

ECOLOGICAL ASSESSMENT AND INDICATOR SPECIES ANALYSES OF THE CHOLISTAN DESERT USING MULTIVARIATE STATISTICAL TOOLS

SANA RASHEED¹, SHUJAUL MULK KHAN^{1,2*}, ZEESHAN AHMAD¹, GHAZALA MUSTAFA¹, ZAHOOR UL HAQ¹, HUSSAIN SHAH³, LUBNA ANSARI⁴ AND TAHIRA JATT⁵

¹Department of Plant Sciences, Quaid-i-Azam University, Islamabad, Pakistan

²Pakistan Academy of Sciences Islamabad, Pakistan

³Pakistan Agriculture Research Council Islamabad, Pakistan

⁴Department of Forestry & Range Management, PMAS Arid Agriculture University Rawalpindi, Pakistan

⁵Department of Botany, Shah Abdul Latif University, Khairpur

*Corresponding author's email: shujaqau@gmail.com

Abstract

It was hypothesized that the vegetation structure of Cholistan desert shows a significant correlation with moisture (water), edaphic and climatic variables. Is it possible to identify plant communities of Cholistan desert using indicator species statistical approach in relation to environmental gradients? To answer these questions quadrat quantitative ecological techniques were used for vegetation data collection in the vicinity of ponds (Tobas/water bodies) of the Cholistan Desert. A total of 4800 quadrats were established in 100 randomly selected Tobas in each direction. Sizes of the quadrats were 64m², 16m² and 1m² for trees, shrubs and herbs, respectively. All the data were put in MS Excel for analyses in PCORD and CANOCO software's through Two-way Cluster Analysis, Cluster Analysis, Indicator Species Analysis and Canonical Correspondence analysis using Monte Carlo procedures. A total of 49 plant species belonging to 25 families were recorded from Cholistan desert. Cluster analysis and indicator species analysis identified four different plant communities i.e., (i) *Prosopis-Dipterygium-Cymbopogon* community, (ii) *Zizyphus-Suaeda-Cenchrus* community, (iii) *Tamarix-Haloxylon-Tribulus* community and (iv) *Capparis-Calotropis-Zaleya* community. It is concluded that the available phosphorus, organic matter, soil moisture and grazing pressure were the significant ($p < 0.05$) environmental variables in the determination of vegetation structure, formation of plant communities and its respective indicators in the Cholistan desert.

Key words: Cholistan desert, Plant communities, Indicator species, Edaphic factors, Multivariate statistical packages, Arid land.

Introduction

Water is the main ecological factor in arid and semi-arid regions for survival of rare sorts of biodiversity (Pedram *et al.*, 2018). Proper ecological functions and the soil-vegetation system is mainly determined by hydrological processes (Li *et al.*, 2011, Tesfaye & Negash, 2018). Moisture is most important ecological variable for conservation of biodiversity (Wu and Zhang, 2018, Zeb *et al.*, 2021). A recent overview of wetland vegetation showed that vegetation pattern changes around these water bodies by the change in soil moisture level (Shan *et al.*, 2018, Mitre *et al.*, 2018, Hui *et al.*, 2018). Soil moisture is an important factor that affects normal physiological process of plant as a result of which species composition and pattern of distribution have significant changes (Bi *et al.*, 2018, Nazakat *et al.*, 2020, Abdullah *et al.*, 2021). Interpretation of phytosociology and impact of various environmental variables on plants could be a guideline for the improvement and management of rangeland and desert ecosystems (Jafari *et al.*, 2004, Asmat *et al.*, 2020). Various ecological studies have reported the correlation between vegetation distribution and a variety of environmental factors (Iqbal *et al.*, 2017, Haq *et al.*, 2020, Manan *et al.*, 2020, Rahman *et al.*, 2020, Abbas *et al.*, 2021). The vegetation of an area needs to be studied properly at both species and community level as it indicates a specific set of environmental conditions prevailing at a specific time in that particular habitat (Khan *et al.*, 2012, Khan *et al.*, 2017; Bano *et al.*, 2018). Alongside the natural drivers, anthropogenic variables also affect vegetation at a regional as well global scale (Bai *et al.*, 2013, Van der Merwe *et al.*, 2018, Iqbal *et al.*, 2021).

In desert environments, vegetation alters mainly due to low water availability, soil physiochemical composition and anthropogenic disturbances. Physical factors such as rainfall, soil texture and moisture, groundwater depth, aspect, slope, altitude, topography and landforms have a pronounced effect on vegetation distribution (Ali *et al.*, 2001). The vegetation of Cholistan desert mainly consists of xerophytes like perennial shrubs and small trees. Several annuals and ephemerals emerge soon after rainfall that completes their lifecycle rapidly (Rashid *et al.*, 2018; Arshad *et al.*, 2008). Various studies have been conducted to analyze species composition and distribution patterns along with various environmental variables. Soil properties are one of the important factors for formation of vegetation communities (Ahmad *et al.*, 2016, Rahman *et al.*, 2021). Different soil types are present and have an association with specific plant communities in the Cholistan desert (Arshad & Akbar, 2002).

Furthermore, computer-based statistical and multivariate programs help ecologists in determination of the effect of environmental variables on species (Anderson *et al.*, 2006, Haq *et al.*, 2020, Khan *et al.*, 2020). The problem in handling huge data can be resolved by classification of data with the help of statistical packages (McCune & Mefford, 1999). Vegetation ecologists use several multivariate techniques to summarize large data sets (Khan *et al.*, 2012, Ahmad *et al.*, 2021). Then these summarized data set helps in explanation and hypothesis formation regarding vegetation's community studies. Distribution of vegetation can be comprehensively represented with the help of classification and ordination (Haq *et al.*, 2015).

Little efforts have been made to provide a quantitative investigation of the plant communities along with a variety of ecological gradients that have an indispensable role in structure of desert vegetation via multivariate statistical techniques. Therefore, the current study was carried out for description and analyses of plant species and communities in the Cholistan desert using robust multivariate statistical techniques. It also identifies edaphic and other environmental factors responsible for plant communities and species distribution patterns of the Cholistan desert.

Material and methodology

Study area: Cholistan desert extends over an area of 26000 Km² between 27°42'N to 29°45'N latitude to 69°52'E and 75°24'E longitude at an elevation of about 112 m above sea level in the south of Bahawalpur Punjab, Pakistan (Akhter & Arshad, 2006). A total of 8% of land area of Punjab is covered by Cholistan desert and two-third of Bahawalpur Division. Formerly, part of princely state of Bahawalpur, Cholistan is now administered as part of the districts of Bahawalpur (50% of the area), Rahimyar Khan (40% of the area), and Bahawalnagar (10% of the area) (FAO, 1993). During 1200 BC Hakra River was flowing through the area that became irregular and diminished in 600 BC. The Cholistan had heavy monsoon rainfall before 5000 years ago likewise other parts of the Indus Valley. The area ultimately changed into a desert due to gradual change in monsoon rain, wind patterns and perhaps other reasons.

This desert can be divided into two geomorphic regions i.e., the lesser Cholistan and the greater Cholistan, on the bases of topography, parent rock material and vegetation & soil pattern. Lesser Cholistan is a northern region consisting of canal irrigated areas covering about

7770 Km². The southern region is known as Greater Cholistan covering 18130 Km² (Akbar & Arshad, 2000). The rainfall occurs during July to September in the summer and January to March in the winter 100-250 mm annually. Extremely, high temperature in summer and mild in the winter season. The mean summer temperature 34°C-48°C with highest 51.6°C and mean winter temperature is 15- 20°C (Arshad *et al.*, 2002). Main source of water in Cholistan is rainwater because groundwater is present. Groundwater is not suitable for drinking of both human and livestock because of its extreme brackish nature. The scarcity of water thus becomes main problem of this desert area. Water becomes available only in wet season when rainwater is stored in manmade ponds locally known as Tobas (Fig. 1).

