Vegetation zonation along the desert-wetland ecosystem of Taif Highland, Saudi Arabia

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1. Introduction

The Saudi Arabian Kingdom belongs to the arid and semi-arid regions with about 2,250,000 km² comprised various ecosystems and biodiversity (Abdel Khalik et al. 2013; Alsherif 2019). It has no permanent lakes or rivers; but, wadis are numerous along with the country (Al-Robai et al. 2017). The Kingdom's vast landscape comprises various habitats, including mountains, wadis, rocky and sandy deserts, floodplains, and sabkhas (Al-Yasi et al. 2019). From the geographical viewpoint, Saudi Arabia has two distinct zones: the western and southwestern rainy highlands, including Taif Province, and the arid and hyper-arid zone of the north (Al-Nafie 2008). The rainwater is mainly collected in the low floodplains of wadis, and sometimes it forms streams, small water reservoirs and wet meadows (Omar and Hassan 2018). In addition to temperature, infiltration, wind and evapotranspiration, rainfall can be heavy or light in magnitude, determining the soil's wet or dry times (Snyder and Tartowski 2006). The wadis vegetation is the main center of biodiversity in the desert ecosystems; these wadis are home to grazing communities rendering the area as pasture for various animals (Hamed et al. 2018).

Wetlands, as an essential ecosystem, are increasingly becoming an exciting issue for many researchers (Huang et al. 2012; Ansari and Golabi 2019). Wetland management and evaluation become a crucial hotspot for researchers (Landmann et al. 2013). The con-
trast of wetlands with the surrounding desert habitat raises assumptions about their ecological importance (Fensham et al. 2011). Desert wetlands are characteristic ecosystems in the arid environments maintained in the geologic record as deposits discharged from the groundwater (Springer et al. 2015). Wet meadows, a type of desert wetlands, are large seeps with seasonal standing water in short periods after heavy rains (Honke et al. 2019). Desert wetlands are characterized by chemical, physical, and morphological properties, which create various habitats for aquatic organisms (Williams 1999). According to Pigati et al. (2014), desert wetlands responded dynamically to the paleoclimate change. Some of these wetlands have several endemics, but mainly, they support widespread species with cosmopolitan distributions (Strong et al. 2008).

Understanding the vegetation ecology and composition of the desert wetland is vital in estimating the wetland communities’ stability and interacting with other habitats in the total desert ecosystem (Maneja et al. 2020). Vegetation depends mainly on a combination of phenology, growth form and plant habit, climatic conditions, and the common species (Al-Aklabi et al. 2016). With the increasing conservation demand of the natural resources and utilization of the wild plants, quantitative investigation of the vegetation is urgently required to elucidate species’ distributional behaviour concerning environmental variations (Alyemeni 2001). Vegetation classification is an important tool for interpreting natural ecosystems and habitats (Brown et al. 2013). Classification technique emphasizes diagnostic or indicator species, which may differentiate one cluster from another (Feldmeyer-Christie et al. 2005). The current vegetation is affected mainly by climate change, aridity, and anthropogenic activities such as urbanization (El-Sheikh et al. 2011). Desert wetlands are characteristic ecosystems in the arid environment as deposits discharged from the groundwater (springer et al. 2015). Wet meadows, a type of desert wetlands, are large seeps with seasonal standing water in short periods after heavy rains (Honke et al. 2019). Desert wetlands are characterized by chemical, physical, and morphological properties, which create various habitats for aquatic organisms (Williams 1999). According to pigati et al. (2014), desert wetlands responded dynamically to the paleoclimate change. Some of these wetlands have several endemics, but mainly, they support widespread species with cosmopolitan distributions (Strong et al. 2008).

