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STRUCTURE, COMPOSITION AND DIVERSITY OF THE VEGETATION OF HUB DAM CATCHMENT AREA, PAKISTAN

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Abstract

A study of vegetation structure, composition and diversity of Hub-dam catchment area was conducted. A total of 106 species were recorded of which 57 were annuals while 49 were perennials. The vegetation was dominated by small trees and shrubs. Spatial patterns within-community of plant populations using variance/mean ratio and Morisita's index was also investigated. Of the 14 perennial species investigated seven (*Barleria acanthoides*, *Grewia tenax*, *Indigofera oblongifolia*, *Aerva persica*, *Rhazya stricta*, *Iphiona grantioides* and *Cymbopogon jwarancusa*) predominately exhibited aggregated pattern. Four species (*Acacia senegal*, *Prosopis juliflora*, *Salvadora oleoides* and *Calotropis procera*) usually exhibited random distribution but infrequently aggregated pattern. Three species (*Senna holosericea*, *Zizyphus nummularia* and *Vernonia cinerescens*) showed aggregated pattern or random distribution more or less equally often.

The distribution pattern of vegetation composition and the underlying environmental gradients, correspondence analysis (CA) ordination and canonical correspondence analysis (CCA) were employed. Group structure inherent in the vegetation was disclosed using Ward's agglomerative cluster analysis. Species diversity was measured and diversity was averaged for each group. Diversity of group I (*Acacia senegal* and *Prosopis juliflora* community type) was highest because this community included a number of mid-succession species, while diversity was lowest for group 4 (*Prosopis juliflora* and *Capparis decidua* community type) as this community was highly disturbed. In the climax community (group 3), the diversity level slightly decreased, suggesting the monopolization of resources by this community. Four major community types were recognized by Ward's cluster analysis, each of which was associated with particular topographic-edaphic factors, while one was mainly governed by anthropogenic disturbance. Biological spectrum constructed for the flora showed dominance of therophytes and chamaephytes.

Introduction

Hub-dam is situated at about 41km north of Karachi city on the provincial boarder of Baluchistan and Sindh. The dam is a large water reservoir which supplies water for irrigation to the district of Lasbella, Baluchistan and part of the domestic water supply for Karachi. The allocation of water for Lasbella is 27.6% and for Karachi being 62.4%. The dam was constructed in 1981 on Hub River which originates from Khirthar Mountains. The total drainage area of the river is 9391 Km^2 (Ahmed, 2008).

The water reservoir at Hub Dam is designated as wild life sanctuary which serves as a habitat for a number of water birds. The area comprises of Hills and plains with a catchment area of about 95 km^2. Hub River is surrounded by calcareous hills which are of Tertiary origin. A little away from the river banks and spill-ways, the soil is mostly dry. Since with respect to rainfall (195 mm) the area belongs to arid region, the prevailing vegetation in the catchment area is predominately xerophytic. The vegetation of the area includes open communities mostly dominated by shrubs, small tress or perennial herbs while a variety of annuals and ephemerals appear in summer. The predominant species include *Acacia senegal* (a tree) as a climax species of the hill slopes, while *Prosopis juliflora and Calotropis procera* (both shrubs) dominate the disturbed vegetation on sandy plains. The distribution pattern of the vegetation types and the individual species of desert ecosystems have most often been related to three groups of factors, physical environmental characteristics (soils and topography) determining moisture regime, soil chemistry, governing nutrient regime and anthropogenic disturbances regulating community composition and species diversity (Shaukat *et al.,* 1981b; Enright *et al.,* 2005). The ecological work done on Hub catchment area is scanty. However, Khatoon *et al.,* (2005) reported 35 species from the estuary of Hub River. Enright *et al.,* (2005) carried out a vegetation survey of Kirthar National Park located in the north of the study area, describing the community types and their associated habitat conditions. While most vegetation/phytosociological studies conducted in Indo-Pak subcontinent completely ignore the within community patterns of plant populations (exception being Khan *et al.,* 1987), the present study also examines the small-scale spatial patterns of plant populations prevailing within the communities. Such patterns are a central concern of ecology as they shed light on some interesting ecological processes operating at community level and provide explanation of not only within community patterns of plant populations but also community processes such as vegetation dynamics and stability, functioning and structuring of communities and species diversity (Monzeglio, 2007; Legendre & Fortin, 1989; Harte *et al.,* 2005; Warren *et al.,* 2009). However, despite their recognized significance, only a few ecological studies have focused attention on these processes (Tilman & Kareiva, 1997; Bolker *et al.,* 2003; Herben *et al.,* 2006; Maestre, 2006). The present study analyses the spatial patterns of 14 important perennial species that occurred in 10 or more stands and attempts to explain their within community dispersion patterns, their causes and ecological consequences. The major focus of the study is on the exposition of composition and structure and diversity of the vegetation and the factors regulating the species diversity and the distribution pattern of vegetation.