Vegetation sampling and soil analyses: Quadrat quantitative ecological techniques were used for vegetation sampling in the region during summer 2016. One hundred Tobas were randomly selected from both in the greater and the lesser Cholistan desert. At each Toba, 4 transects of 100-meter length were established towards N, S, E & W. At each transect 4 plots (stations/samples) were established at 30 m interval starting from bank of water body. As a whole 4800 quadrats (1200 for each tree, shrub and herb species) were taken around 100 Tobas. A total of 48 quadrats were established at single Toba with 12 quadrats on each side direction. Quadrat size for trees, shrubs and herbs were taken 64 m², 16 m² and 1 m² respectively. Absolute and relative density, cover and frequency along with their Importance Values Index (IVI) of each plant species were calculated using phytosociological formulae (Iqbal *et al.*, 2018, Anwar *et al.*, 2019, Kamran *et al.*, 2020). All the collected plant specimens were identified with the help of Flora of Pakistan and other available literature (Arshad & Rao, 1994).

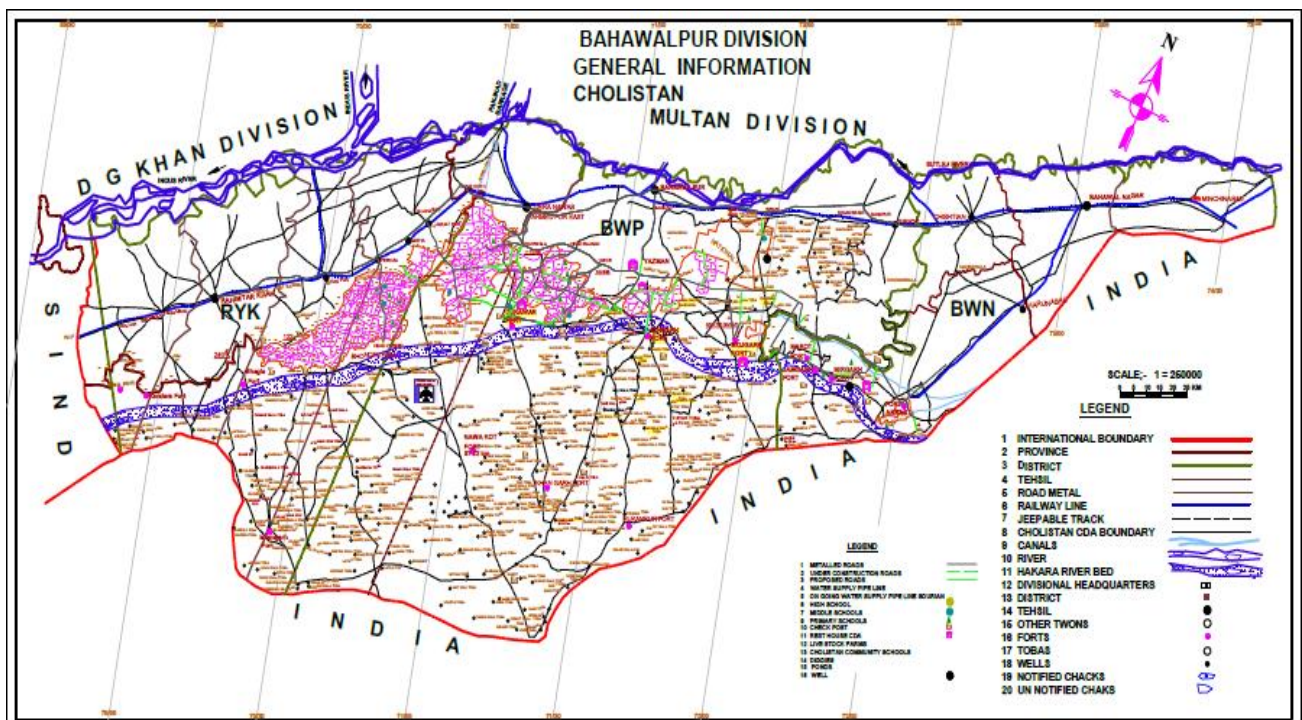


Fig. 1. Map of the Cholistan Desert Bahawalpur Punjab, Pakistan.

Soil samples were collected from each site kept in polythene bags and labeled properly. Soil texture was determined via Bouyoucos Hydrometer Method (Sarir *et al.*, 2006, Bergeron *et al.*, 2013) and texture triangle was used for determination of textural class (Adamu & Aliyu, 2012). Electrical conductivity was measured using the method of Wilson & Bayley 2012. The organic matter was determined using the Walkley and Black's titration method (Jackson, 1963, Iqbal *et al.*, 2018). To determine available phosphorus spectrophotometer was used (Page & Page, 1982). For the determination of phosphorus 2.5g soil sample was taken in a 250 ml conical flask, 50 ml extracting reagent was added and shake for 30 minutes on a flatbed reciprocal shaker and extract was filtered. Potassium was determined in ppm by graph readings taken from the flame photometer.

Data analyses: All vegetation and environmental data matrices were prepared following the PCORD V.5 requirements using MS Excel. Cluster Analysis (CA) and Two-way Cluster Analyses (TWCA) identified significant habitat and plant community types using Sorensen measures of similarity using presence and absence data (Greig-Smith, 1983). Indicator Species Analysis (ISA) was subsequently used to link the floristic composition and abundance data with the environmental variables. This combined information provides insight into the concentration of species abundance in a particular group and the faithfulness (fidelity) of occurrence of a species in that varied group (Ahmad *et al.*, 2019). Indicator values for each species in each community were obtained and tested for statistical significance using the Monte Carlo test. Indicator Species Analysis evaluated each species for the strength of its response to the environmental variables, from the environmental matrix. A threshold level of indicator value of 20% with 95% significance (p^* value ≤ 0.05) was chosen as the cut-off for identifying indicator species (Dufrêne & Legendre, 1997) and the identified indicator species were used for naming the plant communities present in this desert ecosystem.

Results

A total of 49 plant species belonging to 24 families were identified and documented from vicinity of 100 tobas (water bodies) in the Cholistan Desert of Bahawalpur, Pakistan. According to habit 37 plants were perennials and 12 annuals species. The family importance index showed that Poaceae was the dominant family with 12 species followed by Amaranthaceae with 6 species and Aizoaceae with 3 species. Based upon plant growth habit 6 were trees, 13 shrubs and 30 herbs.

Cluster Analysis of PCORD software classified all the plant species, environmental variables and stations into four major communities (Fig. 2). Two Way Cluster Analysis further comprehended distribution of plant species at each station that can be seen in two main branches of cluster dendrogram. The black dots illustrated the presences while white dots indicated absence of species in the region (Fig. 3). The detail descriptions of each community are as follows:

Prosopis-dipterygium-cymbopogon community: Cluster and Two Way Cluster Analysis based on Sorensen Similarity Index clustered a total of 10 stations/tobas in this plant community. The top 3 indicator species of this community were *Prosopis cineraria*, *Dipterygium glaucum* and *Cymbopogon jawarancusa* (Tables 1 and 2 & Fig. 4). Other dominant tree and shrub species comprised *Capparis decidua*, *Haloxylon salicornicum*, *Callotropis procera* and *Aerva javanica*. Dominant herb species included *Cynodon dactylon*, *Mukia maderaspatana* and *Zaleya pentandra* each with an importance value of more than 100.