The information about mainland vegetation is expanding, and its analyses become more complex; therefore, the vegetation ecology on the desert wetlands of the Saudi Arabian southwestern highlands requires further investigations (Abbadi and El Sheikh 2002). Sustainable management and assessment are necessary for conserving aquatic flora’s diversity and ecological habitats, as they play a crucial role in the biogeochemical nutrients cycling in wetland ecosystems (Ansari 2016). Species diversity studies in desert wetlands have less attention than desert ecosystems due to the lack of experimental data because of the unstable conditions of the aquatic ecosystems (Murphy et al. 2003). Conservation plans for protecting desert wetlands must be prepared for possible responses to environmental changes (Springer et al. 2015). For these reasons, the present study investigates the zonation pattern and environmental impacts on the desert-wetland vegetation in Taif highlands in terms of species composition, distribution, and diversity of plant communities. Such studies may help in managing vegetation in the desert-wetland ecosystems of Saudi Arabian highlands.

2. Materials and methods

2.1. Study area

Taif region lies on the western mountains’ foothills at about 2500 m above sea level (21° 26’ 14.1828” N and 40° 30’ 45.7704’ E) (Fig. 1). The foothills of Al-Sarawat Mountains are characterized by coarse pink granite intermingled by grey granodiorite and diorite (Ady 1995). Precipitation water flows from the main wadis and their tributaries and aggregates, in specific depression, to form discrete desert wetlands (wet meadows). These wetlands are inhabited by several true aquatic macrophytes (e.g., Lemma gibba, Potamogeton nodosus, and P. pectinatus), which are considered invasive to the desert ecosystem. The study area is characterized by a typically arid and tropical climate. The climatic data recorded in Taif meteorological station (1997 – 2009) showed that June is the hottest month (27.6 °C), while January is the coldest (15.2 °C) with an annual average air temperature of 22.2 °C (Fig. 2). In addition, rainfall in the Taif region is summer and autumn with the maximum (30.4 mm mon⁻¹) in May and the minimum (0.6 mm mon⁻¹) in April with an annual average of 121.5 mm yr⁻¹.

2.2. Sampling and data collection

Sampling was carried out in the desert wetlands (wet meadows) of Taif highlands from four locations: Shafa, Al-Roddaf, Wadi Sessid, and Wadi Al-Arge, Saudi Arabia (Fig. 1). To study the vegetation zonation, we randomly selected 41 stands (10 × 10 m) to cover three main habitats: wet meadows (water zone), slopes (desert-wetland transition zone), and the terraces (desert zone). During the rainy seasons in summer and autumn, the stands were investigated to list plant species and visually estimate the cover of each species (%). The identification and nomenclature of the listed species followed Boulos (1999; 2000; 2002; 2005; 2009), Chaudhary (1999, 2000), Collenette (1999), and Migahid (1978). Plant specimens were put in the Biology Department Herbarium, College of Sciences, Taif University. Plant species were classified according to their status into aquatic, natural, segetal, and escaped (cultivated) plants. According to the Raunkiaer scheme (after Al-Yasi et al. 2019), the recorded species’ life forms were identified. The recorded species’ global geographical distribution was determined according to Feinbrun-Dothan (1978, 1986), Tackholm (1974), Wickens (1977), and Zohary (1966, 1973).

2.2.1. Soil sampling and analysis

A composite soil sample, from each stand, was collected from 0 to 50 cm depth, transferred to the laboratory in plastic bags. Samples were left to air-dry and sieved to get rid of debris and gravel for chemical analysis. Soil-water extracts (1:5 w/v) were prepared for measuring pH and electrical conductivity (EC) through a pH meter (Model 9107 BN, ORION type) and a conductivity meter (Model 410). All the procedures mentioned above were reported in Allen (1989) and Jackson (1962).

2.3. Data analysis

2.3.1. Multivariate analysis

The matrix of cover estimates for the recorded species in 41 studied sample sites of the desert-wetland ecosystem in Taif highlands was analyzed using two-way indicator species analysis (TWINSPLAN) and detrended correspondence analysis (DCA), a classification (Hill 1979) and an ordination (Hill and Gauch 1980) technique, respectively. The relationships between the dominant plant communities resulted from TWINSPLAN, and their environmental variables can be assessed by applying principal component analysis (PCA) (Kent and Coker 1992).