An important qualitative ecological characteristic that gives a certain structure to the flora, i.e., life-form or biological spectrum (Raunkiaer, 1934) which reflects the climatic influence and the disturbance regime (Cain & Castro, 1959; Mueller-Dumbois & Ellenberg, 1974) was also investigated. The objectives of this study were: 1) to provide a quantitative description of vegetation, species diversity and the relationship with the environmental factors using multivariate techniques of cluster analysis and ordination, 2) to analyze spatial patterns within communities, 3) to investigate the intensity of grazing/ harvesting of the vegetation to assess the degree of perturbation and stability of the ecosystem.

Materials and Methods

Study area: Hub Dam is located approximately 40 km on the North of Karachi (25°15 N and 67° 07 E) with an elevation of 150 m. The dam is surrounded by Kirthar Hills Mountains and was constructed on Hub River in 1981. The northern part of the dam is located in Baluchistan province while western and southern part comes under Sindh province. The former greater part is unprotected; however, the later is protected as it is included in the Hub Dam Wildlife Sanctuary. The vegetation sampling was performed between 25° 27 N and 67° 06 E and 25° 15 N and 67° 13 E.

The area comprises of arid plains and stony hills. There are many shallow bays and small islands within this natural reservoir which become unconsolidated when the hydraulic flow increases. Soils of the area are mostly to sandy-rocky. Limestone and shale are the major constituent rocks that give a typical geologic form to the area.

The climate of the area is of the type BWh (Koppen system) with annual rainfall is 195 mm indicating arid climate. The wet spell mostly starts in July and end in September. Average monthly temperature ranges between 12°C in January to 35ºC in May-June (Albulohom *et al.,* 2001).

Primarily, the attention was focused on the perennial species so that a significant differentiation among the habitats and their relationships with the environmental components could be determined. Moreover, the inclusion of monsoon annual flora in the analysis would mask the community structure and composition and any existing environmental gradients because of high year-to-year variability and diversity of such flora.

Sampling methodology: The study area comprises of the catchments area of Hub River in which 30 stands were sampled during April to September, 2011. The slopes and the hill tops were sampled by square plot 20×20 m in size, located within each stand. The criteria for the selection of stands were a) adequate size, b) as far as possible least recent disturbance from burning and c) visual homogeneity of vegetation. Each plot was subdivided into twenty five (4×4 m) square quadrats. The plots were permanently marked using steel nails and their geographical coordinates were noted using a GPS. Shrubs and trees and perennial herbs were sampled within the plots while the quadrats were used to determine the frequency of the sampled species (Mueller-Dumbois & Ellenberg, 1974). The frequency of summer annuals was noted in the sub-plots (quadrats) in each of the 30 stands during August & September, 2011.

Phytosociological attributes: The numbers of individuals were counted and the coverage of perennial herbs, shrubs and trees were measured in each plot. For each species percentage and relative frequency and absolute and relative density and coverage were calculated. The importance value (IV) was computed as the average of relative frequency, relative density and relative cover (Curtis and McIntosh, 1951).

