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Original article

Climate change and hydrological regime in arid lands: Impacts of dams on the plant diversity, vegetation structure and soil in Saudi Arabia

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A B S T R A C T

As the direct effects of climate change on the hydrological regime, Saudi Arabia has constructed more than 522 dams of various capacities as part of economic and environmental development. The study aims to assess the impact of dams on plant diversity, vegetation structure and soil in Saudi Arabia. Thirty-five stands were selected from the dams of different sizes of Saudi Arabia. Vegetation samples were established before (upstream) and after (downstream) the dam, and at the undammed (unaffected by the dam) to compare species diversity in the dam sites and undammed sites and to document the potential effects of dams on vegetation structure. A total of 151 plant species belonging to 36 families have been recorded. The vegetation associations are essentially shrubby with widespread annuals. Six novel associations were identified with the application of TWINSPAN, DCA, and CCA programs. They were named after the characteristic species as follows: VG I: *Acacia gerrardii-Caralluma retrospiciens;* VGII: *Acacia tortilis-Maerua oblongifolia;* VGIII: *Lycium shawii-Farsetia aegyptiaca;* VG IV: *Farsetia stylosa-Cornulaca monocantha;* VG V: *Suaeda aegyptiaca-Salsola imbricata-Prosopis farcta* and VGVI: *Xanthium strumarium-Ochradenus baccatus*. These plant communities are evaluated and discussed according to their floristic structure, vegetation diversity and edaphic variables. The riparian or streamside zones upstream and downstream that are periodically flooded contain highly diverse plant communities that are structured by flooding, which creates disturbance and acts as a dispersal mechanism for plants than undammed sites.

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1. Introduction

Climate change is an essential component for strategic water resource management in arid and semi-arid countries, including Saudi Arabia. It is a well-known fact that climate change could eventually deepen the water resource crisis in water-scarce regions (Abu-Allaban et al., 2015, Attenborough 2020, Šulyová et al., 2021). The Saudi authorities have implemented many strategies to safeguard water resources sustainability, including valuation of available water resources, new dams construction, desalination plants construction for domestic water supply, drafting of water conservation regulations, as well as the design and eventual enforcement of water-saving measures in agriculture (Darfaoui and Al Assiri 2010, MEWA 2019). But still, the higher temperature and inconsistent rainfall patterns in the hyper-arid areas e.g. Saudi Arabia is creating confusion in developing sustainable water resource management strategies (Tarawneh and Chowdhury 2018). Climatic variations will affect the hydrological regime, water availability, and quality by increasing the frequency and severity of droughts and floods, rainfall variability, and higher temperatures (Luhunga et al., 2017). Boulange et al., (2021) reported the role played by dams in minimizing flood risk in the future in the context of global climate change by using a hybrid model, integrating the universal hydrological model with a new generation of universal hydrodynamics model, which is very important in the sustainability and saving of freshwater. In Saudi Arabia, there are 522 dams across the country with a total storage capacity of 2.304.390.647 Billion cubic meters (MEWA 2020) to

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collect, store, recharge runoff and control flash floods. Dams are of great importance in development projects implemented by the MEWA (Ministry of Environment, Water and Agriculture, Saudi Arabia) to support water sources and develop these resources to provide drinking water and irrigation. It is reported that for a dam reservoir in the southwest region of Saudi Arabia, the loss through surface evaporation was in the range of 4.7–6.0 m per year (Missimer et al., 2012).

At the same time, dams also have various adverse effects on the environment and community, both during construction and afterward, but the most catastrophic effects occur during the operational phase, which can span thousands of years. The extent of impact is mainly related with the location of the dam, height of dam, size of reservoir and water residence time. Dams' most prevalent effects are on water and air quality, aquatic ecology, land use, vegetation, and also on terrestrial animals (Alla and Liu 2021). The other major impacts include disturbance of wadi continuity, homogenization of habitats, downstream wadi bed incision, modification of wadi/groundwater exchange, downstream flow and water quality change, reduced water flow and silt deposition of wadi bed and the sediments carrying nutrients gets deposited in the reservoirs, the fertility of the land along the wadi gets reduced (Schmutz and Sendzimir 2018).

The vegetation is an important renewable natural resource on which the inhabitants of arid and semi-arid lands depend since ancient times. It meets most of the nutritional requirements of all living beings that live in their environment (Al-Nafi 2005).

The study of the impact of dams on vegetation has become a topic of scientific concern, especially during the past decades (Nilsson and Berggren 2000, New and Xie 2008). However, dam construction, despite its importance for agricultural production in semi-arid regions, can lead to a decrease in the diversity of vegetation (Chikodzi et al., 2013). Flood flows from dams also negatively affect ecosystems, especially plant reproduction for some species that may lead to their extinction (New and Xie 2008).

A dam's impact on biodiversity can be divided into upstream influences induced by confined water and downstream influences brought about by changes in stream flow and the quality water. According to some studies, dams generally reduce biodiversity because organisms, materials, and energy are hindered from crossing the dam, but the effects are greatly scale-dependent and will also reduce the complexity of types of vegetation as well as impact predominant vegetation in surroundings (Jansson 2006). Al-Sodany et al., (2015) on the other side, reported that the dams had no effect on plant diversity. In Saudi Arabia, investigations to examine the influence of dams on flora and vegetation are scarce. Sayed et al., (2020) studied the impact of the Wadi Jizan dam reservoir on its immediate ecosystems and local floristic diversity and deduced that the dam altered the sedimentation pattern, aided in the establishment of invasive aquatic plants, and caused changes in regional floristic diversity and distribution. As a result, the main goal of this study is to evaluate the influence of dams on the vegetation composition, species diversity and soil of dam sites in various regions of Saudi Arabia.

2. Materials and methods

2.1. Study location

Saudi Arabia has five distinct geological units. 1. The Arabian Shield, 2. The Arabian Platform, 3. The Tertiary and Quaternary harraat, 4. The Red Sea Coastal Plain and 5. The Major Sand Seas – Rub' al Khali and Nafud. Landform regions of Arabia can be divided into coastal plains, salt flats, or sabkhahs, wadis, deltas, desert islands, sand deserts, plateau, mountains, and scarp mountain regions (Fig. 1) (Edgell 2006).

2.2. Climate

The dominant air mass incursion over this region during winter is Polar Continental air which develops as an intense anticyclone over central Asia. High-pressure conditions give rise to dry stable air (Fig. 2) (Alrashed and Asif 2015). In summer, the high temperatures over the Peninsula lead to the development of Tropical Continental air which forms part of the Monsoon low circulation centered over north-west India. The air is very dry and the intense convection raises vast quantities of dust into the lower atmosphere and gives rise to poor visibility and generally hazy conditions. The summer heat over the Peninsula also draws in unstable Tropical Maritime Monsoon air from the Arabian Sea and the two tropical air masses merge at the Intertropical Convergence Zone (ITCZ). In winter, Polar Maritime air sometimes invades the Kingdom from the Mediterranean. Depressions embedded in this air mass often track across the desert plains of northern Saudi Arabia and give rise to much-needed rainfall. Four seasons are generally recognized in the Kingdom, although their distinctiveness varies from region to region. This is particularly true when comparing coastal locations such as Jeddah or Jizan with more continental locations such as Riyadh at 591 m a.sl.

2.3. Sampled stands

Five different dam sites were carried out located at the dams constructed in the wadis in the central (Riyadh and Al-Qassim), Western south (Bisha and Jizan) and northern regions (Hail) in Saudi Arabia (Fig. 1a). Vegetation samples were established before (upstream) and after (downstream) the dam, and at the undammed (unaffected by the dam) to compare species diversity in the dam sites and undammed sites and to document the potential effects of dams on vegetation structure (Fig. 1b). Thirty-five stands were selected from these five sample dam sites, during the spring season of 2018. Each stand was approximately 50 × 50 m, covering most of the plant species inside it (Table 1).

2.4. Floristic analysis

All the plants from the sampled stands were listed. Identification of the species and their chorotypes was carried out based on (Collenette 1998) and (Chaudhary 1999, 2000, 2001). The life forms of the collected species were determined (Raunkiaer 1934). The percentage of vegetation coverage for each plant species studied in each study site was estimated by following the abundance cover method, where it was estimated as a percentage (Kent 2011).

2.5. Soil analysis

Thirty five soil sample were collected from each stand at a depth of 0–30 cm and air dried and sieved into 2 mm. Soil organic matter was estimated by the soil ignition method (Dean 1974). Soil texture was determined by the hydrometer method (Bouyoucos 1962). Soil water extract was prepared (1:5), by dissolving 100 g air dried soil in 500 ml distilled water for estimation of pH and electrical conductivity (EC) as mS/cm using pH and Conductivity Meter (McLean 1983). Elemental analysis was performed to determine the concentrations of K, Ca, Mg, Na, Fe, Mn, and P through the Inductively Coupled Plasma Mass Spectrometry instrument (NexION 300D ICP-MS). The total nitrogen content in the samples was determined using the Micro-Kjeldahl method (AOAC 1980; Allen et al., 1974).

