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

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**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 $64m^2$, $16m^2$ and $1m^2$ 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 moister 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 Km$^2$ 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 Km$^2$. The southern region is known as Greater Cholistan covering 18130 Km$^2$ (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$^o$C with highest 51.6$^o$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 m$^2$, 16 m$^2$ and 1 m$^2$ 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).

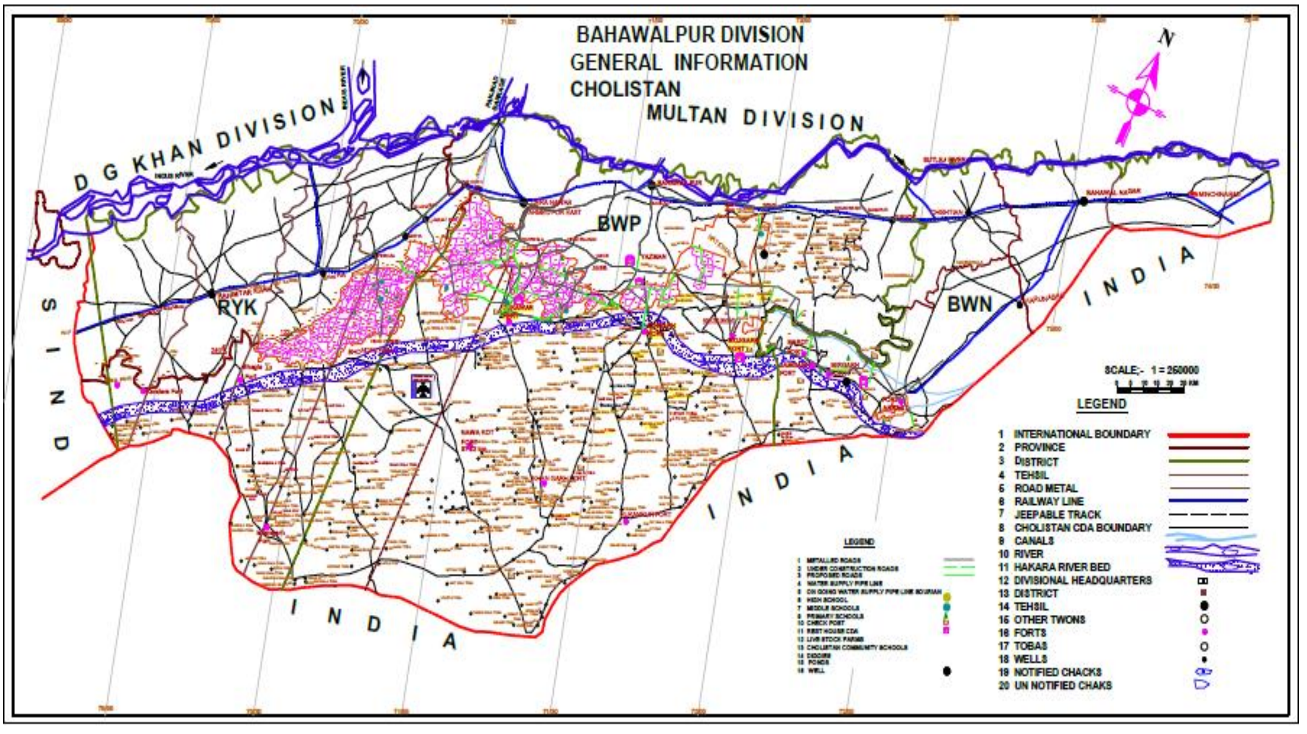


Fig. 1. Map of the Cholistan Desert Bahawalpur Punjab, Pakistan.

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 $\leq 0.05$) 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 Sorenson 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 pentendra* 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 maurtiana, Suaeda fruticosa* and *Cenchrus ciliarus* (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 aphyla*, *Haloxylon stocksii* and *Tribulus terristris* 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 imbricate*. Dominant herb species included *Cenchrus ciliarus*, *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.