Frequency and intensity of livestock grazing and wood/foliage harvesting were assessed using ordered scale ranging from zero (no exploitation) to 3 (highly grazed or harvested) in accordance with the practice of Enright *et al.,* (2005). Grazing could be recognized in the field with eaten leaves or twigs and broken branches while harvesting was exhibited by cut stumps of trees or bushes (see Enright *et al*., 5005) Each species was classified into its appropriate Raunkiaer's life-form class (Shaukat & Qadir, 1971) to construct the biological spectrum of the area.

Detection of spatial pattern of plant populations: Spatial pattern of individual species was detected employing two different indices of pattern detection using quadrat data of each stand. The indices were computed for those species present in at least 10 stands. Morisita's index (Morisita, 1971) which is unaffected by random thinning was used as one of the quadrat based method, as follows:

$$I_\delta = Q\ \Sigma\ X_i\ (X_i - 1)/\ N\ (N\text{-}1)$$

where N= Σ X*i*, Q equals the number of quadrats and X*i* are the number of individuals in each quadrat. The jackknife method of robust estimation was employed to obtain the variance of each estimate of I_δ (Chernick, 2011; Staudte & Sheather, 2011). The significance of I_δ was checked using an F-distribution (Greig-Smith, 1983):

$$F = (I_\delta\ (N\text{-}1) + Q\text{-}N)/\ (Q\text{-}1))$$

which is tested against $\upsilon_1 = Q$ and $\upsilon_2 = \infty$. Based on the quadrat data, the popular variance/mean ratio was also computed. The variance/mean ratio (s^2/m) of 1 corresponds to complete spatial randomness (CSR), a ratio >1 indicates aggregation, while a ratio <1 implies regular distribution. The significance of the ratio is usually determined using a t-test where the expected value is 1 (for CSR) and the standard error (SE) of the ratio is:

$$SE = (2/\ (n\text{-}1))^{½}$$

where n equals the number of quadrats. Alternatively, the significance of s^2/m ratio can be tested using a chi-squared (χ^2) test (Greig-Smith, 1983) as follows:

$$\chi^2 = (n\text{-}1)\ s^2/m$$

with n-1 degrees of freedom (Hurlbert, 1990). Despite some criticism regarding a ratio of 1 for random (Poisson distribution), the index is reliable for large and significant values of the ratio.

Simulation studies have shown that the methods used here for detection of spatial pattern are adequately powerful against both aggregate and regular alternatives (Shaukat, 2001). In addition to the above mentioned tests of significance developed for different pattern detection methods, 500 Monte Carlo simulations were performed using uniform random distributions in a sampling window A with the given plant density incorporating the edge effect (Shaukat, 2001; Shaukat & Siddiqui, 2005). The computer programs for all the computations of pattern analysis were developed by the first author (S.S.S.) and are available on request.

Multivariate analysis: Cluster analysis of the data was performed using Ward's clustering strategy and the Euclidean distance as the resemblance function (McCune & Grace, 2002) so as to expose the group structure in the vegetation data. Ordination was performed using correspondence analysis (CA) (Hill, 1973) and canonical correspondence analysis (CCA) (Ter Braak, 1986). Of these two methods, the former mostly exposes the vegetation pattern and compositional gradients while the latter disentangles simultaneously the vegetation-environmental pattern and the relationships between vegetation composition and the environmental gradients. The computations were performed using the program PC-ORD (version 6.0) (McCune and Grace, 2002; Peck, 2010) and the ordination plots were developed using the same package.

Correlations were sought between ordination axes and environmental variables (Zar, 2009).