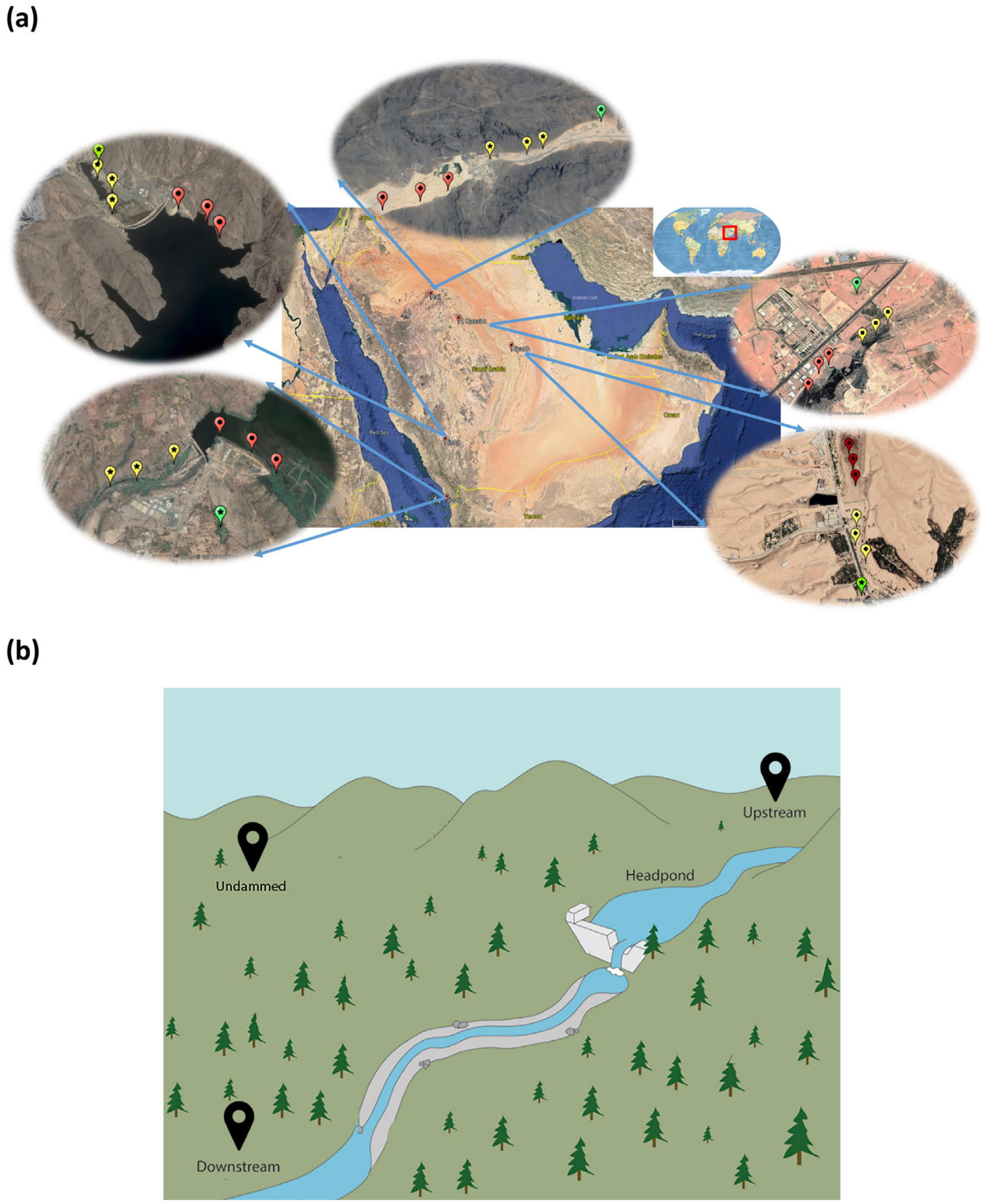

Fig. 1. (a) Main physiographic regions of the Arabian Peninsula with stand distribution "Google Earth", red labels indicate upstream stands, yellow labels indicate downstream stands, and green labels indicate undammed stands, (b) Diagram of the distribution of stands: Upstream, Downstream, and Undammed stands.

2.6. Vegetation data analysis

The calculated plant coverage values for all plant species in all sites studied were subjected to multivariate analysis using the TWINSPAN program and the DECORANA ordination program, according to the methods mentioned by (Hill 1979a, Hill 1979b) to highlight the key plant communities in the area of research. The CANOCO software was then used to identify the most relevant environmental factors that influence the distribution of plant populations in the research region based on the plant species cover, diversity indices, and soil parameters (Ter Braak and Smilauer 2002). Species richness (α-diversity) was calculated as the average number of species/stands. Species relative evenness was calculated by Shannon-Wiener index $\hat{H}$ = -$\sum_{i=1}^{s} p_i \log p_i$, and the relative concentration of dominance was expressed by Simpson index C = $\sum_{i=1}^{s} p_i^2$ where (s) is the number of species and (P*i*) is the relative cover value of the *i*-th species (Pielou 1975, Magurran 1988, 2004).

2.7. Statistical analysis

The Pearson's correlation coefficient (r) was used to examine the relationship between coordination axes on the one hand and soil variables and plant communities on the other. The difference in plant diversity, site characteristics and soil variables of plant populations was also evaluated by analyzing one-way ANOVA, then applying correlation and analyzing the variations in the plant communities and prevailing environmental -variables by the SPSS Program.

3. Results

3.1. Floristic composition, life forms spectra, and biogeographic affinities

The surveyed sites yielded a total of 151 plant species from 117 genera and 36 families (Table 2). The highest number of plant spe-

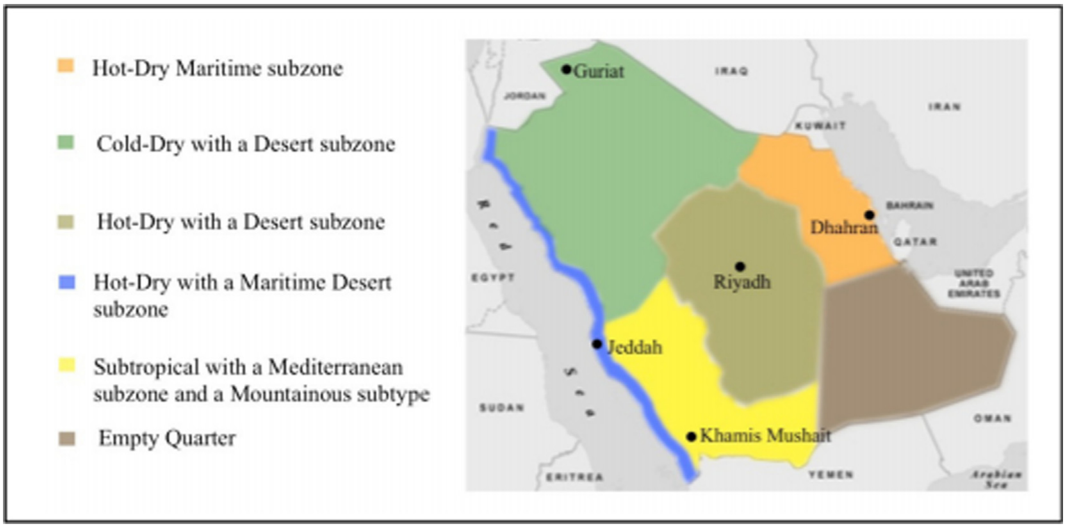

Fig. 2. The climatic zones in Saudi Arabia after (Alrashed and Asif 2015).

Table 1
The distribution of study samples and their locations.

No:	Dam Site	GPS Location	Stand no.
1	Riyadh	24°46′29.2″N 46°31′52.7″E	1,2,3,4,5,6,7
2	Hail	26°49′19.2″N 41°36′08.5″E	22,23,24,25,26,27,28
3	Bisha	19°41′46.2″N 42°29′14.4″E	8,9,10,11,12,13,14,
4	Jizan	17°02′56.5″N 42°57′27.5″E	15,16,17,18,19,20,21
5	ALQassim	26°11′57.2″N 44°01′24.7″E	29,30,31,32,33,34,35

cies were represented in the pre-dam site (upstream) with 108 species (71.5%), followed by the post-dam site (downstream) with 107 species (70.8%), and the lowest number was in the unaffected site (undammed) with 36 species (23.8%), Among the 36 represented families, Poaceae was the most dominant with 23 species (15.2%) followed by Asteraceae (12.5%), Fabaceae (10%), Chenopodiaceae (8%), Brassicaceae (6.6%) and Boraginaceae (5.2%). Annuals (39.74%) represented the main floristic group followed by perennial herbs (18.54%), shrubs (15.23%), sub-shrubs (8.61%), annual and perennial grasses (7.28% each) and trees (3.31%). Chorological analysis of the species in the study area revealed that monoregional elements have dominant representation with 87 species (57.62%) belonging to (SA), followed by biregionals with 24 species (27.81%), having representatives of SA-IT and SA-SM elements, while the pluriregional elements have the lowest number with only 22 species (14.57%) of which SA-IT- Med were dominated.