It indicated sandy loam soil due to location of these tobas/stations in the deep desert along with sand dunes. It was the most significant environmental variable for determination of this Cholistan desert region. Sand particles from surrounding areas flow with water towards the depression, that's why amount of sand particles was greater as compared to other plant communities. This community also figures out high grazing pressure because of the temporary settlements of nomads along with their herds. Available phosphorus of this community ranges from 2.4 -8.1 ppm, organic matter varies from 0.16 - 0.85 % and saturation fluctuate from 28 -34 %.

Zizyphus-Suaeda-Cenchrus plants community: A total of 28 Tobas clustered this plants community. The topmost indicator species of this community were *Zizyphus mauritiana*, *Suaeda fruticosa* and *Cenchrus ciliaris* (Table 1; & Fig. 5). These were the indicators of phosphorus and water saturation as environmental variables. Other dominant tree and shrub species were *Capparis decidua*, *Acacia nilotica*, *Prosopis cineraria*, *Salsola imbricata* and *Calotropis procera*. Organic matter was the main environmental variable of this community as compared to others. Instead of organic matter available phosphorus 1.13-26.99 ppm and saturation 29 -54% were the important environmental variables in the establishment of this community.

Tamarix-Haloxylon-Tribulus plants community: A total of 26 Tobas clustered the plants community. *Tamarix aphylla*, *Haloxylon stocksii* and *Tribulus terrestris* were the top most indicator species under the influence of moderate grazing pressure (Tables 1 and 2 & Fig. 6). Other dominant tree and shrub species include *Tamarix aphylla*, *Acacia nilotica*, *Capparis decidua*, *Suaeda fruticosa* and *Salsola imbricata*. Dominant herb species included *Cenchrus ciliaris*, *Cynodon dactylon*, *Cyprus rotundus* and *Portulaca oleracea* with Importance Value more than 100.

Most important environmental factors determining the establishment of this community were pH 7.59-8.65, Phosphorus 5.8-22.4 ppm, organic matter (0.1-0.72%, soil saturation 32- 42% and grazing pressure. This community is an indicator of moderate grazing pressure, although the indicator species of this community are palatable. All these stands are located at distance from the settled areas so less preferential for local people to stay there. Because of the difficulty to move from these areas towards settled parts in dry season, due to lack of proper tracks for traveling. As consequence numbers of cattle are also relatively less.

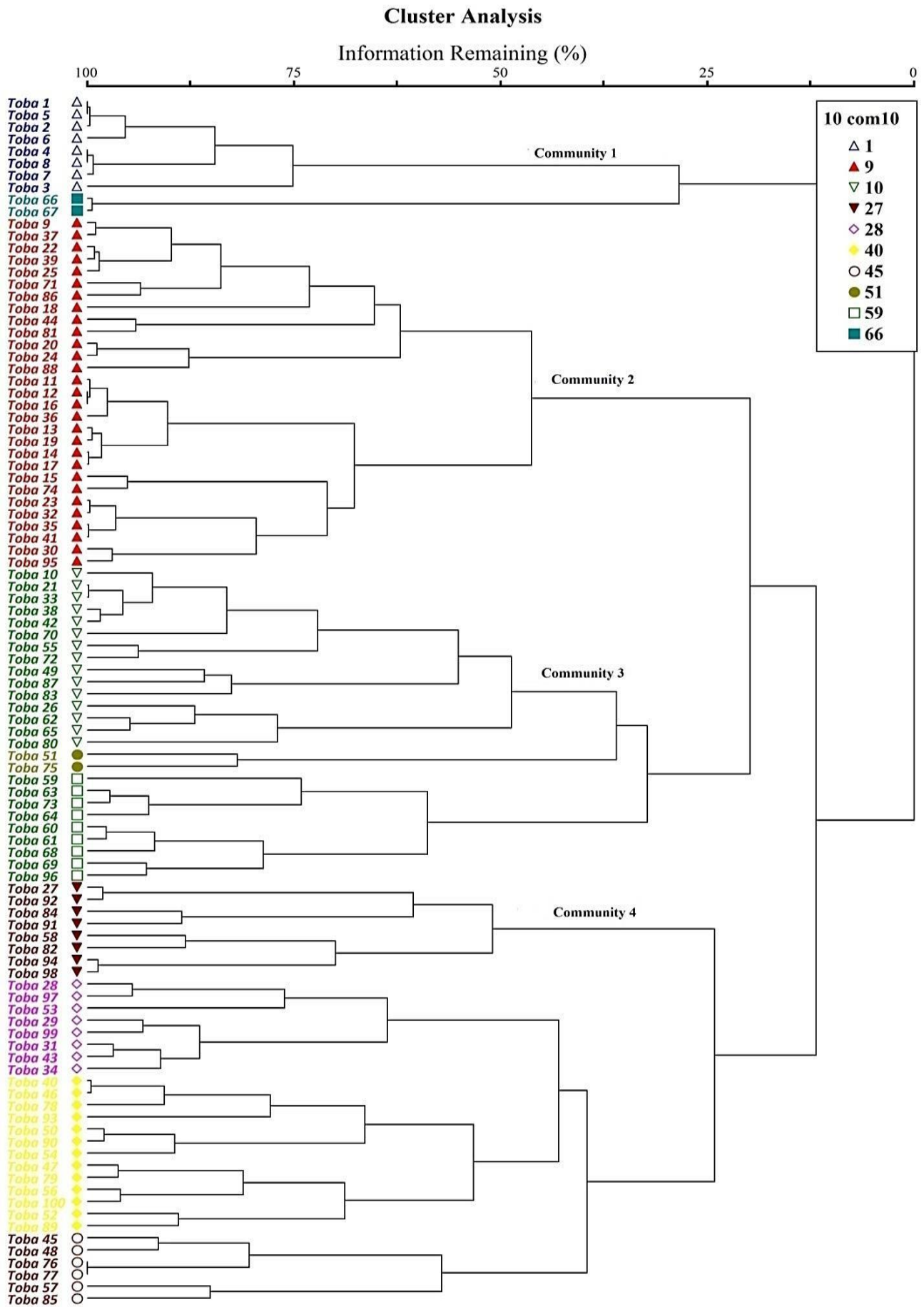


Fig. 2. Cluster dendrogram of 100 stations (Tobas) based on Sorenson measures showing four plant communities.

Table 1. Topmost indicator species of each plants communities along with their indicator values, constancy and fidelity in the Cholistan desert.

S. No.	Indicator species	Constancy		Fidelity		IV	P*
		%	Class	%	Class		
<i>Prosopis-Dipterygium-Cymbopogon</i> community							
1.	<i>Prosopis cineraria</i>	80	4	35	2	71.4	0.0052
2.	<i>Dipterygium glaucum</i>	100	5	40	2	75.7	0.0034
3.	<i>Cymbopogon jawarancusa</i>	60	3	54	3	71.2	0.0479
<i>Zizyphus-Suaeda-Cymbopogon</i> community							
1.	<i>Zizyphus mauritiana</i>	32	2	64	3	27	0.0216
2.	<i>Suaeda fruticosas</i>	92	5	33	2	21.6	0.0406
3.	<i>Cenchrus ciliaris</i>	96	5	40	2	26.1	0.0491
<i>Tamarix-Haloxylon-Tribulus</i> community							
1.	<i>Tamarix aphylla</i>	57	3	38	2	20.5	0.035
2.	<i>Haloxylon stocksii</i>	57	3	28	2	24.3	0.0521
3.	<i>Tribulus terrestris</i>	42	3	72	4	19.3	0.0116
<i>Capparis-Calotropis-Zaleya</i> community							
1.	<i>Capparis decidua</i>	72	4	26	2	20.2	0.0028
2.	<i>Calotropis procera</i>	100	5	27	2	23.1	0.0052
3.	<i>Zaleya pentandra</i>	42	3	50	3	49.4	0.019