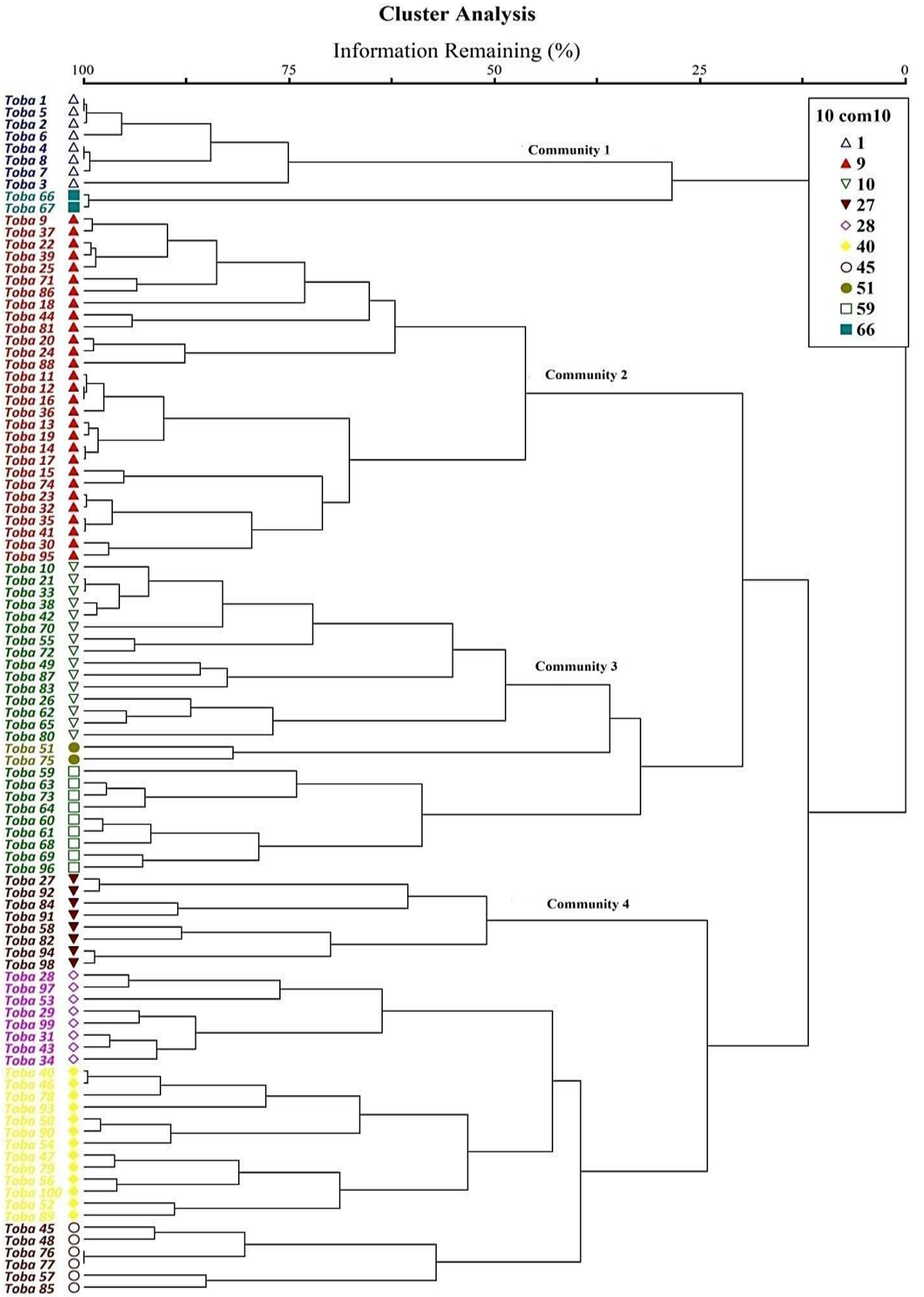


Fig. 2. Cluster dendrogram of 100 stations (Tobas) based on Sorenson measures showing four plant communities.