3.2. Plant associations

TWINSPAN was applied to divide and determine the composition of the plant communities based on the coverage of 151 plant species from 35 sites. The plant communities were separated at the fourth level of the TWINSPAN Program (Fig. 3a; Table 3; Table 4). Six plant communities i.e. associations were obtained and were named according to the dominant plants with the highest value for presence and coverage as follows: VGI: *Acacia gerrardii-Caralluma retrospiciens*; VG II: *Acacia tortilis-Maerua oblongifolia;* VGIII: *Lycium shawii-Farsetia aegyptiaca*; VGIV: *Farsetia stylosa-Cornulaca monocantha;* VG V: *Suaeda aegyptiaca-Salsola imbricata-Prosopis farcta* and VGVI: *Xanthium strumarium-Ochradenus baccatus.* The application of DCA confirmed the separation among these communities. A Detrended Correspondence Analysis (DCA) also confirmed the separation of the same six vegetation groups, by placing them along two primary axes AX1 and AX2 (Fig. 3b).

3.3. The relationship between the distribution of the designated sites and soil characteristics

There was a definite relation between sites distribution and environmental variables along the AX1 axis (Fig. 4, Table 5), where

Table 2
Composition of plant species and families, genera, life forms and biogeographic affinities in the dam locations.

Floristic variables	Upstream- site		downstream site		Undammed site		Total	
	No.	%	No.	%	No.	%	No.	%
Floristic Diversity Species number	108.0	71.5	107.0	70.8	36.0	23.8	151.0	–
Family number	33.0	91.6	28.0	77.7	18.0	50.0	36.0	–
Genera number	90.0	76.9	86.0	73.5	32.0	27.3	117.0	–
Life form Annual herb	47.0	78.3	44.0	73.3	13.0	21.6	60.0	39.74
Annual grass	8.0	72.7	10.0	90.9	1.0	9.09	11.0	7.28
Perennial grass	7.0	63.6	7.0	63.6	1.0	9.09	11.0	7.28
Perennial herb	17.0	60.71	17.0	60.71	8.0	28.5	28.0	18.54
Shrub	14.0	60.86	15.0	65.21	9.0	39.13	23.0	15.23
Sub-shrub	11.0	84.61	10.0	76.9	1.0	7.69	13.0	8.61
Tree	4.0	80.0	4.0	80.0	3.0	60.0	5.0	3.31
Chorological distribution Monoregional elements	58.0	53.7	61.0	57.01	19.0	52.78	87.0	57.62
Biregional elements	33.0	30.56	30.0	28.84	13.0	36.11	24.0	27.81
Pleuriregional elements	17.0	15.74	16.0	14.95	4.0	11.11	22.0	14.57

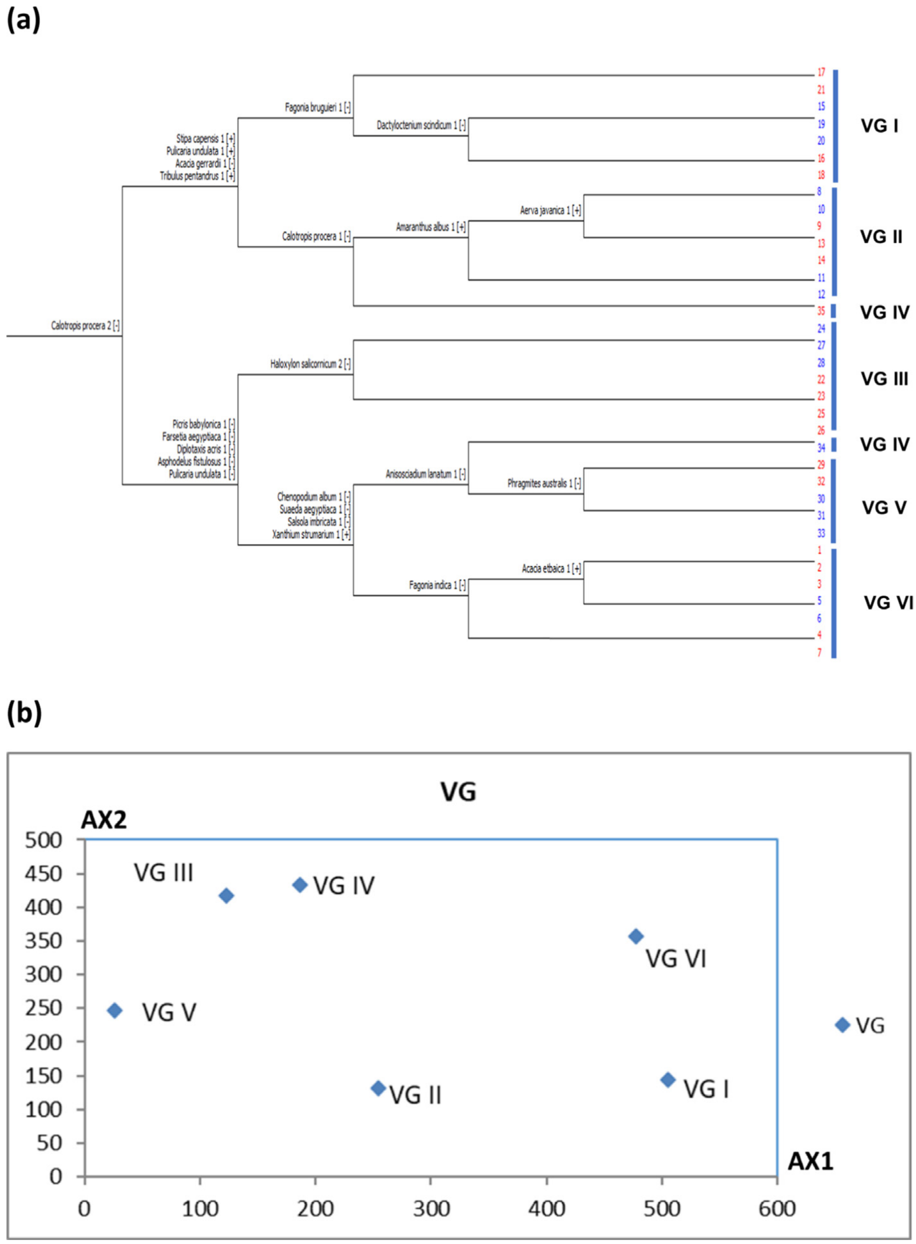

Fig. 3. Analysis of the cross-division of plant species in TWINSPAN program (a) and conifrmed by DECOARNA program (b). The six vegetation groups are: VGI: *Acacia gerrardii; Caralluma retrospiciens* VG II: *Acacia tortilis -Maerua oblongifolia;* VG III: *Lycium shawii - Farsetia aegyptiaca*; VG IV: *Farsetia stylosa-Cornulaca monocantha;* VG V: *Suaeda aegyptiaca-Salsola imbricata- Prosopis farcta* and VG VI: *Xanthium strumarium-Ochradenus baccatus.*

the values of sand, EC, Ca, Fe and species richness were positively correlated by (r = 0.50, 0.62, 0.81, 0.75, 0.50), respectively. While the silt ratio was negatively correlated with the AX1 axis by (r = −0.54). Na (r = 0.43) was correlated positively with the AX2 axis while Shannon (r = −0.42) was correlated negatively with that axis.

3.4. The relationship of plant distribution correlation with soil variables

The woody plants in the upper negative left side of the axis AX1 were associated with values of clay, Silt, O.M., and Simpson, and these plants include *Acacia gerrardii*, *Heliotropium curasavicum*, *Lawsonia inermis* and *Acacia oerfota* (Fig. 5). Xerophytes plant at the upper positive right-hand side of the axis AX1 were associated with K, Na, Ca, Fe, Mg and EC, and among these plants were *Echinops spinosissimus*, *Lepidium aucheri* and *Spergularia diandra*. Psammophytes located in the lower negative right of the axis AX2 were also associated with sand, soil pH, Shannon and species richness and the number of Total plant species such as *Rumex vesicarius*, *Aizoon canariense*, *Lycium shawii*, *Zilla spinosa*, and *Emex spinosa.* While, the ruderal plants located at the negative left side of the axis AX2 were associated with N, P species evenness, and total cover (e.g. *Xanthium strumarium* subsp. *brasilicum*, *Haloxylon salicornicum*, *Citrullus colocynthis*, *Teucrium polium*, and *Aristida adscensionis*).