IV = Indicator value, P = Probability, IVI = Importance value index

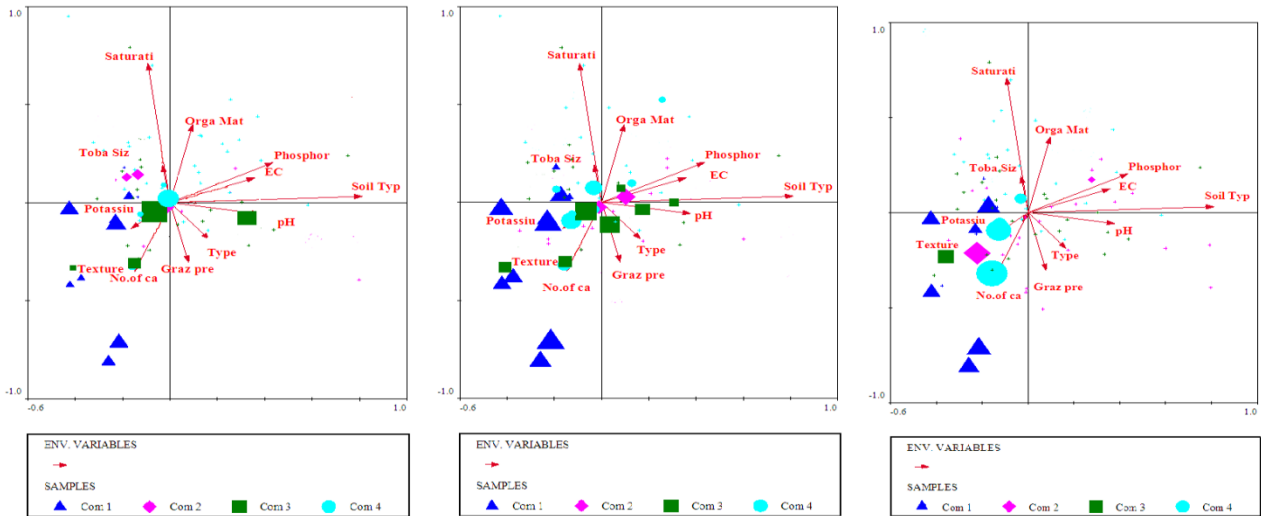


Fig. 4. Data attribute plots (from left to right) of *Prosopis cineraria*, *Dipterygium glaucum* and *Cymbopogon jawarancusa* indicator species of first plants community.

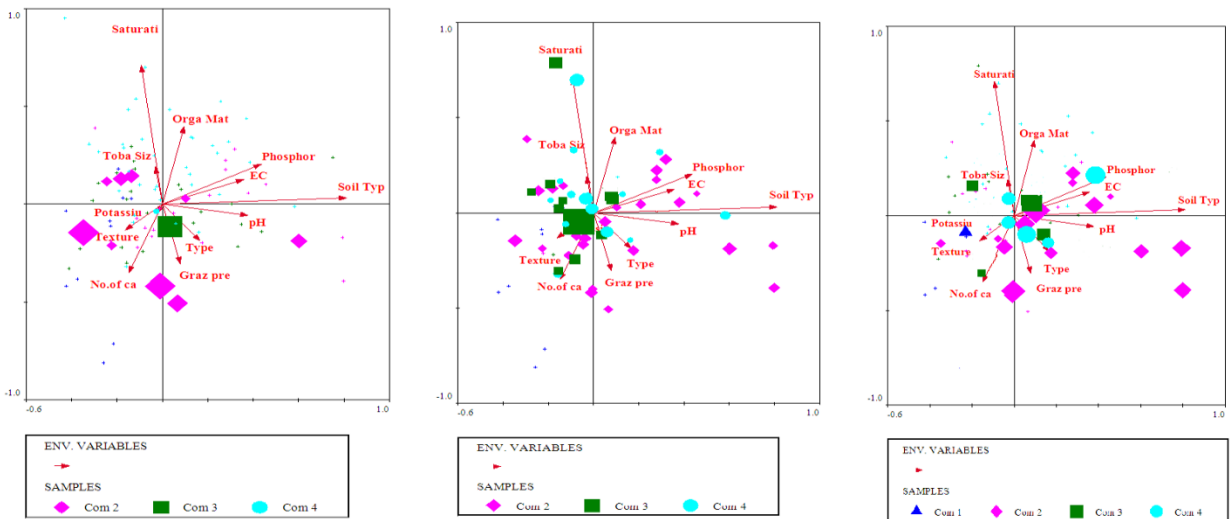


Fig. 5. Data attribute plots of top 3 indicator species of the 2nd plants community in relation to different environmental variables after CCA analysis of CANOCO software.

Table 2. Results of Indicator Species Analysis (ISA) through PC-ORD, showing top Indicator plant species of each of the four plant communities at a threshold level of indicator 20% and Monte Carlo tests of significance for observed maximum indicator value of species (p value<0.05).

S. No.	Botanical name	Prosopis-Dipterygium-Cymbopogon community		Zizyphus-Suaeda-Cenchrus community		Tamarix-Haloxylon-Tribulus community		Capparis-Calotropis-Zaleya community	
		Group defined by soil texture		Group defined by organic matter		Group defined by grazing pressure		Group defined by phosphorus	
		IV	p*	IV	p*	IV	p*	IV	p*
1.	<i>Acacia nilotica</i> L.	30.5	0.5585	32.4	0.1258	21.2	0.8362	20.2	0.9028
2.	<i>Capparis decidua</i>	49.8	0.1216	19.8	0.0094	27.1	0.5713	28.9	0.0028
3.	<i>Dalbergia sisso</i>	1.1	1	14.3	0.4829	2.8	1	10	0.5053
4.	<i>Prosopis cineraria</i>	71.4	0.0052	9.9	0.7684	27.1	0.103	29.4	0.031
5.	<i>Tamarix aphylla</i>	19.8	0.6687	14.5	0.3295	20.5	0.035	9.1	0.7778
6.	<i>Zizyphus mauritiana</i>	11	1	27	0.0216	11.1	0.1102	34	0.0304
7.	<i>Abutilon indicum</i>	4.3	1	11.9	0.4655	4.1	0.4715	10.2	0.4695
8.	<i>Abutilon muticum</i>	5.4	1	6.3	0.907	6.9	0.3089	14.1	0.3353
9.	<i>Aerva javanica</i>	25.8	0.5469	12.5	0.5029	23.7	0.1484	15.2	0.3847
10.	<i>Aerva persica</i>	20.7	0.5083	16.5	0.2987	12.8	0.2641	17.5	0.215
11.	<i>Calligonum polygonoides</i>	59	0.019	8.6	0.7632	16.3	0.175	30.7	0.0482
12.	<i>Calotropis procera</i>	51	0.072	10.6	0.871	42.3	0.0032	23.1	0.0052
13.	<i>Crotalaria burhia</i>	15.2	0.6591	7.5	0.8528	10	0.3859	12.2	0.5059
14.	<i>Dipterygium glaucum</i>	75.7	0.0034	13.4	0.4215	26.8	0.2589	36.8	0.0072
15.	<i>Haloxylon salicornicum</i>	31.2	0.0916	7.6	0.7688	12.2	0.1448	51.9	0.0042
16.	<i>Haloxylon stocksii</i>	39.8	0.2603	21.9	0.2883	24.3	0.0521	9.8	0.882
17.	<i>Salsola imbricata</i>	36.2	0.6551	10.2	0.7413	34.6	0.1964	12	0.3641
18.	<i>Suaeda fruticosa</i>	46.5	0.1028	21.8	0.0406	34.5	0.081	11.6	0.7429
19.	<i>Boerhavia procumbens</i>	36.1	0.1242	7.7	0.8098	11.5	0.4417	17.8	0.2326
20.	<i>Cenchrus biflorus</i>	14.8	0.3315	24.9	0.0828	7.2	0.4489	7.4	0.821
21.	<i>Citrullus colocynthis</i>	7.6	1	9.4	0.6505	4.2	0.7119	11.2	0.5719
22.	<i>Coronopus didymus</i>	9.8	0.9132	4.6	0.9672	4.7	0.8138	12	0.5151
23.	<i>Euphorbia prostrata</i>	4.3	1	18.7	0.2348	8.7	0.0828	18.4	0.226
24.	<i>Fagonia indica</i>	5.4	1	10	0.6535	5.6	0.3399	33.7	0.0382

Table 2. (Cont'd.).