2.3.2. Diversity indices

Plant diversity was estimated for the produced vegetation groups (VG) from TWINSPLAN. Species richness was measured as the average number of species per stand, while species turnover was calculated by dividing the total number of species of a VG by its species richness. The relative evenness as Shannon-Wiener index was calculated as $H = -\sum_i P_i \log P_i$, where $s$ is the species diversity index.
count and \( \Pi \) is the species cover, while the relative concentration of dominance as Simpson’s index was expressed as \( D = 1/C \)
\[ C = \sum s (\Pi)^2, \]
where \( s \) is the species count and \( \Pi \) is the species cover. The indices mentioned above were reported in Pielou (1975) and Magurran (1988).

2.3.3. Statistical analysis

After testing the homogeneity and normality of the data, the soil variables variation among the produced VG was estimated through one-way analysis of variance (ANOVA) using SPSS software (SPSS 2012).

3. Results

3.1. Floristic analysis

On-hundred and forty-two species related to 111 genera and 45 families were recorded in the desert wetlands of Taif Province (Appendix 1). Asteraceae was the dominant family (16.9% of the total species), followed by Poaceae (13.4%), Amaranthaceae (7.7%), Solanaceae (5.6%), Lamiaceae (4.2%), and Fabaceae (3.5%) (Fig. 3). In contrast, 19 families (e.g., Lemnaceae, Typhaceae, and Tamaricaeaceae) had only one species.

The status of the identified species in the desert-wetland ecosystem of the Taif area indicated that 64.1% of the total species were natural (desert) plants, while 25.4% were segetal weeds, 7.7% were aquatic weeds, and 2.8% were plants escaped from cultivation (Fig. 4a). Besides, the life forms of the identified species (Fig. 4b) revealed the dominance of therophytes (46.5% of the total species), followed by chamaephytes (16.7%), phanerophytes and hemicryptophytes (12.7%), and geophytes (4.9%). Meanwhile, hydrophytes were represented by 2.8%, and geophytes-helophytes had 2.1% of the total species. Moreover, the chorological analysis of the identified species showed that 35.9% of the entire species were monoregional elements, while 33.8% were biregional, 18.3% were pluriregional and 12.0% were cosmopolitan (Fig. 4c).

3.2. Vegetation analysis

Multivariate analysis was applied to the 142 species cover estimates recorded in 41 sampled stands in the desert-wetland ecosystem of Taif Province (Appendix 2 and Table 1). TWINSPAN produced eight vegetation groups (VGs), which exhibited proper segregation on the DCA-axes (Figs. 5 and 6). The VGs were named after the 1st and 2nd dominant species (species with the highest presence percentage or cover). Four vegetation groups (VG) represented the wetland habitat: VG (A): Potamogeton nodosus- Nasturtium officinale, VG (B): Lemma gibba-Leptochloa fusca, VG (C): Typha domingensis- Xanthium strumarium and VG (D): Conyza stricta- Cyperus longus. In addition, two vegetation groups represent the slopes: VG (E): Acacia gerrardii- Commicarpus plumbagineus and VG (H): Osteospermum vaillantii- Eragrostis Pilosa. Moreover, two other vegetation groups represent the terraces:...
3.3. Community diversity

The species diversity of the eight vegetation groups (Table 2) indicated that Conyza stricta- Cyperus longus group, which inhabits the three habitats, had the highest number of species, species turnover, and relative evenness (65, 4.68, and 3.66). While the Potamogeton nodosus- Nasturtium officinale group, inhabiting the wetlands, had the lowest number of species and species richness (6 species and 3.3 species stand⁻¹). The Osteospermum vaillantii- Eragrostis pilosa group inhabiting the desert terraces had the highest species richness (18.7 species stand⁻¹) and the relative concentration of dominance (25.65). Moreover, the Lemna gibba- Leptochloa fusca group, inhabiting the wetlands, had the lowest species turnover, relative evenness, and relative concentration of dominance (1.75, 0.93, and 1.69), respectively.