3.5. The relationship of the diversity indices with soil factors

A correlation analysis matrix confirms the relationships between diversity indices and edaphic factors (Table 6). It was found that the total species number was correlated positively with pH (r = 0.436), and the total plant cover was negatively correlated with clay (r = 0.362). While the species richness was positively cor-

Table 3
Synoptic table of plant species in six vegetation clusters after the application of TWINSPAN. The six vegetation groups are: VGI: *Acacia gerrardii-Caralluma retrospiciens;* VG II: *Acacia tortilis-Maerua oblongifolia;* VG III: *Lycium shawii-Farsetia aegyptiaca*; VG IV: *Farsetia stylosa-Cornulaca monocantha;* VG V: *Suaeda aegyptiaca-Salsola imbricata- Prosopis farcta* and VG VI: *Xanthium strumarium-Ochradenus baccatus.*

Group No.	Family	Life form	Chorotype	1	2	3	4	5	6
No. of relevés				**7**	**7**	**7**	**2**	**6**	**6**
Acacia gerrardii	**Fabaceae**	**SA**	**Tree**	**82.2**	**–**	**–**	**–**	**–**	**–**
Caralluma retrospiciens	**Asclepiadaceae**	**SA + SZ**	**Perennial herb**	**72.5**	–	–	–	–	–
Dactyloctenium scindicum	Poaceae	TR	Perennial grass	72.5	–	–	–	–	–
Setaria verticillate	Poaceae	TR	Annual grass	72.5	–	–	–	–	–
Blepharis ciliaris	Acanthaceae	SA-IT	Perennial herb	72.5	–	–	–	–	–
Cenchrus ciliaris	Poaceae	SA	Perennial grass	62	–	–	–	–	–
Aerva lanata	Amaranthaceae	SA-SI-SZ	Perennial herb	62	–	–	–	–	–
Trianthema triquetra	Aizoaceae	Med-SA-IT	Annual herb	62	–	–	–	–	–
Senna alexandrina	Fabaceae	SM	Shrub	50	–	–	–	–	–
Ochthochloa compressa	Poaceae	SM	Perennial grass	50	–	–	–	–	–
Stipagrostis uniplumis	Poaceae	SA	Perennial grass	50	–	–	–	–	–
Eleusine indica	Poaceae	TR	Annual herb	50	–	–	–	–	–
Salvadora persica	Salvadoraceae	SM	Shrub	50	–	–	–	–	–
Chloris barbata	Poaceae	SM	Annual grass	50	–	–	–	–	–
Prosopis juliflora	Fabaceae	AM	Tree	50	–	–	–	–	–
Sporobolus spicatus	Poaceae	SA-IT-EA	Perennial grass	34.9	–	–	–	–	–
Indigofera spinosa	Fabaceae	SA	Shrub	34.9	–	–	–	–	–
Sesuvium portulacustrum	Aizoaceae	TR	Perennial herb	34.9	–	–	–	–	–
Cissus rotundifolius	Vitaceae	TR-AF	Perennial herb	34.9	–	–	–	–	–
Indigofera semtrijuga	Fabaceae	SM	Perennial herb	34.9	–	–	–	–	–
Acacia oerfota	Fabaceae	TR- AF	Shrub	34.9	–	–	–	–	–
Scoparia dulcis	Scrophulariacea	TR	Perennial herb	34.9	–	–	–	–	–
Zaleya pentandra	Aizoaceae	SM	Perennial herb	34.9	–	–	–	–	–
Dactyloctenium aegyptium	Poaceae	TR	Perennial grass	34.9	–	–	–	–	–
Abutilon bidentatum	Malvaceae	SA	Subshrub	34.9	–	–	–	–	–
Lawsonia inermis	Lythraceae	SU-ZA	Tree	34.9	–	–	–	–	–
Tephrosia nubica	Fabaceae	TR-AF	Perennial herb	7.3	50.8	–	–	–	–
Tribulus pentandrus	**Zygophyllaceae**	**SM**	**Annual herb**	**–**	**91.3**	**–**	**–**	**–**	**–**
Calotropis procera	**Asclepiadaceae**	**SM**	**Shrub**	**27.8**	**70**	**–**	**–**	**–**	**–**
Conyza bonariensis	Asteraceae	TR-AM	Annual herb	–	62	–	–	–	–
Lotus arabicus	Fabaceae	SA-SI-SU-ZA	Annual herb	–	62	–	–	–	–
Acacia tortilis	Fabaceae	SA	Shrub	–	62	–	–	–	–
Chloris virgata	Poaceae	TR	Annual grass	–	50	–	–	–	–
Maerua oblongifolia	Capparaceae	SU	Shrub	–	50	–	–	–	–
Ricinus communis	Euphorbiaceae	SA-SM	Shrub	–	50	–	–	–	–
Retama raetam	Fabaceae	SA	Shrub	–	50	–	–	–	–
Amaranthus albus	Amaranthaceae	AM	Annual herb	–	50	–	–	–	–
Verbesina encelioides	Poaceae	AM	Annual herb	–	50	–	–	–	–
Xanthium brasilicum	Asteraceae	EU-Med	Annual herb	–	50	–	–	–	–
Heliotropium curasavicum	Boraginaceae	AM	Perennial herb	–	34.9	–	–	–	–
Anticharis linearis	Scrophulariacea	SA-IT	Annual herb	–	34.9	–	–	–	–
Portulaca oleraceae	Portulacaceae	COSM	Annual herb	–	34.9	–	–	–	–
Indigofera oblongifolia	Fabaceae	SM	Shrub	–	34.9	–	–	–	–
Moltkiopsis ciliate	Boraginaceae	SM	Subshrub	–	34.9	–	–	–	–
Gypsophila capillaris	Caryophyllaceae	SA	Annual herb	–	34.9	–	–	–	–
Cleome amblyocarpa	Cleomaceae	SA	Perennial herb	–	34.9	–	–	–	–
Rumex dentatus	Polygonaceae	Med-IT-ES	Annual herb	–	34.9	–	–	–	–
Typha domingensis	Typhaceae	Med -IT-SA	Perennial Shrub	–	34.9	–	–	–	–
Echinops spinosissimus	Asteraceae	SA	Perennial herb	–	34.9	–	–	–	–
Pluchea dioscoridis	Asteraceae	SA-SI-SZ	Shrub	–	34.9	–	–	–	–
Datura stramonium	Solanaceae	AM	Annual herb	–	34.9	–	–	–	–
Digitaria ciliaris	Poaceae	TR	Annual grass	–	34.9	–	–	–	–
Heliotropium longiflorum	Boraginaceae	SM	Perennial herb	–	34.9	–	–	–	–
Echinochloa colona	Poaceae	TR	Annual grass	–	34.9	–	–	–	–
Zilla spinosa	**Brassicaceae**	**EU-Med-IT**	**Shrub**	**–**	**–**	**81.6**	**–**	**–**	**–**
Picris babylonica	**Asteraceae**	**SA**	**Annual herb**	**–**	**–**	**82.2**	**–**	**–**	**–**
Diplotaxis acris	Brassicaceae	Med-IR-TR	Annual herb	–	–	82.2	–	–	–
Sclerocepalus arabicus	Caryophyllaceae	SA-IT	Annual herb	–	–	82.2	–	–	–
Asphodelus fistulosus	Asphodelaceae	Med	Perennial herb	–	–	82.2	–	–	–
Spergula fallax	Caryophyllaceae	SA	Annual herb	–	–	82.2	–	–	–
Isatis lusitanica	Brassicaceae	Med-IT	Annual herb	–	–	72.5	–	–	–
Calandula arvensis	Asphodelaceae	Med-IT	Annual herb	–	–	62	–	–	–
Centaurea pseudosiniaca	Asteraceae	SA	Annual herb	–	–	62	–	–	–
Echinops glaberrimus	Asteraceae	SA	Perennial herb	–	–	50	–	–	–
Rostraria pumila	Poaceae	Med-SA-SI	Annual grass	–	–	50	–	–	–
Emex spinosa	Polygonaceae	IT	Annual herb	–	–	50	–	–	–
Echium rauwolfia	Boraginaceae	SZ	Annual herb	–	–	50	–	–	–
Chenopodium murale	Chenopodiaceae	SA-IT	Annual herb	–	–	50	–	–	–
Paronychia arabica	Caryophyllaceae	TR- AF	Annual herb	–	–	50	–	–	–
Trichodesma Africana	Boraginaceae	SA	Subshrub	–	–	50	–	–	–
Notoceros bicorne	Brassicaceae	SA	Annual herb	–	–	50	–	–	–

(*continued on next page*)

Table 3 (*continued*)