S. No.	Botanical name	Prosopis-Dipterygium-Cymbopogon community		Zizuphus-Suaeda-Cenchrus community		Tamarix-Haloxylon-Tribulus community		Capparis-Calotropis-Zaleya community	
		Group defined by soil texture		Group defined by organic matter		Group defined by grazing pressure		Group defined by phosphorus	
		IV	p*	IV	p*	IV	p*	IV	p*
25.	<i>Glirus lotoides</i>	4.3	1	6.1	0.9248	1.8	0.8504	8.7	0.5733
26.	<i>Helictropium strigosum</i>	1.1	1	12.5	0.6455	3.2	0.3219	5.9	1
27.	<i>Launaea capitata</i>	7.6	1	7.7	0.779	5.8	0.4293	26.5	0.1002
28.	<i>Limeum indicum</i>	47.1	0.0316	10.4	0.5075	6.4	0.5587	12	0.5071
29.	<i>Mollugo cerviana</i>	9.8	0.9718	10.1	0.6077	8.2	0.2563	13.2	0.4497
30.	<i>Mukia maderaspatana</i>	19.6	0.5395	11	0.5291	10.6	0.4605	12.9	0.4839
31.	<i>Portulaca oleracea</i>	16.1	0.8384	12.7	0.4525	14	0.8458	10.4	0.6437
32.	<i>Solanum surattense</i>	20.2	0.211	13.3	0.4137	5.9	0.6241	7.1	0.8198
33.	<i>Eclipta prostrata</i>	29.8	0.09	9.1	0.6423	6	0.2715	8	0.6135
34.	<i>Trianthem aporulacastrum</i>	6.5	1	7.4	0.7856	7.9	0.1746	20.6	0.1996
35.	<i>Tribulus longipetalus</i>	23.8	0.1834	17.1	0.2392	7.9	0.5255	9.2	0.7033
36.	Tribulus terrestris	15.2	0.6829	9.6	0.6057	19.3	0.0116	11.1	0.5811
37.	Zaleya pentandra	15.8	0.6141	12.2	0.4783	9.5	0.6575	49.4	0.019
38.	<i>Aeluropus lagopoides</i>	15	0.2949	5.1	0.9598	6.1	0.3129	8.7	0.6535
39.	<i>Aristida adscensionis</i>	24.7	0.1902	23	0.0914	6.1	0.7832	9.3	0.6955
40.	<i>Arundo donax</i>	2.2	1	5.6	1	6.5	0.1002	13	0.3269
41.	Cenchrus ciliaris	36	0.2268	26.1	0.0491	18	0.6401	15.6	0.3773
42.	Cymbopogon jwarancusa	71.2	0.0479	7.5	0.8272	7.1	0.9718	22.8	0.0471
43.	<i>Cynodon dactylon</i>	55	0.0718	10.6	0.5709	28.8	0.7546	13.6	0.5861
44.	<i>Cyperus rotundus</i>	27.1	0.4943	9.4	0.7544	17.3	0.6089	14.7	0.4197
45.	<i>Eragrostis barrelieri</i>	9.8	1	10.1	0.5695	7.7	0.3373	9.8	0.6261
46.	<i>Lasturus scindicus</i>	7.6	1	13.1	0.3703	5.6	0.4569	22.3	0.1314
47.	<i>Ochthochloa compressa</i>	6.5	1	13.4	0.4011	8.4	0.1492	6.4	0.8012
48.	<i>Eragrostis minor</i>	6.5	1	15.7	0.2889	6.7	0.2505	18.5	0.2551
49.	<i>Panicum antidotale</i>	7.6	1	43.4	0.0096	4.5	0.6973	14.7	0.4155

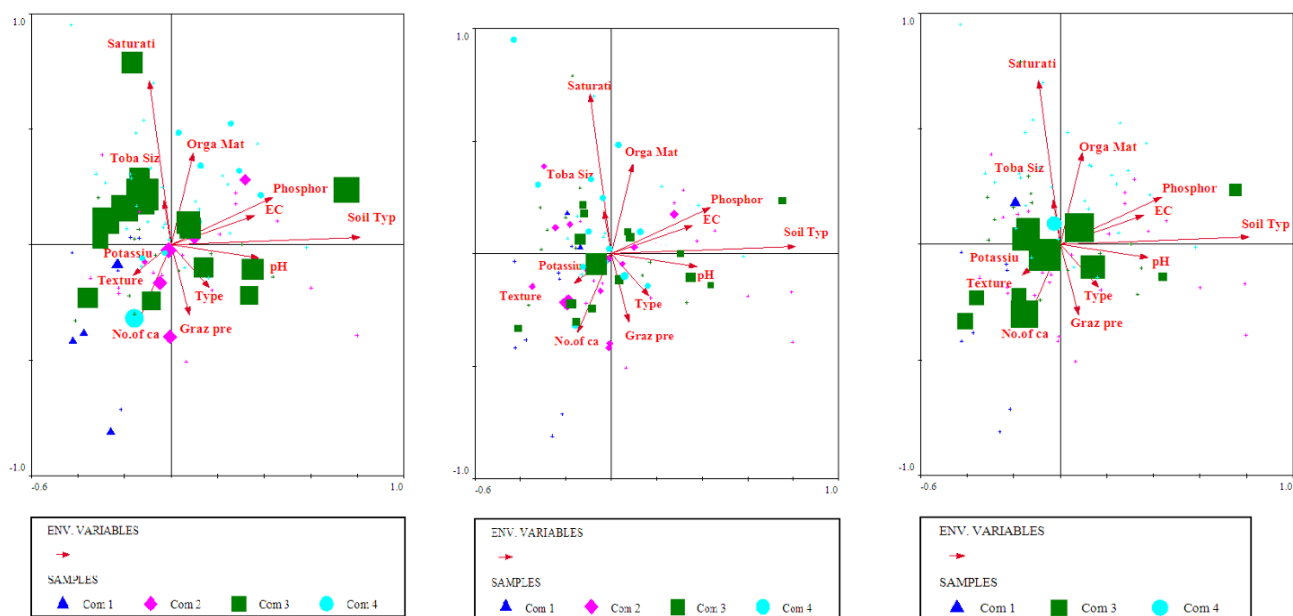


Fig. 6. Data attribute plots of *Tamarix aphylla* (1st indicator), *Haloxylon stocksii* (2nd indicator) and *Tribulus terrestris* (3rd indicator) species of 3rd community after CCA analysis of CANOCO software.