3.4. Soil characteristics

The chemical analysis of the soil of the produced VGs from TWINSPAN showed that the Typha domingensis- Xanthium strumarium group had the highest soil EC (803.10 μS cm⁻¹) as well as Cl, SO₄, Mg, Na and K (19.43, 10.33, 5.44, 2.27 and 2.73 mg kg⁻¹), respectively (Table 3). In addition, the soil of the Acacia gerrardii- Commicarpus plumagineus group had the highest HCO₃, NO₃, and Ca (6.30, 51.52 and 8.48 mg kg⁻¹), and Osteospermum vaillantii- Eragrostis pilosa group had the most elevated pH (7.66), but the lowest Cl and K (5.23 and 0.59 mg kg⁻¹). However, the Argemone ochroleuca- Cyperus rotundus group soil had the lowest EC (185.56 μS cm⁻¹) and the lowest HCO₃, SO₄, Ca, and Mg (4.24, 1.73, 4.41, and 1.96 mg kg⁻¹). While the soils of Conyza stricta- Cyperus longus and Typha domingensis- Xanthium strumarium groups had the lowest pH (6.49) and NO₃ (21.11 mg kg⁻¹), respectively.

3.5. Plant community-soil relationship

The relationship between the common plant communities and their soil variables is described in the PCA diagram (Fig. 7). Bicarbonates, nitrates, magnesium, chlorides, calcium, and pH-value have the most significant influence on the dominant communities. The Potamogeton nodosus community was significantly affected by Cl, while Typha domingensis was influenced considerably by EC and Cl. In addition, the Conyza stricta community was recorded on a
high gradient of Na and K, but a low gradient of Ca. Moreover, Mg is the most significant element in the desert wetlands support high plant diversity (Springer et al. 2015). About 142 species related to 111 genera and 45 families were identified in the 41 sampled stands in the wetlands and their surrounding deserts in Taif highlands. This number represents about 24.8% of Taif highlands’ total recorded species (Al-Yasi et al. 2019). Our results revealed that Asteraceae had the highest contribution, followed by Poaceae and Fabaceae. This result is in line with the trend of the whole Saudi Arabian flora (Col lenette 1999) as well as the flora of southwestern Saudi Arabian highlands (Mosallm, 2007; Alsherif and Fadl 2016; Al-Sodany et al. 2016; Al-Robai et al. 2019; Alsherif 2019; Al-Yasi et al. 2019). Jeffrey (2007) attributed the dominance of Asteraceae to the wide phytogeographical distribution and the seed dispersal efficiency of the family members in Taif highlands.

The identified flora was characterized by many species in proportion to genera (1.3 species/genus), which is a comparable figure to 1.3, 1.5, 1.6, and 1.9 species/genus reported in Sarawat highlands by Alsherif and Fadl (2016), Alsherif et al. (2013), Alsherif (2019), and Al-Yasi et al. (2019), respectively. According to Al-Nafie (2008), the low species / genera ratio is common in desert vegetation indicating high plant diversity. Osman et al. (2014) attributed the increased plant diversity to water sources availability, soil fertility, and habitat heterogeneity. The recorded species showed natural xerophytes’ dominance, followed by segetal, aquatic, and cultivated plants. The present findings documented an increased number of ruderal and segetal plants indicating the agriculture development in the Taif region. Similar findings were reported in the Hail Province by El-Ghanim et al. (2010). About 7.7% of the total species were identified in the wet meadows representing an environment with seasonal inundation of standing water (Pigati et al. 2014) compared to the other wetland types’ dense vegetation with perennial standing water (Honke et al. 2019).