Group No.	Family	Life form	Chorotype	1	2	3	4	5	6
Tribulus terrestris	Zygophyllaceae	SA-SM	Annual herb	–	–	50	–	–	–
Teucrium polium	Lamiaceae	SA	Subshrub	–	–	34.9	–	–	–
Plantago ciliate	Plantaginaceae	SA	Annual herb	–	–	34.9	–	–	–
Aizoon canariense	Aizoaceae	SM	Annual herb	–	–	34.9	–	–	–
Parietaria alsinifolia	Urticaceae	Med	Annual herb	–	–	34.9	–	–	–
Lycium shawii	Solanaceae	SA	Shrub	–	–	34.9	–	–	–
Plantago ovata	Plantaginaceae	SA-IT	Annual herb	–	–	34.9	–	–	–
Aristida adscensionis	Poaceae	Med-IT-SA	Perennial grass	–	–	34.9	–	–	–
Anvillea garcinia	Asteraceae	SA	Subshrub	–	–	34.9	–	–	–
Acacia ehrenbergiana	Fabaceae	SM	Shrub	–	–	34.9	–	–	–
Salvia deserti	Lamiaceae	SA	Subshrub	–	–	34.9	–	–	–
Farsetia stylosa	**Brassicaceae**	**SA**	**Perennial herb**	**–**	**–**	**–**	**100**	**–**	**–**
Launaea nudicaulis	**Asteraceae**	**SA-SI-IR-TR**	**Annual herb**	**–**	**–**	**–**	**100**	**–**	**–**
Plantago boissieri	Plantaginaceae	SA-SM	Annual herb	–	–	–	100	–	–
Cornulaca monocantha	Chenopodiaceae	SA-SI	Shrub	–	–	–	100	–	–
Polycarpae repens	Caryophyllaceae	SH-SM	Perennial herb	–	–	–	100	–	–
Eragrostis barrelieri	Poaceae	SM	Perennial grass	–	–	–	80	–	–
Suaeda aegyptiaca	**Chenopodiaceae**	**SA**	**Annual herb**	**–**	**–**	**–**	**–**	**89.8**	**–**
Salsola imbricata	**Chenopodiaceae**	**SA**	**Subshrub**	**–**	**–**	**–**	**–**	**89.8**	**–**
Chenopodium album	Chenopodiaceae	TR	Annual herb	–	–	–	–	89.8	–
Spergularia diandra	Caryophyllaceae	Med-IT-Eu	Annual herb	–	–	–	–	79.1	–
Cressa cretica	Convolvulaceae	PAL	Annual herb	–	–	–	–	79.1	–
Chenopodium glaucum	Chenopodiaceae	Med	Annual herb	–	–	–	–	79.1	–
Bassia eriophora	Chenopodiaceae	SA-SM	Annual herb	–	–	–	–	79.1	–
Tetraena simplex	Zygophyllaceae	SM	Annual herb	1	–	–	–	69.6	–
Polypogon monospeliensis	Poaceae	Med-IT-SA	Annual grass	–	–	1	–	69.6	–
Lactuca serriola	Asteraceae	Med-IT- Eu	Subshrub	–	–	–	–	67.4	–
Oligomeris linifolia	Resedaceae	Med-SA-SZ	Annual herb	–	–	–	–	67.4	–
Senecio flavus	Asteraceae	SA-IT	Annual herb	–	–	–	–	67.4	–
Prosopis farcta	Fabaceae	SS-IT	Shrub	–	–	–	–	54.2	–
Mesembryanthemum nodiflorum	Aizoaceae	Med-SA-Eu	Annual herb	–	–	–	–	54.2	–
Lolium rigidum	Poaceae	Med-IT	Annual grass	–	–	–	–	54.2	–
Phragmites australis	Poaceae	Med-IT-SA	Perennial grass	–	–	–	–	54.2	–
Diplotaxis harra	Brassicaceae	SA	Annual herb	–	–	–	–	37.8	–
Suaeda vermiculata	Chenopodiaceae	SA	Perennial herb	–	–	–	–	37.8	–
Lepidium aucheri	Brassicaceae	IR-TR	Annual herb	–	–	–	–	37.8	–
Fumaria parviflora	Papaveraceae	Med	Annual herb	–	–	–	–	37.8	–
Heliotropium aegyptiacum	Boraginaceae	SA	Subshrub	–	–	–	–	37.8	–
Conyza stricta	Asteraceae	SA-TR-IT	Perennial herb	–	–	–	–	37.8	–
Trigonella anguina	Fabaceae	SA	Annual herb	–	–	–	–	37.8	–
Frankenia pulverulenta	Frankeniaceae	ES-Med-IT	Annual herb	–	–	–	–	37.8	–
Asphodelus tenuifolius	Asphodelaceae	SA-SM	Annual herb	–	–	–	–	37.8	–
Gastrocotyle hispida	Boraginaceae	SA-IT	Annual herb	–	–	–	–	37.8	–
Xanthium strumarium	**Asteraceae**	**EU-Med**	**Annual herb**	**–**	**–**	**–**	**–**	**–**	**81.3**
Ochradenus baccatus	**Resedaceae**	**SA-SM**	**Shrub**	**–**	**–**	**–**	**–**	**–**	**79.1**
Salsola cyclophylla	Chenopodiaceae	SA	Shrub	–	–	–	–	–	54.2
Atriplex halimus	Chenopodiaceae	Med-SA-SI-TR	Shrub	–	–	–	–	–	54.2
Panicum maximum	Poaceae	TR-EA	Perennial grass	–	–	–	–	–	54.2
Carthamus oxycantha	Asteraceae	SA	Subshrub	–	–	–	–	–	37.8
Tribulus macropterus	Zygophyllaceae	TR AF	Subshrub	–	–	–	–	–	37.8
Avena fatua	Poaceae	Med	Annual grass	–	–	–	–	–	37.8
Cuscuta campestris	Cuscutaceae	AM	Annual herb	–	–	–	–	–	37.8
Echinops erinaceus	Asteraceae	IT	Perennial herb	–	–	–	–	–	37.8
Zygophyllum coccineum	Zygophyllaceae	SA	Perennial herb	–	–	–	–	–	37.8
Catapodium rigidum	Poaceae	Med	Annual grass	–	–	–	–	–	37.8
Heliotropium bacciferum	Boraginaceae	SA	Subshrub	–	–	26.8	–	–	33.8
Cynadon dactylon	Poaceae	SA-IT	Perennial grass	–	18.5	–	–	–	23.3
Fagonia indica	Zygophyllaceae	SA	Perennial herb	–	–	–	–	34.5	53.4
Acacia etbaica	Fabaceae	SM	Tree	1	–	–	–	–	69.6
Capparis spinosa	Capparaceae	SA-IT	Shrub	–	–	–	–	20	60
Pulicaria incisa	Asteraceae	SA-SZ	Perennial herb	–	–	5.2	–	–	56.8
Tamarix nilotica	Tamaricaceae	SA	Shrub	5.2	–	–	–	–	56.8
Citrullus colocynthis	Cucurbitaceae	SA	Perennial herb	–	16.9	16.9	–	2	2
Anisosciadium lanatum	Apiaceae	SA	Annual herb	–	–	35.6	–	15.5	–
Polygonum argyrocoleon	Polygonaceae	IR-TR	Annual herb			2.0	16.7	2.0	0.17
Forsskaolea tenacissima	Urticaceae	SA-SM	Perennial herb	–	29.9	13.1	–	–	–
Malva parviflora	Malvaceae	SA-SM	Annual herb	–	–	2.2	54.2	23.9	–
Caylusea hexagyna	Resedaceae	SH-SM	Shrub	–	20	20	–	–	–
Solanum nigrum	Solanaceae	SM	Annual herb	–	18.5	–	–	23.3	–
Bassia muricata	Chenopodiaceae	SA	Annual herb	–	–	10.5	–	42	–
Anastatica hierochuntica	Brassicaceae	SA	Annual herb	–	–	71.7	–	2.5	–
Rumex vesicarius	Polygonaceae	SA	Annual herb	–	–	45.9	–	37.5	–
Sisymbrium irio	Brassicaceae	Med-SA	Annual herb	–	–	40.3	–	50.9	–
Stipa capensis	Poaceae	SA-SM	Annual grass	–	50	50	–	–	–
Fagonia bruguieri	Zygophyllaceae	SM	Perennial herb	4.6	34.4	19.5	–	–	–

Table 3 (*continued*)

Group No.	Family	Life form	Chorotype	1	2	3	4	5	6
Tamarix aphylla	Tamaricaceae	Med	Tree	3.3	32.6	–	–	42.4	–
Haloxylon salicornicum	Chenopodiaceae	SA	Shrub	–	–	31.5	75.1	–	–
Aerva javanica	Amaranthaceae	TR	Perennial herb	17	46	17	–	–	–
Farsetia aegyptiaca	Brassicaceae	SH-SM-SA	Subshrub	–	–	42.4	70.7	–	–
Pulicaria undulata	Asteraceae	SA-SM	Perennial herb	–	41.9	55.9	–	–	–

Table 4

The percentage of presence and coverage of plants prevalent in the plant associated with the number of sites according to the TWINSPAN program (C = coverage, P = presence). The six vegetation groups are: VGI: *Acacia gerrardii; Caralluma retrospiciens* VG II: *Acacia tortilis-Maerua oblongifolia;* VG III: *Lycium shawii-Farsetia aegyptiaca*; VG IV: *Farsetia stylosa-Cornulaca monocantha;* VG V: *Suaeda* aegyptiaca-*Salsola imbricata Prosopis farcta* and VG VI: *Xanthium strumarium-Ochradenus baccatus.* Significant levels are *P ≤ 0.05, **P ≤ 0.01, ***P ≤ 0.001. Up: Upstream, Do: Downstream and Un: Undammed.