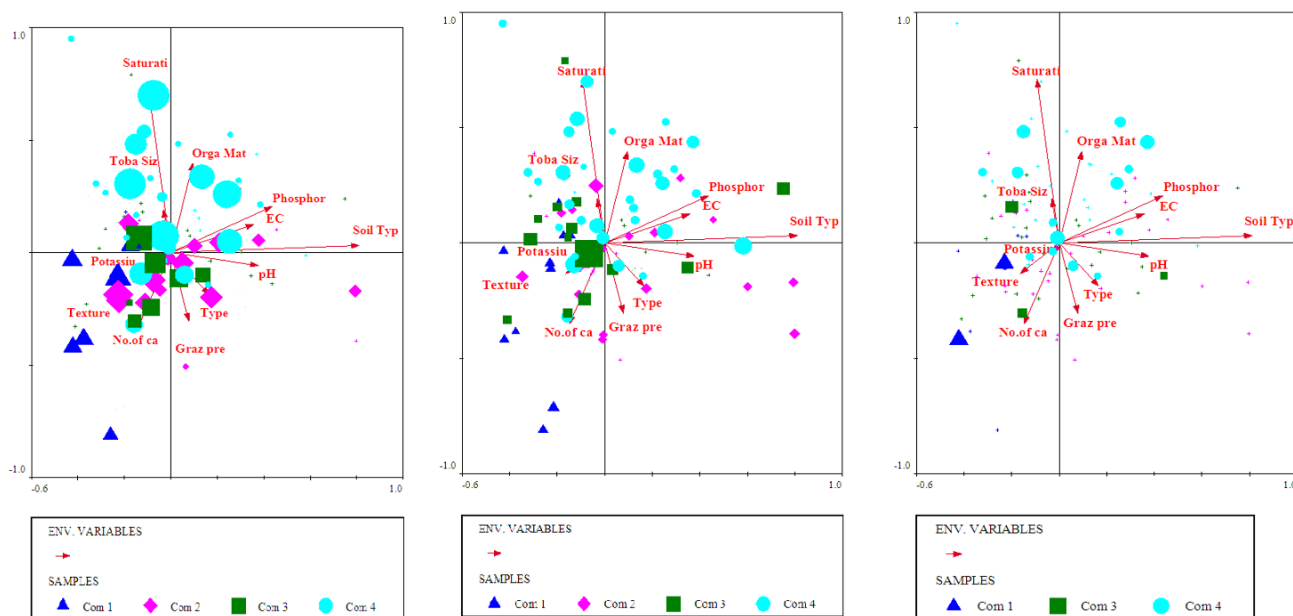


Fig. 7. Data attribute plots (from left to right) *Capparis deciduas*, *Calotropis procera* and *Zaleya pentandra* indicator species of 4th plants community along with various measured variables.

***Capparis-Calotropis-Zaleya* plants community:** A total of 36 Tobas comprised this plant community via CA and TWCA based on Sorenson Similarity Index. *Capparis deciduas*, *Calotropis procera* and *Zaleya pentandra* were the topmost indicator species under the influence of phosphorus environmental variables (Table 1 & Fig. 7). Other dominant tree and shrub species included *Acacia nilotica*, *Suaeda fruticosa*, *Salsola imbricate*, *Haloxylon stocksii* and *Aerva javanica*. Dominant herb species comprised *Cynodon dactylon*, *Cenchrus ciliaris*, *Cymbopogon jawarancusa* and *Aristida adscensions* having IVI value more than 100.

Soil state of this community revealed organic matter 0.16 -1.72%, available phosphorus 1.95- 46.84 ppm along with grazing pressure higher to moderate.

Discussion

The information regarding floristic composition is mandatory for any ecological, phytogeographical and conservation studies. The identification of a particular species in a specific area is important for giving information about the growing season of species and effect of overgrazing and anthropogenic pressures on vegetation (Ali, 2008). The present study provides preliminary data about flora in the vicinity of water collecting points (tobas) in Cholistan desert. A total of 49 plant species belonging to 23 families are recorded in this study that is low as compared to the already reported species from Cholistan desert (Gill *et al.*, 2012, Wariss *et al.*, 2013). This small number might be because only limited

habitat around the tobas was sampled in a specific area of a vast desert. Poaceae was dominant family followed by Amaranthaceae. The recorded vegetation is typical of arid climate mostly xerophytes that are adapted to extremely high temperatures, low humidity and varied edaphic conditions (Arshad *et al.*, 2002).

Community structure describes vegetation structure of a specific area (Malik *et al.*, 2007). Not all the species in a community have same importance, few have developed good adaptation to environment, therefore, grow very well and also affect the growth of other species (Gaston, 2000). Many environmental factors such as climatic, anthropogenic and biotic stresses affect the phytosociological attributes density, frequency and cover (Singh & Singh, 2010). The problem of extensive and large data sets is solved by classification and ordination by arranging the data in low-dimensional space with similar species and samples placing closer and dissimilar ones at a distance (Khan *et al.*, 2016). A total of four communities have been established from data of 100 tobas/stands and 49 species by Cluster Analysis and Two-way Cluster Analysis. In the communities trees and perennials almost remain same while a change in community occurs due to herbaceous vegetation particularly annuals (Therophytes) that flourish during monsoon. Breidenkamp *et al.*, 2003 reported that several habitat variables including topography, altitude, geology, soil texture and depth are important factors influencing plant communities. At the study site species composition almost remains same in four communities as limited small areas around the water bodies were sampled in present study. Vegetation and other associated parameters almost remain same at all selected sites. Difference appears only in abundance and importance value of specific species in respective community.

Four plant communities identified by cluster analysis include *Prosopis cineraria*, *Dipterygium glaucum*, *Cymbopogon jwarancusa* (PDC), *Zizyphus mauritiana*, *Suaeda fruticosa*, *Cenchrus ciliaris* (ZSC), *Tamarix aphylla*, *Haloxylon stocksii*, *Tribulus terrestris* (THT) and *Capparis decidua*, *Calotropis plicata*, *Zaleya pentandra* (CCZ). These plant communities are not reported by previous studies conducted in Cholistan desert. Various previous studies have reported three habitat types sandunal, interdunal sandy and clayey saline habitats (Abdullah *et al.*, 2013). These studies had identified up to 20 plant communities based on the importance value of these species. Sampled areas in present study were more or less similar because most of them are around natural depressions. These tobas are present at dahars that consist of clayey flat areas. These areas are shaped by the flow of water due to which upper layer of fine silt is removed. Due to these reasons, distribution and abundance of vegetation are different in these areas from rest of the desert. The species variation was observed in sampled areas due to soil composition, grazing pressure and distance from water bodies (Ahmad *et al.*, 2007).

Conclusion

It is concluded that the available phosphorus, soil texture, organic matter, soil moisture and grazing pressure were the significant environmental variables in the determination of vegetation structure, formation of plant communities and its indicators in the Cholistan desert. Furthermore, species richness and abundance of vegetation were decreasing with the increase in aridity or decrease of moisture in the region. Techniques adapted in the current study for identification of indicators could further be used for conservation management of desert in particular and other such ecosystems in general.