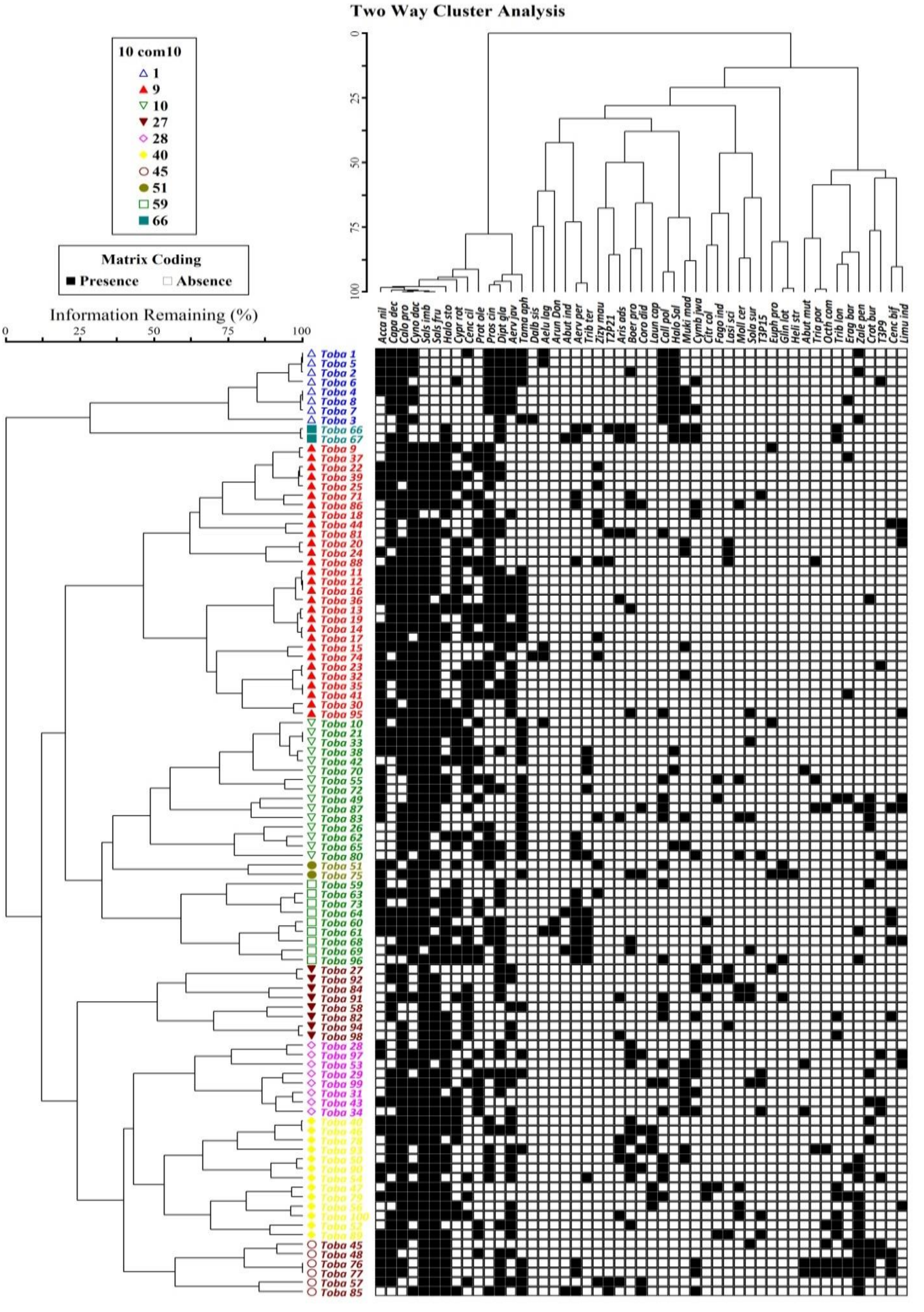

Fig. 3. TWCA Dendrogram of 49 species and 100 toba (s) showing distribution of plant species around each of the hundred tobas.