VG	Total stand	Stand no. %	Stands	Habitat %	1st dominant sp	C	P%	2nd dominant sp	C	P%
VG I	7	20	15, 16, 17, 18, 19, 20,21	Up = 42.85 Do = 42.85 Un = 14.28	*Acacia gerrardii*	11	57.1	*Caralluma retrospiciens*	0.6	57.1
VG II	7	20	8, 9, 10, 11,12,13,14	Up = 42.85 Do = 42.85 Un = 14.28	*Acacia tortilis*	1.0	42.9	*Maerua oblongifolia*	4.0	28.6
VG III	7	20	22,23,24, 25,26,27,28	Up = 42.85 Do = 42.85 Un = 14.28	*Lycium shawii*	0.1	14.3	*Farsetia aegyptiaca*	1.6	71.4
VG IV	2	6	34, 35	Do = 50.00 Un = 50.00	*Farsetia stylosa*	0.5	50	*Cornulaca monocantha*	0.5	50
VG V	5	14	29, 30, 31, 32, 33	Up = 60.00 Do = 40.00	*Suaeda aegyptiaca*	5	83.3	*Salsola imbricata*	2.7	83.3
VG VI	7	20	1, 2, 3, 4, 5, 6,7	Up = 42.85 Do = 42.85 Un = 14.28	*Xanthium strumarium*	6.6	100	*Ochradenus baccatus*	1.0	66.7

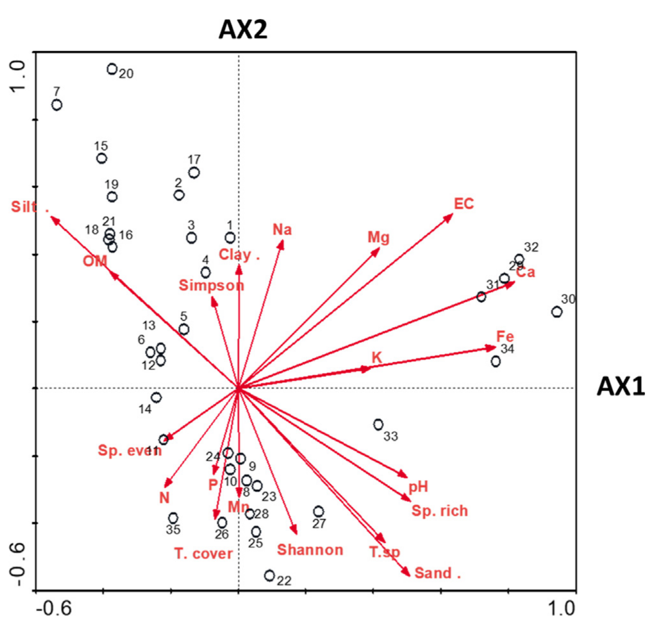

Fig. 4. The relationship of the studied sites distribution in dams to soil factors, CCA ordination.

related with sand, pH, and Fe (r = 0.336, 0.668, 0.385), respectively, and a negative correlation was observed with silt (r = –0.377). The species evenness has a negative correlation with P (r = 0.430). The Shannon index has shown a positive correlation with pH (0.477), while the Simpson index was associated negatively with pH (r = –0.420) and Fe (r = –0.35) content.

3.6. Soil properties of plant associations

The plant community of VGI: *Acacia gerrardii-Caralluma retrospiciens* community characterized by the high percentage of silt (32.84%) and Simpson index (0.22), while the low values were K, Mn, species richness and Shannon index values (3.58, 0.002, 2.08, 0.002) respectively (Table 7). The *Acacia tortilis-Maerua oblongifolia* community VG II had the high values of species cover (208.57 m/100 m), while the low value was recorded with clay (8.34%) and pH (7.29). *Lycium shawii-Farsetia aegyptiaca* VG III had the high values of pH, total plant species, the species richness, species evenness and Shannon index (8.37, 17.75, 4.00, 0.91, 1.11), respectively, while the EC, Ca, Mg, and Simpson index had the lowest values of (0.12, 9.58, 2.06, 0.08), respectively. The plant community of *Farsetia stylosa- Cornulaca monocantha* VG IV had the high values in the sand, EC, Na, Ca, K, Mg, N and P (82.40, 1.92, 74.82, 247.92, 57.72, 30.39,10.30, 2.93) respectively, while the low values of it were O.M., silt and species evenness (1.72, 5.15, 0.77), respectively. Finally, the community dominated by *Xanthium strumarium-Ochradenus baccatus* VG VI had high contents of O.M. (3.36%), and clay (19.41%), while sand, Na, Fe, P, and the total number of species had the lowest values (54.72, 6.68, 0.40, 0.04, and 9.33), respectively.

4. Discussion

Climate change, population growth, and other anthropogenic factors have increased global demand for water, particularly in arid zones. Dam construction is one of the main strategies for storing and protecting runoff water for consumption and agricultural needs. Despite these socioeconomic roles, desert reservoirs fell into controversy because of their complex impact on desert ecosystems such as their influence over climate, ability to modify sedimenta-

Table 5
The Person simple correlation coefficient (r) between environmental variables and DCA axes. The significant values are in bold, * p ≤ 0.05, **p ≤ 0.01, *** p ≤ 0.001.

NAME	AX1	AX2	AX3	AX4
O.M. %	−0.3771	0.3403	0.2128	0.0396
Silt %	**−0.5486****	**0.4987***	−0.0697	−0.0321
Sand %	**0.5028****	**−0.5434****	−0.0729	−0.0796
Clay %	0.0014	0.3603	0.5733	0.4568
E.C. mS/cm	**0.6284****	**0.5062****	−0.1037	−0.1672
pH	**0.4956***	−0.2562	0.5891	−0.3763
Na mg/L	0.1302	**0.4329***	−0.2062	−0.2641
Ca mg/L	**0.8106****	0.3096	−0.1477	−0.0564
K mg/L	0.3881	0.0593	0.1323	−0.1878
Fe mg/L	**0.7537*****	0.1214	0.0472	−0.1572
Mg mg/L	**0.4139***	**0.4086***	−0.0561	−0.1706
Mn mg/L	0.0025	−0.3164	0.4068	−0.285
N mg/L	−0.2172	−0.2869	0.0994	−0.0257
P mg/L	−0.0736	−0.2497	0.2549	−0.2856
Total no. of species.	**0.4289***	**−0.4453***	0.2083	−0.2577
Total cover %	−0.0687	−0.3805	−0.6517	0.0464
Sp. Richness	**0.5042****	−0.3263	0.5097	−0.2646
Sp. Evenness	−0.2183	−0.1505	0.3026	−0.0404
Shannon-H	0.1711	**−0.4236***	0.2395	−0.21
Simpson-(C)	−0.0766	0.2676	−0.1862	0.1244

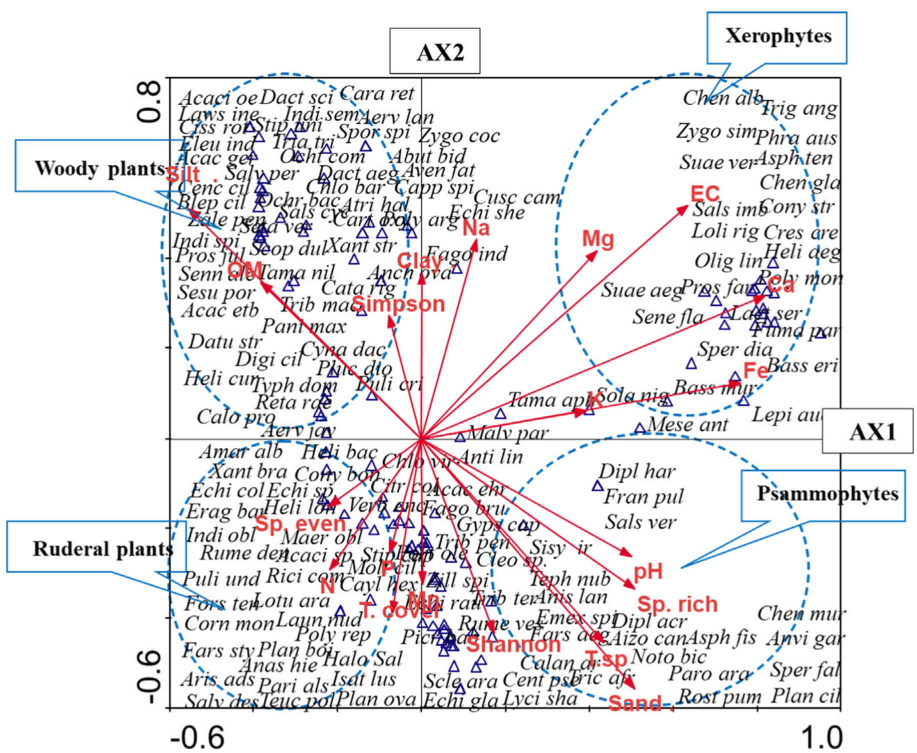

Fig. 5. The relationship of plant species distribution to soil factors that have a significant effect of the direct coordination axes (CCA ordination). For compelate species name see Table 2.

Table 6
Correlation between diversity indices and soil factors. The significant values are in bold, * p ≤ 0.05, **p ≤ 0.01, *** p ≤ 0.001.