In the arid regions, the plant life forms are closely related to the landform and topography (Alatar et al. 2012). In the present study, the identified species’ life form spectra revealed therophytes’ dominance over chamaephytes, phanerophytes, and hemichryptophytes. This vegetation pattern is in line with that of the desert habitats of other Saudi Arabian regions (e.g., El-Demerdash et al. 1995; Collenette 1999; Chaudhary 2000, 2001; Al-Turki and Al-Qlayan 2003; Fahmy and Hassan 2005; El-Ghanim et al. 2010; Alatar et al. 2012), Mosallm (2007) attributed therophytes’ dominance to the sampling time and the study area’s overgrazing. In contrast, Al-Sodany et al. (2016), Al-Robai et al. (2017), and Al-Yasi et al. (2019) attributed the dominance of chamaephytes to the hot-dry climate, topography, and biotic factors. Moreover, the highest therophytes representation may be due to the wet meadows’ climatic conditions and efficient discrete rainfall of Taif highlands (Alsherif 2019). Simultaneously, the highest number of chamaephytes is an indicator of drought, salinity, and grazing resistance (Galal and Fahmy 2012). The vegetation structure of the Taif area’s desert-wetland ecosystem withstands the harsh environmental

**Table 1**

Characteristics of the 8 vegetation groups produced after the application of TWINSPLAN on the 41 stands of the desert wetlands of Taif highlands. VG: vegetation group; NS: number of stands; G/P: number of stands of each group to the total number of stands; P: presence of species. C: cover (%).

| VG | NS | G/P | Habitat       | Location        | 1st Dominant          | P (%) | C (%) | 2nd Dominant          | P (%) | C (%) |
|----|----|-----|---------------|-----------------|----------------------|-------|-------|----------------------|-------|-------|
| A  | 3  | 7.3 | 100.0         | Natural plants  | Potamogeton nodosus | 100.0 | 9.3   | Nasturtium officinale | 100.0 | 4.0   |
| B  | 2  | 4.9 | 100.0         | Segal weeds     | Lemna gibba         | 100.0 | 2.0   | Leptochloa fusca     | 50.0  | 30.0  |
| C  | 4  | 9.8 | 100.0         | Aquatic plants  | Typha domingensis   | 100.0 | 26.0  | Xanthium strumarium  | 100.0 | 13.8  |
| D  | 11 | 26.8| 45.5          | Shafa           | Conyza stricta     | 90.9  | 5.2   | Cyperus longus       | 54.6  | 20.9  |
| E  | 5  | 12.2| 20.0          | Shafa           | Acacia gerrardii    | 100.0 | 10.6  | Commicarpus plumbagineus | 80.0  | 4.8   |
| F  | 7  | 17.1| 42.9          | Shafa           | Argemone ochroleuca | 71.4  | 6.7   | Cyperus rotundus     | 42.9  | 23.0  |
| G  | 6  | 14.6| 16.7          | Wadi Sessid Al-Rodaf | Pulsatilla undulata | 83.3  | 4.2   | Solanum incanum      | 66.7  | 4.7   |
| H  | 3  | 7.3 | 100.0         | Shafa           | Osteosperum vaillentii | 100.0 | 15.0  | Ergagris pilosa      | 100.0 | 5.7   |
conditions, which is reflected by annuals preponderance and the presence of a lot of drought-resistant species (Abd El-Ghani and Amer 2003).

The flora of Saudi Arabia is a mixture of various phytogeographical elements (Ouda 2014). The chorological data of the identified species in the Taif region’s desert-wetland ecosystem showed the highest contribution of Saharo-Arabian taxa, followed by Mediterranean, Sudano-Zambezian, and Irano-Turanian chorotypes. According to Hegazy and Amer (2001), Saharo-Arabian elements increased southwards, and decreased northward; where, they are replaced by Irano-Turanian and Mediterranean chorotypes. Saharo-Arabian and Sudano-Zambezian elements are potential indicators for high aridity xeric environment, while the Mediterranean taxa are suitable for mesic habitats (Hamed et al. 2018; Alsherif 2019). The global phytogeographical distribution of the recorded species in Taif highlands’ desert-wetland ecosystem showed the predominance of the monoregional taxa over the other chorotypes. This result coincided with Al-Yasi et al. (2019) on Taif highlands. In Contrast, Galal and Fahmy (2012) attributed the reverse trend, related to the dominance of interregional chorotypes (bi-, tri-, and pluriregionals) to the presence of habitat heterogeneity.