**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 | | |
| | ***Prosopis-Dipterygium-Cymbopogon* community** | | | | | | |
| 1. | *Prosopis cineraria* | 80 | 4 | 35 | 2 | 71.4 | 0.0052 |
| 2. | *Dipterygium glaucum* | 100 | 5 | 40 | 2 | 75.7 | 0.0034 |
| 3. | *Cymbopogon jawarancusa* | 60 | 3 | 54 | 3 | 71.2 | 0.0479 |
| | ***Zizyphus-Suaeda-Cymbopogon* community** | | | | | | |
| 1. | *Zizyphusmauritiana* | 32 | 2 | 64 | 3 | 27 | 0.0216 |
| 2. | *Suaedafruticosas* | 92 | 5 | 33 | 2 | 21.6 | 0.0406 |
| 3. | *Cenchrusciliaris* | 96 | 5 | 40 | 2 | 26.1 | 0.0491 |
| | ***Tamarix -Haloxylon-Tribulus* community** | | | | | | |
| 1. | *Tamarix aphyla* | 57 | 3 | 38 | 2 | 20.5 | 0.035 |
| 2. | *Haloxylon stocksii* | 57 | 3 | 28 | 2 | 24.3 | 0.0521 |
| 3. | *Tribulus teristris* | 42 | 3 | 72 | 4 | 19.3 | 0.0116 |
| | ***Capparis-Calotropis-Zaleya* community** | | | | | | |
| 1. | *Capparis decidua* | 72 | 4 | 26 | 2 | 20.2 | 0.0028 |
| 2. | *Calotropis procera* | 100 | 5 | 27 | 2 | 23.1 | 0.0052 |
| 3. | *Zaleya pentendra* | 42 | 3 | 50 | 3 | 49.4 | 0.019 |

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

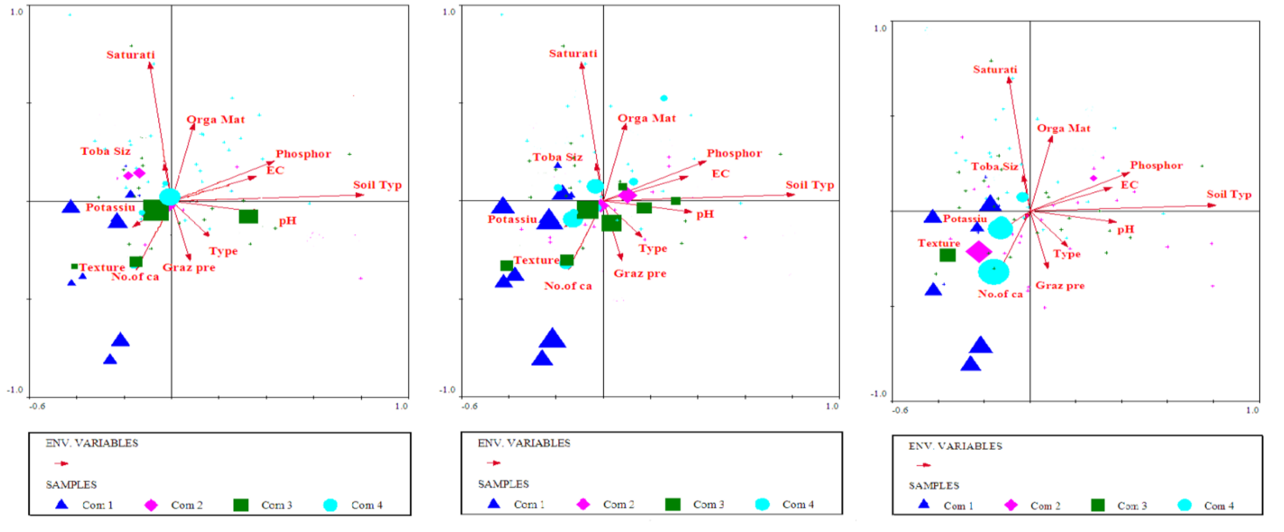


Fig. 4. Data attribute plots (from left to right) of *Prosopis cineraria*, *Dipterygium glaucum* and *Cymbopogon jawarancusa* indicator species of first plants community.