References:

- Abbas, Z., S.M. Khan, J. Alam, T. Peer, Z. Abideen, R.W. Bussmann and S. Muhammad. 2021. Vegetation dynamics along altitudinal gradients in the Shigar Valley (Central Karakorum) Pakistan: Zonation, physiognomy, ecosystem services and environmental impacts. *Pak. J. Bot.*, 53(5): 1865-1874.
- Abdullah, M., R.A. Khan, S. Yaqoob and M. Ahmad. 2013. Community structure of browse vegetation in Cholistan rangelands of Pakistan. *Pak. J. Agri. Sci.*, 50: 237-247.
- Abdullah., S.M. Khan, A. Pieroni, A. Haq, Z.U. Haq, Z. Ahmad, S. Sakhi, A. Hashem, A.B.F. Al-Arjani, A.A. Alqarawi and E.F. Abd_Allah. 2021. A comprehensive appraisal of the wild food plants and food system of tribal cultures in the Hindu Kush Mountain Range; a Way Forward for Balancing Human Nutrition and Food Security. *Sustainability*, 13(9): 5258.
- Abdullah., S.M. Khan, R.A. Kashif, Z.U. Haq, Z. Ahmad, A.U. Haq and M.A. Haq. 2021. Ethnobotanical appraisal of medicinal plants from Bajaur; A remote area of the Khyber Pakhtunkhwa province of Pakistan. In: (Eds.): Abbasi, A.M. and R.W. Bussmann. *Ethnobiology of Mountain Communities in Asia*. Springer, pp. 277-293.
- Adamu, G. and A. Aliyu. 2012. Determination of the influence of texture and organic matter on soil water holding capacity in and around Tomas Irrigation Scheme, Dambatta Local Government Kano State. *Res. J. Environ. Earth Sci.*, 4: 1038-1044.
- Ahmad, K., M. Hussain, M. Ashraf, M. Luqman, M.Y. Ashraf and Z.I. Khan. 2007. Indigenous vegetation of Soone Valley; At the risk of extinction. *Pak. J. Bot.*, 39: 679-690.
- Ahmad, Z., S.M. Khan and S. Page. 2021. Politics of the natural vegetation to balance the hazardous level of elements in marble polluted ecosystem through phytoremediation and physiological responses. *J. Hazard. Mater.*, 414: 125451.
- Ahmad, Z., S.M. Khan, E.F. Abd_Allah, A.A. Alqarawi and A. Hashem. 2016. Weed species composition and distribution pattern in the maize crop under the influence of edaphic factors and farming practices: A case study from Mardan, Pakistan. *Saudi J. Biol. Sci.*, 23(6): 741-748.
- Ahmad, Z., S.M. Khan, M.I. Ali, N. Fatima and S. Ali. 2019. Pollution indicandum and marble waste polluted ecosystem; role of selected indicator plants in phytoremediation and determination of pollution zones. *J. Clean. Prod.*, 236: 117709.
- Akbar, G. and M. Arshad. 2000. Developing sustainable strategies for Cholistan desert: opportunities and perspectives. *Science Vision*, 5: 77-85.
- Akhter, R. And M. Arshad. 2006. Arid rangelands in the Cholistan desert (Pakistan). *Science et changements planétaires/Sécheresse*, 17: 210-217.

- Ali, M., I.A. Qamar, A. Ali, M. Arshad and J. Iqbal. 2001. Evaluation of tropical grasses for forage yield and crude protein content in the Pothowar plateau of Pakistan. *J. Biol. Sci.*, 466-470.
- Ali, S. 2008. Significance of flora with special reference to Pakistan. *Pak. J. Bot.*, 40: 967-971.
- Anwar S, S.M. Khan, Z. Ahmad, Z. Ullah and M. Iqbal. 2019. Floristic composition and ecological gradient analyses of the Liakot Forests in the Kalam region of District Swat, Pakistan. *J. For. Res.*, 30(4): 1407-1416.
- Arshad, M. and A. Rao. 1994. Flora of the Cholistan desert: systematic list of trees, shrubs and herbs. *J. Econ. Taxon. Bot.*, 18: 615-625.
- Arshad, M. and G. Akbar. 2002. Benchmark of plant communities of Cholistan desert [Pakistan]. *Pak. J. Biol. Sci.*, (Pakistan).
- Arshad, M., A. Hassan, M.Y. Ashraf, S. Noureen and M. Moazzam. 2008. Edaphic factors and distribution of vegetation in the Cholistan desert, Pakistan. *Pak. J. Bot.*, 40: 1923-1931.
- Arshad, M., G. Akbar and S. Rashid. 2002. Wealth of medicinal plants of Cholistan desert, Pakistan. *Hamdard Medicus* (Pakistan).
- Asmat, S., S.M. Khan, Z. Ahmad, Abdullah, M. Arif, R. Noor, R.W. Bussmann, A. Pieroni and H. Ahmad. 2020. Study of medicinal plants of the Chitral Gol National Park (CGNP) with special emphasis on future conservation and sustainability. In: (Eds.): Abbasi, A.M. and R.W. Bussmann. *Ethnobiology of Mountain Communities in Asia*. Springer, pp. 71-85.
- Bai, Y., H. Xu, X. Liu and H. Ling. 2013. Spatial distribution characteristics and ecological protection of the desert riparian forest in the mainstream of the Tarim River. *J. Nat. Res.*, 28: 776-785.
- Bano, S., S.M. Khan, J. Alam, A.A. Alqarawi, E.F. Abd-Allah, Z. Ahmad, I.U. Rahman, H. Ahmad, A. Aldubise and A. Hashem. 2018. Eco-Floristic studies of native plants of the Beer Hills along the Indus River in the districts Haripur and Abbottabad, Pakistan. *Saudi J. Biol. Sci.*, 25(4): 801-810.
- Bergeron, S.P., R.L. Bradley, A. Munson and W. Parsons. 2013. Physico-chemical and functional characteristics of soil charcoal produced at five different temperatures. *Soil Biol. Biochem.*, 58: 140-146.
- Bi, X., Li, B., Nan, B., Fan, Y., Fu, Q. and X. Zhang. 2018. Characteristics of soil organic carbon and total nitrogen under various grassland types along a transect in a mountain-basin system in Xinjiang, China. *J. Arid Land.*, 1-16.
- Bredenkamp, G.J. and L.R. Brown. 2003. A reappraisal of Acocks' Bankenveld: origin and diversity of vegetation types. *S. Afr. J. Bot.*, 69(1): 7-26.
- Dufrène, M. and P. Legendre. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecol. Monogr.*, 67: 345-366.
- Gaston, K. 2000. Global patterns in biodiversity. *Nature*, 405: 220-227.
- Gill, A.H., K.S. Ahmad, S. Habib, M. Hameed, M.S.A. Ahmad, T. Nawaz, F. Ahmad and R. Batool. 2012. Impact of highly saline wetland ecosystem on floral diversity of the cholistan desert. *Pak. J. Bot.*, 44: 107-112.
- Greig-Smith, P. 1983. *Quantitative plant ecology*, Univ of California Press.
- Haq, Z.U., S.M. Khan, A. Razzaq, F. Manan, S. Kamran, S. Rasheed and Z. Ahmad. 2020. Heavy metals uptake ability from water by the Himalayan alder growing in Riparian habitat of Sino Japanese regions in Pakistan. *Pure and Applied Biology*, 9(1): 704-713.
- Haq, Z.U., S.M. Khan, Z. Ahmad, S.A. Shah, G. Mustafa, A. Razzaq, F. Manan, A. Ullah and M. Hussain. 2020. An evaluation of conservation status and ecological zonation of *Alnus nitida*; a monophyletic species of the sino-Japanese region. *JAPS: J Anim Plant Sci.*, 30(5): 1224-1235.
- Hui, Y., Q. Zhang, C.Y. Xu, L. Xiong, J. Chen and P. Xie. 2018. Vegetation's role in controlling long-term response of near ground air temperature to precipitation change in a semi-arid region. *J. Arid Environ.*, 152: 83-86.
- Iqbal, M., S.M. Khan, M.A. Khan, Z. Ahmad and H. Ahmad. 2018. A novel approach to phytosociological classification of weeds flora of an agro-ecological system through Cluster, Two Way Cluster and Indicator Species Analyses. *Ecol. Ind.*, 84: 590-606.
- Iqbal, M., S.M. Khan, M.A. Khan, Z. Ahmad, Z. Abbas, S.M. Khan and M.S. Khan. 2017. Distribution pattern and species richness of natural weeds of wheat in varying habitat conditions of district Malakand, Pakistan. *Pak. J. Bot.*, 49(6): 2371-2382.
- Iqbal, M., S.M. Khan, Z. Ahmad, M. Hussain, S.N. Shah, S. Kamran, F. Manan, Z.U. Haq and S. Ullah. 2021. Vegetation classification of the Margalla Foothills, Islamabad under the influence of edaphic factors and anthropogenic activities using modern ecological tools. *Pak. J. Bot.*, 53(5): 1831-1843.
- Jackson, M. 1963. Interlayering of expansible layer silicates in soils by chemical weathering. *Clay Clay Minr.*, 11: 29-46.
- Jafari, M., M.Z. Chahouki, A. Tavili, H. Azarnivand and G.Z. Amiri. 2004. Effective environmental factors in the distribution of vegetation types in Poshtkouh rangelands of Yazd Province (Iran). *J. Arid Environ.*, 56: 627-641.
- Kamran, S., S.M. Khan, Z. Ahmad, A.U. Rahman, M. Iqbal, F. Manan, Z.U. Haq and S. Ullah. 2020. The role of graveyards in species conservation and beta diversity: a vegetation appraisal of sacred habitats from Bannu, Pakistan. *J. For. Res.*, 31(4): 1147-1158.
- Khan, M., S.M. Khan, M. Ilyas, A.A. Alqarawi, Z. Ahmad and E.F. Abd-Allah. 2017. Plant species and communities assessment in interaction with edaphic and topographic factors; an ecological study of the mount Eelum District Swat, Pakistan. *Saudi J. Biol. Sci.*, 24(4): 778-786.
- Khan, S.A., S.M. Khan, Z. Ullah, Z. Ahmad, J. Alam, N. Alam, S.N. Shah, R. Khan and M. Zada. 2020. Phytogeographic classification using multivariate approach; a case study from the Jambil Valley Swat, Pakistan. *Pak. J. Bot.*, 52(1): 279-90.
- Khan, S.M., S. Page, H. Ahmad and D. Harper. 2012. Anthropogenic influences on the natural ecosystem of the Naran Valley in the western Himalayas. *Pak. J. Bot.*, 44: 231-238.
- Khan, W., S.M. Khan, H. Ahmad, Z. Ahmad and S. Page. 2016. Vegetation mapping and multivariate approach to indicator species of a forest ecosystem: A case study from the Thandiani sub Forests Division (TsFD) in the Western Himalayas. *Ecol. Indc.*, 71: 336-351.
- Li, J., D.J. Batten and Y. Zhang. 2011. Palynological record from a composite core through Late Cretaceous-early Paleocene deposits in the Songliao Basin, Northeast China and its biostratigraphic implications. *Cretac. Res.*, 32: 1-12.
- Malik, N.Z., M. Arshad and S.N. Mirza. 2007. Phytosociological attributes of different plant communities of Pir Chinasi hills of Azad Jammu and Kashmir. *Int. J. Agri. Biol.*, 9: 569-574.
- Manan, F., S.M. Khan, Z. Ahmad, S. Kamran, Z.U. Haq, F. Abid and M. Iqbal. 2020. Environmental determinants of plant associations and evaluation of the conservation status of *Parrotiopsis jacquemontiana* in Dir, the Hindu Kush Range of Mountains. *Trop. Ecol.*, 61(4): 509-526.
- Mccune, B. and M. Mefford. 1999. PC-ord. *Multivariate analysis of ecological data, version, 4.*