The phytosociological analysis of the identified species produced eight vegetation groups representing Taif highlands’ desert-wetland ecosystem’s different habitats. Four community types dominated the wetland habitat, while two community types represent each of the slopes and terraces of the desert habitats. In harmony with the present study, Hamed et al. (2018) reported T.
**Fig. 6.** DCA-ordination of the eight vegetation groups identified after the application of TWINSPLAN on the 41 sampled stands in desert wetlands of Taif highlands.

### Table 2

Diversity indices of the 8 vegetation groups produced after the application of TWINSPLAN on the 41 stands of the desert wetlands of Taif highlands.

| Diversity index | A   | B   | C   | D   | E   | F   | G   | H   |
|-----------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Number of species | 6   | 7   | 9   | 85  | 37  | 41  | 48  | 39  |
| Species richness | 3.3 | 4.0 | 4.8 | 3.9 | 13.9| 11.6| 11.6| 16.0|
| Species turnover | 1.82| 1.75| 1.88| 4.68| 2.79| 3.53| 3.00| 2.00|
| Shannon index    | 1.63| 0.93| 1.55| 3.66| 3.22| 3.00| 3.42| 3.37|
| Simpson index    | 5.06| 1.69| 3.91| 21.25| 20.63| 11.20| 22.64| 25.65|

### Table 3

Soil chemical characteristics (Means ± standard deviations) of the 8 vegetation groups of desert wetlands of Taif highlands. The minimum and maximum values were underlined.

| Soil variable | Vegetation Group | A         | B         | C         | D         | E         | F         | G         | H         | F-value |
|---------------|------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|---------|
| pH            |                  | 6.72 ± 0.88| 7.11 ± 0.72| 7.60 ± 1.26| 6.49 ± 0.59| 7.23 ± 0.83| 7.41 ± 0.46| 7.23 ± 0.82| 7.66 ± 0.20| 1.06    |
| EC (μS cm⁻¹)  |                  | 272.71 ± 26.31| 274.42 ± 56.14| 243.27 ± 42.45| 345.32 ± 88.32| 185.56 ± 20.01| 249.59 ± 73.90| 203.61 ± 11.69| 14.25***|
| HCO₃ mg kg⁻¹  |                  | 5.61 ± 0.61| 5.28 ± 0.42| 5.17 ± 1.17| 5.32 ± 0.63| 6.30 ± 1.96| 4.24 ± 0.51| 4.72 ± 0.91| 5.00 ± 0.64| 1.96    |
| Cl⁻ kg⁻¹      |                  | 6.63 ± 0.19| 7.18 ± 1.26| 19.43 ± 2.95| 8.54 ± 1.54| 8.52 ± 1.71| 5.29 ± 0.34| 6.23 ± 1.01| 5.33 ± 0.66| 25.24***|
| SO₄²⁻ kg⁻¹    |                  | 5.2 ± 0.75 | 3.65 ± 0.63| 10.33 ± 1.91| 2.06 ± 0.66| 4.15 ± 1.08| 1.73 ± 0.60| 2.64 ± 0.21| 1.78 ± 0.29| 13.79***|
| NO₃⁻ kg⁻¹     |                  | 32.21 ± 4.21| 35.69 ± 3.34| 21.11 ± 2.46| 46.95 ± 6.52| 51.51 ± 12.6| 47.22 ± 9.77| 40.16 ± 6.06| 49.77 ± 8.32| 3.27*   |
| Ca kg⁻¹       |                  | 8.12 ± 2.01| 5.89 ± 1.26| 6.46 ± 1.31| 5.95 ± 1.51| 8.48 ± 1.35| 4.41 ± 1.07| 5.64 ± 1.04| 4.58 ± 0.48| 3.03*   |
| Mg kg⁻¹       |                  | 2.94 ± 0.73| 3.06 ± 0.86| 5.44 ± 1.10| 2.26 ± 0.31| 2.60 ± 0.55| 1.96 ± 0.30| 2.16 ± 0.48| 2.22 ± 0.15| 9.55*** |
| Na kg⁻¹       |                  | 0.11 ± 0.01| 0.23 ± 0.18| 0.27 ± 0.09| 0.27 ± 0.09| 0.45 ± 0.04| 0.14 ± 0.02| 0.12 ± 0.01| 0.15 ± 0.06| 20.24***|
| K kg⁻¹        |                  | 0.63 ± 0.10| 0.96 ± 0.55| 2.73 ± 0.78| 0.71 ± 0.13| 0.63 ± 0.01| 0.66 ± 0.05| 0.63 ± 0.01| 0.59 ± 0.04| 13.76***|