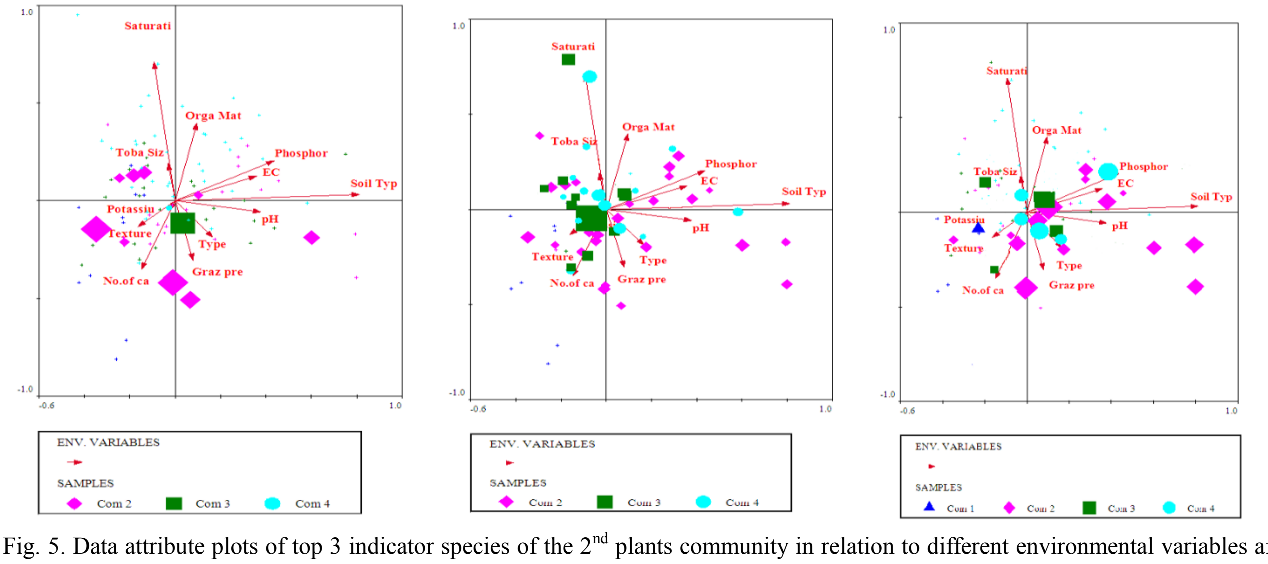


Fig. 5. Data attribute plots of top 3 indicator species of the 2nd plants community in relation to different environmental variables after CCA analysis of CANOCO software.