- Mitre, S.K., S.F. Mardegan, C.F. Caldeira, S.J. Ramos, A.E.F. Neto, J.O. Siqueira and M. Gastauer. 2018. Nutrient and water dynamics of *Amazonian canga* vegetation differ among physiognomies and from those of other neotropical ecosystems. *Plant Ecol.*, 219: 1341-1353.
- Nazakat, S., S.M. Khan, Abdullah, R. Noor, I.U. Zaman, M. Arif, N. Khalid and Z. Ahmad. 2020. Floral composition, sustainable utilization, and conservation of important medicinal plants in the Ayubia National Park, Abbottabad, Khyber Pakhtunkhwa, Pakistan. In: (Eds.): Abbasi, A.M. and R.W. Bussmann. *Ethnobiology of Mountain Communities in Asia*. Springer, pp. 103-123.
- Page, A. and A. Page. 1982. *Methods of soil analysis: Chemical and microbiological properties*, Amen Society of Agronomy.
- Pedram, S., X. Wang, T. Liu and L. Duan. 2018. Simulated dynamics of soil water and pore vapor in a semiarid sandy ecosystem. *J. Arid Environ.*, 151: 58-82.
- Rahman, A.U, S.M. Khan, Z. Ahmad, S. Alamri, M. Hashem, M. Ilyas, A. Aksoy, C. Dülgeroğlu, G. Khan and S. Ali. 2021. Impact of multiple environmental factors on species abundance in various forest layers using an integrative modeling approach. *Glob. Ecol. Conserv.*, 29: 01712.
- Rahman, A.U., S.M. Khan, Z. Saqib, Z. Ullah, Z. Ahmad, S. Ekercin, A.S. Mumtaz and H. Ahmad. 2020. Diversity and abundance of climbers in relation to their hosts and elevation in the monsoon forests of Murree in the Himalayas. *Pak. J. Bot.*, 52(2): 601-612.
- Rasheed, S., Z. Ahmad and S.M. Khan. 2017. Role of Tobas (Water Bodies) in Ethno-Ecology and Pastoralism in the Cholistan Desert of Pakistan. *Abasyn J. Soc. Sci.*, 10, pp.193-198.
- Sarir, M., M. Durrani and I.A. Mian. 2006. Effect of the source and rate of humic acid on phosphorus transformations. *J. Agric. Biol. Sci.*, 1: 29-31.
- Shan, L., W. Zhao, Y. Li, Z. Zhang and T. Xie. 2018. Precipitation amount and frequency affect seedling emergence and growth of *Reaumuria soongarica* in northwestern China. *J. Arid Land.*, 10: 574-587.
- Singh, E. and M. Singh. 2010. Biodiversity and phytosociological analysis of plants around the municipal drains in Jaunpur. *World Acad. Sci., Engn. & Techn.*, 4: 01-28.
- Tesfaye, M. and M. Negash. 2018. Combretum-Terminalia vegetation accumulates more carbon stocks in the soil than the biomass along the elevation ranges of dryland ecosystem in Southern Ethiopia. *J. Arid Environ.*, 155: 59-64.
- Van Der Merwe, H., J. Du Toit, L. Van Den Berg and T. O'connor. 2018. Impact of sheep grazing intensity on vegetation at the Arid Karoo Stocking Rate Trial after 27 years, Carnarvon, South Africa. *J. Arid Environ.*, 155: 36-45.
- Wariss, H.M., M. Mukhtar, S. Anjum, G.R. Bhatti, S.A. Pirzada and K. Alam. 2013. Floristic composition of the plants of the Cholistan Desert, Pakistan. *Am. J. Plant Sci.*, 4: 58.
- Wilson, M.J. and S.E. Bayley. 2012. Use of single versus multiple biotic communities as indicators of biological integrity in northern prairie wetlands. *Ecol. Indic.*, 20: 187-195.
- Wu, L. and Y. Zhang. 2018. Precipitation and soil particle size co-determine spatial distribution of biological soil crusts in the Gurbantunggut Desert, China. *J. Arid Land.*, 1-11.
- Zeb, S.A., S.M. Khan, Z. Ahmad and Abdullah. 2021. Phytogeographic Elements and Vegetation along the River Panjkora-Classification and Ordination Studies from the Hindu Kush Mountains Range. *Bot. Rev.*, 1-25.

(Received for publication 11 March 2020)