Name	O.M. (%)	Silt (%)	Sand (%)	Clay (%)	EC (mS/cm)	pH	Na (mg/L)	Ca (mg/L)	K (mg/L)	Fe (mg/L)	Mg (mg/L)	Mn (mg/L)	N (mg/L)	P (mg/L)
Total no. of species	−0.226	−0.302	0.327	−0.248	0.083	**0.436****	−0.024	0.193	0.059	0.175	0.070	0.032	−0.054	−0.044
Total. Cover (m /100 m)	−0.219	0.028	0.089	**−0.362***	−0.071	−0.251	0.024	−0.034	−0.149	−0.140	−0.048	−0.179	−0.056	−0.066
Sp.richness	−0.154	**−0.38***	**0.336***	−0.075	0.146	**0.668****	−0.017	0.293	0.134	**0.385***	0.115	0.213	0.002	−0.065
Sp. evenness	0.176	0.038	−0.045	0.044	−0.040	0.310	−0.019	0.072	−0.294	0.252	−0.077	0.238	−0.080	**−0.43**
Shannon H	−0.088	−0.224	0.236	−0.162	0.064	**0.477****	0.021	0.194	−0.072	0.278	0.045	0.156	−0.061	−0.228
Simpson-(C)	−0.037	0.106	−0.114	0.082	−0.089	**−0.42***	−0.075	−0.195	0.138	**−0.35***	−0.063	−0.237	0.047	0.298

Table 7
Mean and ± standard deviation results of one-way ANOVA summarizing the attributes of each of the six vegetation types according to various environmental and edaphic variables.

Factor	VG1	VG2	VG3	VG4	VG5	VG6	Total Mean	F- value
O. M. (%)	3.15 ± 1.67	1.94 ± 0.91	1.82 ± 1.00	**1.72** ± 0.58	2.18 ± 1.79	**3.36** ± 1.92	2.43 ± 1.50	1.337
Silt (%)	**32.84** ± 17.29	17.75 ± 13.37	9.53 ± 6.58	**5.15** ± 5.76	6.38 ± 3.17	25.87 ± 17.58	17.85 ± 15.63	4.339^{**}
Sand (%)	54.86 ± 17.44	73.91 ± 14.62	79.28 ± 6.76	**82.40** ± 11.31	81.28 ± 4.83	**54.72** ± 27.16	69.63 ± 18.86	3.793^{**}
Clay (%)	12.30 ± 3.61	**8.34** ± 1.53	11.19 ± 1.00	12.45 ± 5.56	12.34 ± 2.81	**19.41** ± 10.70	12.52 ± 5.84	3.287^{**}
EC (mS/cm)	0.93 ± 0.84	0.36 ± 0.24	**0.12** ± 0.04	**1.92** ± 1.44	1.54 ± 1.16	0.35 ± 0.22	0.72 ± 0.86	4.875^{**}
pH	7.32 ± 0.19	**7.29** ± 0.14	**8.37** ± 0.16	8.04 ± 0.13	8.23 ± 0.37	7.32 ± 0.13	7.72 ± 0.53	36.237^{***}
Na (mg/L)	49.16 ± 32.65	20.52 ± 25.61	7.93 ± 10.72	**74.82** ± 33.66	39.58 ± 39.30	**6.68** ± 4.40	27.73 ± 31.73	4.142^{**}
Ca (mg/L)	33.73 ± 25.38	36.36 ± 54.72	**9.58** ± 3.56	**247.92** ± 301.32	231.41 ± 184.44	22.60 ± 13.49	73.64 ± 128.23	5.629^{***}
K (mg/L)	**3.58** ± 1.35	4.51 ± 1.29	5.63 ± 2.05	**57.72** ± 41.72	27.39 ± 22.35	7.08 ± 3.35	11.95 ± 18.20	9.247^{***}
Fe (mg/L)	0.51 ± 0.34	0.54 ± 0.63	1.16 ± 1.05	2.59 ± 2.58	**3.19** ± 1.80	**0.40** ± 0.22	1.21 ± 1.44	6.705^{***}
Mg (mg/L)	11.83 ± 9.45	5.79 ± 4.17	**2.06** ± 0.66	**30.39** ± 13.72	21.42 ± 19.77	5.13 ± 3.23	10.22 ± 12.34	4.792^{**}
Mn (mg/L)	**0.002** ± 0.00	0.002 ± 0.00	**0.02** ± 0.03	0.01 ± 0.01	0.02 ± 0.04	0.00 ± 0.00	0.01 ± 0.02	1.527
N (mg/L)	2.67 ± 1.64	3.56 ± 2.70	3.24 ± 2.33	**10.30** ± 3.11	**1.67** ± 1.47	3.32 ± 2.41	3.34 ± 2.76	4.797^{**}
P (mg/L)	0.06 ± 0.05	0.05 ± 0.03	0.35 ± 0.17	**2.93** ± 4.11	0.09 ± 0.15	**0.04** ± 0.03	0.28 ± 0.98	5.175^{**}
Total species	9.71 ± 3.55	12.00 ± 4.86	**17.57** ± 6.35	11.00 ± 2.83	15.67 ± 3.78	**9.33** ± 2.34	12.77 ± 5.21	3.673^{**}
Total. Cover	80.29 ± 47.14	**208.57** ± 133.03	78.86 ± 70.40	37.00 ± 29.70	75.67 ± 81.15	**34.00** ± 12.60	94.46 ± 95.30	3.940^{**}
Sp. Richness	**2.08** ± 0.65	2.13 ± 0.55	**4.00** ± 0.97	3.15 ± 1.67	3.80 ± 0.51	2.43 ± 0.77	2.89 ± 1.09	8.114^{***}
Sp. Evenness	0.80 ± 0.09	0.82 ± 0.08	**0.91** ± 0.04	**0.77** ± 0.29	0.85 ± 0.11	0.83 ± 0.09	0.84 ± 0.10	1.078
Shannon H'	**0.002** ± 0.20	0.20 ± 0.19	**1.11** ± 0.14	0.82 ± 0.39	1.00 ± 0.10	0.81 ± 0.17	0.90 ± 0.21	3.436^{**}
Simpson C	**0.22** ± 0.13	0.18 ± 0.09	**0.08** ± 0.03	0.20 ± 0.25	0.11 ± 0.07	0.19 ± 0.10	0.16 ± 0.11	2.079

The six vegetation groups are: VGI: *Acacia gerrardii; Caralluma retrospiciens* VG II: *Acacia tortilis -Maerua oblongifolia;* VG III: *Lycium shawii-Farsetia aegyptiaca*; VG IV: *Farsetia stylosa-Cornulaca monocantha;* VG V: *Suaeda* aegyptiaca-*Salsola imbricata-Prosopis farcta* and VG VI: *Xanthium strumarium-Ochradenus baccatus.* Significant level $^{*}P \leq 0.05$, $^{**}P \leq 0.01$, $^{***}P \leq 0.001$.

tion patterns, facilitate the establishment of many plant species and last but not least their impact on regional floristic diversity (Sayed et al., 2020, Šulyová et al., 2021).

Floristic analysis during the present study, around the 5 dam sites revealed 151 plant species of 117 genera from 36 plant families. The number of species to genera ratio was about 1.29, which is lower in comparison to the total plant species to genera ratio index in the Kingdom of Saudi Arabia (2172/840 = 2.6) (AlNafie 2008) but contains at least half of the ratio of species-genera index in Saudi Arabia (El-Sheikh et al., 2013). Among the 36 plant families, the Poaceae was represented by the highest number of species followed by Asteraceae, Fabaceae, Chenopodiaceae, Brassicaceae and Boraginaceae. These are the common families in Saudi Arabian flora, and this sequence is comparable more or less with (Collenette 1998, Chaudhary 1999, 2000, 2001). The abundance of Poaceae family (16.7%) members among the total species was due to the fact that most of the plants in the study area are being dominated by dispersal type of anemochore (Shaltout and El-Sheikh 2002, El-Sheikh et al., 2013, Abdel Khalik et al., 2017). The dominance of annual herbs (39.74%) followed by perennial herbs (18.54%) was might be due to the availability of more moisture created by dams in those areas and secondly due to their short life cycle pattern that helps them to resist the instability of the ecosystem (Alatar et al., 2012, Gomaa 2012, Mahmoud et al., 2018). Our results are comparable with the study of Sayed et al., (2020) on the impact of Wadi Jizan desert reservoir which reported that the area around the reservoir harbored several plant species with different life forms and a prevalence of annuals and perennials herbs. Chorological analysis of the surveyed plants revealed the dominance of monoregional elements (57.623%), over the biregionals (27.81%) and pluriregionals, and the presence of the biregional and pluriregonal due to Saudi consider as a meeting point of Africa, South Europe and Asia (Alatar et al., 2012, Al-Sherif et al., 2013, Osman et al., 2014, Abdel Khalik et al., 2017, Mahmoud et al., 2018, Al-Yasi et al., 2019, Al-Shehri et al., 2020).

Our study revealed that there were more plant species number and their floristic diversity in the upstream and downstream dam sites when compared to the reference undammed sites which were far from the dam sites. This is due to the fertility of the soil in the immediate dam environment, since the rainwater helps to transport soil, organic matter and plant seeds from the mountains, slopes and plateaus, which eventually settle in the course of the valley in which the dam is built. These findings are consistent with those of (Abdel-Fattah and Ali, 2005), which examined the association between ecological parameters and the dispersal of plant communities in the Taif region.