**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 | | *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* |
| 1. | *Acacia nilotica* L. | 30.5 | 0.5585 | 32.4 | 0.1258 | 21.2 | 0.8362 | 20.2 | 0.9028 |
| 2. | ***Capparis decidua*** | 49.8 | 0.1216 | 19.8 | 0.0094 | 27.1 | 0.5713 | **28.9** | **0.0028** |
| 3. | *Dalbergia sisso* | 1.1 | 1 | 14.3 | 0.4829 | 2.8 | 1 | 10 | 0.5053 |
| 4. | ***Prosopis cineraria*** | **71.4** | **0.0052** | 9.9 | 0.7684 | 27.1 | 0.103 | 29.4 | 0.031 |
| 5. | ***Tamarix aphylla*** | 19.8 | 0.6687 | 14.5 | 0.3295 | **20.5** | **0.035** | 9.1 | 0.7778 |
| 6. | ***Zizyphus mauritiana*** | 11 | 1 | **27** | **0.0216** | 11.1 | 0.1102 | 34 | 0.0304 |
| 7. | *Abutilon indicum* | 4.3 | 1 | 11.9 | 0.4655 | 4.1 | 0.4715 | 10.2 | 0.4695 |
| 8. | *Abutilon muticum* | 5.4 | 1 | 6.3 | 0.907 | 6.9 | 0.3089 | 14.1 | 0.3353 |
| 9. | *Aerva javanica* | 25.8 | 0.5469 | 12.5 | 0.5029 | 23.7 | 0.1484 | 15.2 | 0.3847 |
| 10. | *Aerva persica* | 20.7 | 0.5083 | 16.5 | 0.2987 | 12.8 | 0.2641 | 17.5 | 0.215 |
| 11. | *Calligonum polygonoides* | 59 | 0.019 | 8.6 | 0.7632 | 16.3 | 0.175 | 30.7 | 0.0482 |
| 12. | ***Calotropis procera*** | 51 | 0.072 | 10.6 | 0.871 | 42.3 | 0.0032 | **23.1** | **0.0052** |
| 13. | *Crotalaria burhia* | 15.2 | 0.6591 | 7.5 | 0.8528 | 10 | 0.3859 | 12.2 | 0.5059 |
| 14. | ***Dipterygium glaucum*** | **75.7** | **0.0034** | 13.4 | 0.4215 | 26.8 | 0.2589 | 36.8 | 0.0072 |
| 15. | *Haloxylon salicornicum* | 31.2 | 0.0916 | 7.6 | 0.7688 | 12.2 | 0.1448 | 51.9 | 0.0042 |
| 16. | ***Haloxylon stocksii*** | 39.8 | 0.2603 | 21.9 | 0.2883 | **24.3** | **0.0521** | 9.8 | 0.882 |
| 17. | *Salsola imbricata* | 36.2 | 0.6551 | 10.2 | 0.7413 | 34.6 | 0.1964 | 12 | 0.3641 |
| 18. | ***Suaeda fruticosa*** | 46.5 | 0.1028 | **21.8** | **0.0406** | 34.5 | 0.081 | 11.6 | 0.7429 |
| 19. | *Boerhavia procumbens* | 36.1 | 0.1242 | 7.7 | 0.8098 | 11.5 | 0.4417 | 17.8 | 0.2326 |
| 20. | *Cenchrus biflorus* | 14.8 | 0.3315 | 24.9 | 0.0828 | 7.2 | 0.4489 | 7.4 | 0.821 |
| 21. | *Citrullus colocynthis* | 7.6 | 1 | 9.4 | 0.6505 | 4.2 | 0.7119 | 11.2 | 0.5719 |