**domingensis** community's dominance in the wet meadows of Tihama hill. This study's vegetation zonation was clear since the plant communities' succession ranged from real aquatic plants, segetal weeds and true xerophytes. Segetal communities were recorded early in the Hail region (El-Ghaim et al. 2010), while the xerophytic communities were recorded in most Saudi Arabian
arid lands of by several researchers (e.g., El-Ghanem et al. 2010; Al-Sodany et al. 2016; Alsherif and Fadl 2016; Hamed et al. 2018; Alatar et al. 2012; Alsherif 2019; and Al-Yasi et al. 2019). As shown on the DCA ordination, there is a gradient of moisture, which indicates the clear zonation of the vegetation in the study area.

The variation in species composition and diversity depends mainly on many factors, including precipitation, slope, elevation gradients, and topography (Al-Robai et al. 2017). The Conyza stricta- Cyperus longus group, a mixed group inhabiting the different study habitats of the wetland-desert ecosystem, had the highest species diversity, while the Potamogeton nodosus-Nasturtium officinale group, inhabiting the wetlands, had the lowest. Shehata and Galal (2015) attributed the species diversity variation in heterogenic habitats to variations in soil variables and the allelopathic effects of species upon each other’s. In addition, Galal and Fahmy (2012) documented low plant diversity in high altitudinal habitats, wetlands, and swamps. Moreover, the low diversity of the wetland habitat may be attributed to the low tolerability of aquatic species to the desert highlands’ harsh environment (Abdel-Fattah and Ali, 2005).

During the field work, the authors observed the natural and artificial destruction of the original vegetation, and thus, habitat restoration is urgently needed. The present study results provide a base for analyzing the vegetation-soil relationship at Taif highland, since the vegetation are significantly affected by soil characteristics (Gomaa 2012). This relationship was investigated on the Principal Component Analysis (PCA) ordination. The ordination results clarified that the bicarbonates, nitrates, magnesium, chlorides, calcium, and pH-value have the most significant effect on the plant communities. In line with this finding, Hamed et al. (2018) reported that the desert wetlands communities were positively correlated to Mg, Cl, and HCO₃.

5. Conclusion

The present study’s obtained results could fill some of the gaps regarding the flora, vegetation, and plant diversity of the desert-wetland ecosystems, southwestern Saudi Arabian highlands. A total of 142 species were identified in the wetlands and their surrounding deserts in Taif highlands. Therophytes’ dominance as a life form and monoregional taxa as a chorotype. By applying multivariate analyses, the vegetation zonation was clear, which started from real aquatic species in the wetlands passing through mixed vegetation in the slopes and ended with proper xerophytic vegetation in the terraces. The presence of many segetal weed species is an indicator of the critical status of the natural habitats of Taif highland, which suffer from the high rate of the human population expansion. Therefore, there is an urgent need to conserve desert-wetland habitats, which are threatened by urbanization and agricultural development. Consequently, the present study recommends avoiding further alteration in the wetland landscape and its buffer area and supplying the required water to the watershed’s wetlands.

6. Authors’ contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Tarek Galal, and Mohamed Fadl. The first draft of the manuscript was written by Hatim Al-Yasi and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.
Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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