The plant associations in the present study can be considered as novel plant communities which were separated according to the regional habitats from the south to the north and related to the geography, size of the dam, rainfall and the retention time of the reservoir water. The associations, VGI -*Acacia gerrardii-Caralluma retrospiciens* and VG II- *Acacia tortilis-Maerua oblongifolia*, are both located at the sites of the large dams i.e., Jizan and Bisha, respectively with long term of water availability for plant life, which was characterized by high plant cover, the high value of silt soil and low pH. In addition, *Acacia gerrardii* and *Acacia tortilis* dominate most habitats and are considered as large cover Acacias in Arabia indicating high groundwater sources (Aref et al., 2003, Mandaville 2013). Furthermore, the well-established *Acacia gerrardii* population contributes to the improvement of ecological niche conditions, such as a suitable microclimate under trees, by giving shelter or sustenance to other species, thereby enhancing plant species diversity (Kurschner 1986, Batanouny 1987, El-Sheikh 2005, El-Sheikh et al., 2013). Also, these umbrella Acacias or nursery trees modify the microhabitats in association with other species such as *Maerua oblongifolia*, *Caralluma retrospiciens*, *Tribulus pentandrus*, *Calotropis procera*, *Chloris virgata*, *Ricinus communis*, *Conyza bonariensis* thereby inhabiting the moist riparian zone with high species richness. As a result of these changes, these two large dams at Jizan and Bisha in the Southwest have attained more plant cover due to the presence of permanent water throughout the year.

The association VGIII, *Lycium shawii-Farsetia aegyptiaca*, which inhabits the comparatively smaller Hail dam at the Northwest of Saudi had lower salinity and high species diversity due to a greater

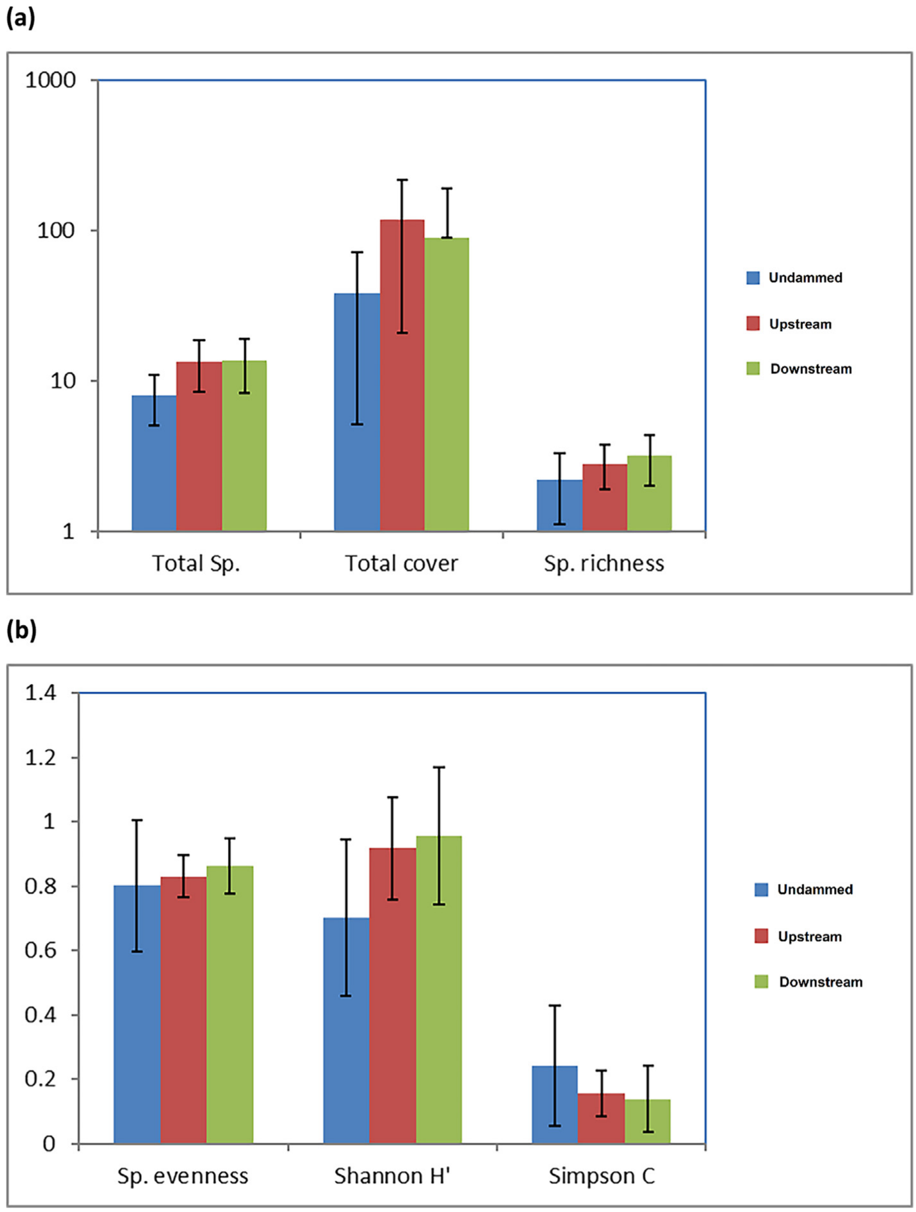

Fig. 6. a and b: Graphical representation of the diversity indices at the different dam sites.

number of therophytes and perennial herbs. This may be due to the ability of this plant community to cope with harsh environmental conditions, as they have a great competitive ability to adapt to this habitat. Additionally, small dams yield relatively small reservoirs, and their leakage may be greater than those of larger dams (Principe 2010). VGIV, *Farsetia stylosa -Cornulaca monocantha*, which inhabits the small arid dam of Al-Qassim area were characterized with high content of sand, minerals and low organic matter. This community had the lowest species diversity due to the aridity as well as less water availability and represented a xerophytic habitat with adaptive and limited plant species distribution (Alatar et al., 2012, Al-Gifri et al., 2018).

The associations, VGV- *Suaeda aegyptiaca-Salsola imbricata-Prosopis farcta*, and VG VI-*Xanthium strumarium-Ochradenus baccatus* inhabits the upper and lower zones of the small dams in Al-Qassim and Al-Riyadh respectively, dominated by a high content of clay and organic matter due to high water permeability along with low rainfall, contributed to lower species diversity (Principe 2010). Further, dams potentially change the flood disturbance regime and block the downstream dispersal of plant propagules such as seeds, which will affect the diversity of many wild plants. They may also drown the riparian zone within their impoundments and cause the riparian ecosystem to become fragmented.

From (Fig. 6a and b) it is clear that the species diversity (total species number, species richness and total cover) of the upstream, downstream and riparian habitat zones were higher than that of undammed habitat. As a consequence, vegetation adaptations will be diversified and evolving over time, resulting in a significantly riparian zone and different landscape within the dam reservoir. These modifications will occur as a result of the loss of prior vegetation, possible invasion by exotics and native plants, and major changes in hydrological regimes, as well as erosion and sedimentation events impacting and forming novel plant communities (New and Xie 2008).

Moreover, the average length of time that water remains within the boundaries of an aquatic system is one of the key parameters controlling the system's biogeochemical behavior. This time scale, known as the water residence period, is critical for various and complicated activities in reservoirs (Rueda et al., 2006). There are also reports on the major consequences of reservoirs, which can be characterized as river continuity interruption, silting of wadi bed, homogeneity of ecosystems, downstream wadi bed incision, adjustment of wadi/groundwater exchange and downstream circulation, and water quality modification (Schmutz and Sendzimir 2018). Moreover, the results of the present study showed that the prevailing soil texture in the dam area was loamy soil other than the undammed sites, and this is considered as a good texture for the growth of woody plants and their spread because it helps in deepening the roots to great distances to absorb water from great depths and in drainage quality (Al-Nafi 2005).

5. Conclusion

The construction of a dam or water conductor system creates certain physical, ecological and social changes. In the present study, six plant associations were identified with high floristic diversity and species richness, which inhabited a modified loamy soil in the riparian zones other than undammed zones. Since, dams potentially change the flood disturbance regime and block the downstream dispersal of plant propagules (i.e., seeds), which may cause a downstream change in native and exotic plant species diversity. Dams also drown the riparian zone within their impoundments and cause the riparian ecosystem to become fragmented. The critical thing is to explore and anticipate all environmental and social impacts early in the planning process so that appropriate steps can be taken to avoid, mitigate, or compensate for such impacts.

Data availability

The authors confirm that the data supporting the findings of this study are available within the article.

CRediT authorship contribution statement

Bander M. Al-Munqedhi: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. **Mohamed A. El-Sheikh:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Supervision, Writing – original draft, Writing – review & editing. **Ahmed H. Alfarhan:** Conceptualization, Formal analysis, Funding acquisition, Supervision, Writing – review & editing. **Abdullah M. Alkahtani:** Investigation. **Ibrahim A. Arif:** . **Rajakrishnan Rajagopal:** Writing – review & editing. **Sauod T. Alharthi:** Validation.

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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