaching approximately 300 mm annually. This rapid increasing in precipitation revitalized vegetation, fostering lush growth and supporting a diverse range of endemic plant species. The trend continued into 2023, with rainfall remaining abundant at an average of 280 mm per year, like the previous year. This sustained moisture further enhanced vegetation health, contributing to robust ecosystems and promoting biodiversity in the area. Between the years 2021 and 2023, daytime temperatures in Wadi Al Arbaein typically ranged from 25°C to 35°C, with nighttime temperatures cooler, averaging around 15°C to 25°C. These moderate temperature variations, characteristic of desert climates, created favorable conditions that supported vegetation growth, particularly during periods when rainfall was sufficient (Gabr *et al.,* 2023).

In the year 2021, vegetation in Wadi Al Arbaein encountered challenges due to below-average rainfall, resulting in reduced growth rates and stress, particularly among more sensitive species. However, the year 2022 and 2023, increased rainfall significantly benefited vegetation by promoting plant growth and facilitating the regeneration of endemic species. The abundant water fostered the development of diverse habitats and bolstered the resilience of the ecosystem. These fluctuating climate patterns from the year 2021 to 2023 underscored the crucial role of rainfall in shaping vegetation dynamics in Wadi Al Arbaein. Adequate precipitation levels proved essential for sustaining biodiversity and promoting healthy ecosystems in this distinctive desert environment (Gabr *et al.,* 2023).

The present study investigates the impact of climate change on vegetation composition in Wadi Al Arbaein, a significant wadi in south Sinai known for its unique flora. The wadi features steep terrain, scattered boulders, and terraced landscapes culminating in a narrow, spring-fed channel. The region experiences an extremely arid climate characterized by long, hot, rainless summers and mild winters. The research conducted a comprehensive vegetation survey, assessing parameters such as total plant cover, soil characteristics (physical and chemical), and environmental factors like temperature and moisture. Findings underscored that these variables play crucial roles in shaping the distribution and structure of vegetation in the area. The study highlights that climate change-induced extreme weather events are increasingly affecting ecosystem functions and vegetation dynamics. This has profound implications for biodiversity conservation and sustainable development. Endemic species, in particular, are highly vulnerable, often serving as indicators of regional biodiversity and conservation priorities. Given these impacts, there is a critical need for proactive conservation strategies. The study emphasizes the importance of predicting future climatically suitable habitats for rare and threatened endemic species to formulate effective long-term

conservation plans. These environmental shifts are altering the distribution and composition of plant species adapted to the area's unique conditions. Native vegetation, crucial for stabilizing soil and supporting local biodiversity, faces challenges such as reduced water availability and heightened heat stress. The impact is visible in changes to vegetation cover and species composition, with potentially significant consequences for ecosystem resilience and the livelihoods of communities dependent on the wadi's resources. Understanding and mitigating these impacts are essential for conserving the ecological integrity and cultural significance of Wadi Al Arbaein in the face of ongoing climate change pressures.

The Church of Al Arbaein, along with its surrounding garden, boasts abundant vegetation nurtured by protective enclosures established between 1998 and 1999. These enclosures serve a crucial role in safeguarding the diverse plant species within the area from various threats. By providing a controlled environment, they help mitigate the impact of external factors such as climate fluctuations and human activities, ensuring the preservation and flourishing of the garden's botanical treasures (Hany *et al*., 2022; Bader and El-Shazly, 2024). This initiative not only enhances the aesthetic appeal of the Church of Al Arbaein but also reinforces its role as a sanctuary for biodiversity, showcasing a harmonious blend of cultural heritage and environmental conservation efforts Photo 17.

Kahf El-Ghoula in Photo 18 is renowned for its dedicated enclosure housing *Primula boveana*, a delicate and rare plant species. Established to protect and nurture this unique flora, the enclosure provides a controlled environment that shields *Primula boveana* from external threats such as habitat disturbance and climate variability. This conservation effort is crucial as it ensures the sustainability of the species within its natural habitat, contributing to the preservation of biodiversity in the region. Visitors to Kahf El-Ghoula can witness firsthand the beauty and significance of *Primula boveana*, underscored by the efforts to safeguard its existence for future generations to appreciate and study. The presence of olive and Ficus trees in gardens reflects a deliberate effort to enhance biodiversity and adds lush greenery to the garden landscapes of Wadi Al Arbaein. Together, the cultivation of olive and ficus trees in Wadi Al Arbaein not only enriches the visual appeal of the area but also underscores the sustainable coexistence between humans and nature in this unique desert setting Photos 19, 20.

Photo 17. Church of Al Arbaein.

Photo 18. Kahf El-Ghoula.

Photo 19. A very huge Olive farm (*Olea europaea* L.) at the end of Wadi Al Arbaein.

Photo 20. Botanical garden of the research center occupied by *Opuntia ficus-indica* (L.) Mill.near to the mouth of Wadi Al Arbaein.

CONCLUSIONS

The target of the present study is to provide an overview of species diversity in Wadi Al Arbaein; the vegetation survey resulted in one hundred and twenty-five plant species which belong to thirty-three families. W. Al Arbaein represented high altitude, very diverse landforms and soil types. Finally, we may conclude that climate change is increasingly influencing the floristic composition of Wadi Al Arbaein. By analyzing vegetation, soil, and climate data, we found that the area supports a diverse range of plant species, including a significant number of endangered endemic plants. Climate change is posing a serious threat to these unique species, and the study emphasizes the urgent need for conservation efforts to protect Wadi Al Arbaein's biodiversity. As global temperatures rise, this region is experiencing shifts in precipitation patterns, more frequent extreme weather events, and changing ecological conditions. These factors are altering the distribution and abundance of plant species, potentially leading to shifts in species composition within various ecosystems. Native plants adapted to specific climatic regimes may face challenges in adapting to these rapid environmental changes, while invasive species and new plant communities could emerge. Understanding and monitoring these shifts are crucial for effective conservation and management strategies in Wadi Al Arbaein, ensuring the resilience of its unique flora in the face of ongoing climate challenges.

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