| 22. | *Coronopus didymus* | 9.8 | 0.9132 | 4.6 | 0.9672 | 4.7 | 0.8138 | 12 | 0.5151 |
| 23. | *Euphorbia prostrata* | 4.3 | 1 | 18.7 | 0.2348 | 8.7 | 0.0828 | 18.4 | 0.226 |
| 24. | *Fagonia indica* | 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. | *Glinus lotoides* | 4.3 | 1 | 6.1 | 0.9248 | 1.8 | 0.8504 | 8.7 | 0.5733 |
| 26. | *Heliotropium strigosum* | 1.1 | 1 | 12.5 | 0.6455 | 3.2 | 0.3219 | 5.9 | 1 |
| 27. | *Launaea capitata* | 7.6 | 1 | 7.7 | 0.779 | 5.8 | 0.4293 | 26.5 | 0.1002 |
| 28. | *Limeum indicum* | 47.1 | 0.0316 | 10.4 | 0.5075 | 6.4 | 0.5587 | 12 | 0.5071 |
| 29. | *Mollugo cerviana* | 9.8 | 0.9718 | 10.1 | 0.6077 | 8.2 | 0.2563 | 13.2 | 0.4497 |
| 30. | *Mukia maderaspatana* | 19.6 | 0.5395 | 11 | 0.5291 | 10.6 | 0.4605 | 12.9 | 0.4839 |
| 31. | *Portulaca oleracea* | 16.1 | 0.8384 | 12.7 | 0.4525 | 14 | 0.8458 | 10.4 | 0.6437 |
| 32. | *Solanum surattense* | 20.2 | 0.211 | 13.3 | 0.4137 | 5.9 | 0.6241 | 7.1 | 0.8198 |
| 33. | *Eclipta prostrata* | 29.8 | 0.09 | 9.1 | 0.6423 | 6 | 0.2715 | 8 | 0.6135 |
| 34. | *Trianthem aportulacastrum* | 6.5 | 1 | 7.4 | 0.7856 | 7.9 | 0.1746 | 20.6 | 0.1996 |
| 35. | *Tribulus longipetalus* | 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. | *Aeluropus lagopoides* | 15 | 0.2949 | 5.1 | 0.9598 | 6.1 | 0.3129 | 8.7 | 0.6535 |
| 39. | *Aristida adscensionis* | 24.7 | 0.1902 | 23 | 0.0914 | 6.1 | 0.7832 | 9.3 | 0.6955 |
| 40. | *Arundo donax* | 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. | *Cynodon dactylon* | 55 | 0.0718 | 10.6 | 0.5709 | 28.8 | 0.7546 | 13.6 | 0.5861 |
| 44. | *Cyperus rotundus* | 27.1 | 0.4943 | 9.4 | 0.7544 | 17.3 | 0.6089 | 14.7 | 0.4197 |
| 45. | *Eragrostis barrelieri* | 9.8 | 1 | 10.1 | 0.5695 | 7.7 | 0.3373 | 9.8 | 0.6261 |
| 46. | *Lasiurus scindicus* | 7.6 | 1 | 13.1 | 0.3703 | 5.6 | 0.4569 | 22.3 | 0.1314 |
| 47. | *Ochthochloa compressa* | 6.5 | 1 | 13.4 | 0.4011 | 8.4 | 0.1492 | 6.4 | 0.8012 |
| 48. | *Eragrostis minor* | 6.5 | 1 | 15.7 | 0.2889 | 6.7 | 0.2505 | 18.5 | 0.2551 |
| 49. | *Panicum antidotale* | 7.6 | 1 | 43.4 | 0.0096 | 4.5 | 0.6973 | 14.7 | 0.4155 |

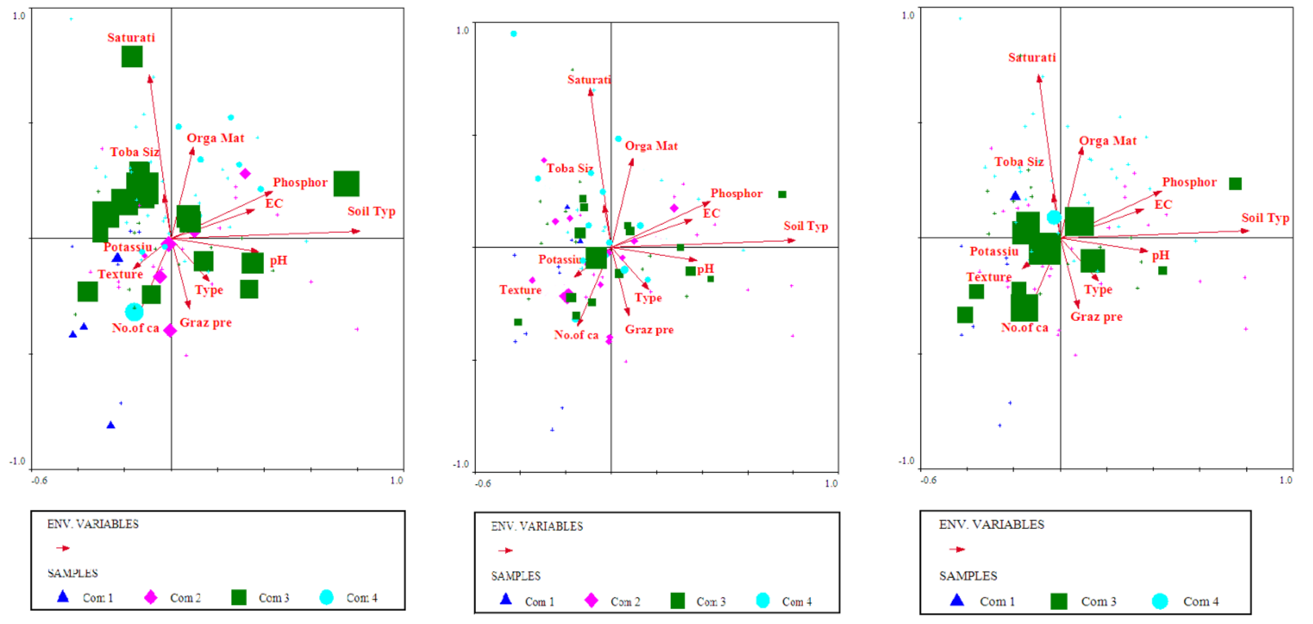


Fig. 6. Data attribute plots of *Tamarix aphyla* (1st indicator), *Haloxylon stocksii* (2nd indicator) and *Tribulus terristris* (3rd indicator) species of 3rd community after CCA analysis of CANOCO software.

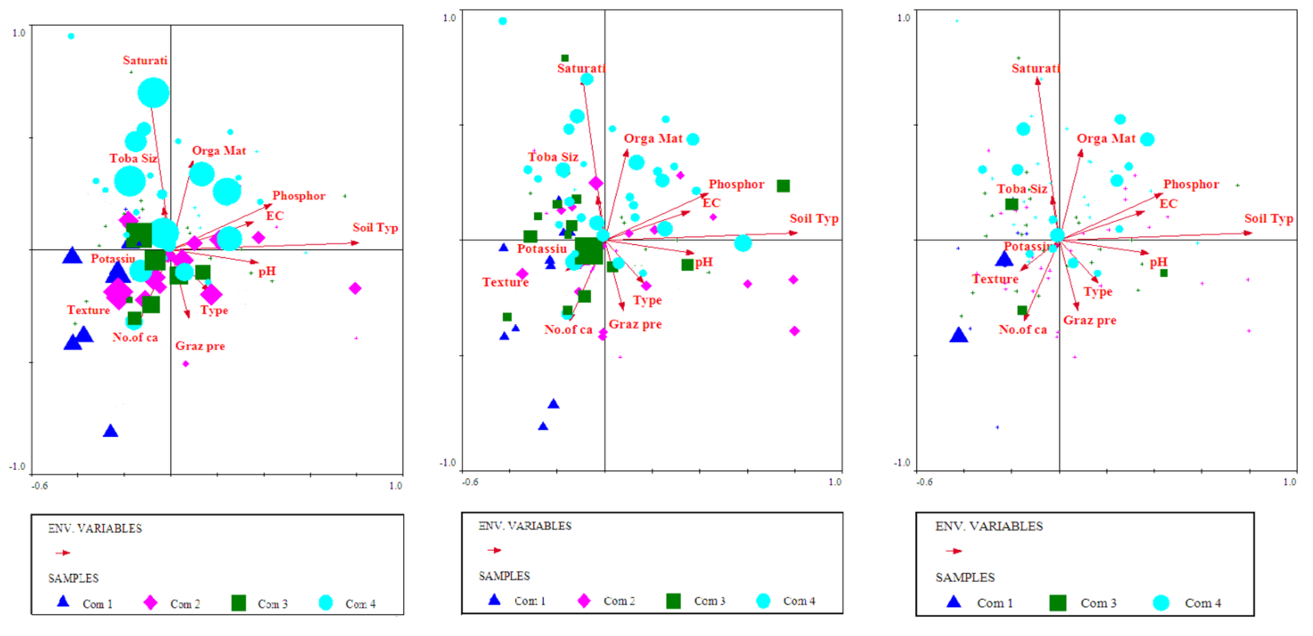


Fig. 7. Data attribute plots (from left to right) *Capparis deciduas, Calotropis procera* and *Zaleya pentendra* indicator species of 4th plants community along with various measured variables.

***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 pentendra* 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 ciliarus, 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 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. Bredenkamp *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 ciliarus* (ZSC), *Tamarix aphylla, Haloxylon stocksii, Tribulus terristris* (THT) and *Capparis decidua, Calotropis prcera, Zaleya pentendra* (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 moister 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.

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