Soil analysis: Soil samples were collected from all stands (plots). Soil samples from a depth of 0-15 cm were collected using a soil auger from 3 random points within a stand. The three soil samples were analyzed separately and the mean value for each characteristic was obtained as a representative value of the stand. The soil samples were analyzed for physical and chemical parameters. Soil pH was determined by a Dynamic digital pH meter (Model sension, TM 105, UK) after preparing a suspension in the ratio of 1:5 (Soil: distilled water w/v). Soil CO_3 (mostly occurring as $CaCO_3$) was determined in accordance with Shaukat *et al.,* (1981a). Kjeldahl method was used for analysis of total soil N (Horneck & Miller, 1998) whereas inorganic phosphate was determined in accordance with Fogg & Wilkinson (1958). Ca, Mg, K and Na were determined using Atomic absorption Spectrophotometer (Pie-Unicam) after preparing the samples as described in Moore & Chapman (1986). Water holding capacity of the soil was determined by the method of Keen (1931) as modified by Shaukat *et al.,* (1976).

Diversity analysis: The general species diversity (H) for perennial species was measured using the Popular Shannon-Weiner index (Booth *et al.,* 2003; Magurran, 2004; Krebs, 1999), as follows:

$$H = -\sum p_i \log p_i \qquad i=1\ldots S$$

where p_i is the proportion of *i*th species. The components of diversity, namely equitability (J) (Pielou, 1977) and species richness (d) (Menhinick, 1964) were calculated as follows:

$$J = H/ H_{max}$$

where H equals the observed diversity and H_{max} equals the maximal diversity (log S).

$$d = S/ \sqrt{N}$$

where S and N are total number of species and the total number of individuals respectively.

Dominance was calculated in accordance with the measure proposed by Simpson (1949) as follows:

$$D = \sum [ni\ (ni-1)/ (N\ (N-1)] \qquad i=1\ldots S$$

The computer program for dominance and diversity analysis DIVER was developed by the first author in C++ (Shaukat & Siddiqui, 2005) and is available on request.

Results

Vegetation: Fig. 1 showed the Hub-dam catchment area where sampling was carried out. The results of vegetation analysis are presented in Tables 1 and 2. In all 49 perennial species were recorded. Only 8 species occurred in 50 percent or more stands, namely: *Acacia senegal*, *Barleria acanthoides*, *Fagonia indica*, *Grewia tenax*, *Prosopis juliflora*, *Senna holosericea*, *Zizyphus nummularia* and *Indigofera oblongifolia* (Table 1). Six species occurred in 25-50 percent of the stands while the rest of the 33 species were present in less than 25 percent of the stands. *Acacia senegal* showed the highest average importance value, followed by *Prosopis juliflora*, *Iphiona grantioides*, *Grewia tenax* and *Indigofera oblongifolia.* *Acacia senegal* occurred as first dominant in 8 stands, as a second dominant in 4 and third dominant in 2 stands. *Prosopis juliflora* was the leading dominant in 7 stands and second dominant in 2 stands. Likewise, *Iphiona grantiodes* attained the position of first dominant in 7 stands but did not occur as second or third dominant.

In all 57 annual species were recorded from the study area (Table 2). Absolute density (number of individuals/ha) was highest for *Acacia senegal*, followed by *Cymbopogon jwarancusa, Senna holosericea*, *Aerva persica*, *Zizyphus nummularia* and *Prosopis juliflora* in that order. Coverage was highest for *Acacia sengal*, followed by *Prosopis juliflora*, *Aacacia nilotica*, *Salvadora oleoides*, *Zizyphus nummularia* and *Senna holosericea*. Six annual species occurred in more than 50 percent of the stands, including: *Aristida adscensionis*, *Conyza canadensis*, *Tragus roxburghii*, *Zygophyllum simplex*, *Cenchrus biflorus*, and *Digera muricata*, with an average frequency of 25.1 percent. Fourteen annual species were found in >25 to <50 percent of the stands, with an average frequency of 13.2 percent. Thirty species occurred in <25 to 3.33 percent of the stands with an average frequency of 3.72 percent. Seven species occurred only in one stand. The biological spectrum of the Hub-area showed the highest percentage of therophytes, followed by chamaephytes and phanerophytes. The hemicryptophytes and cryptophytes life-forms exhibited very low percentages (Fig. 2).

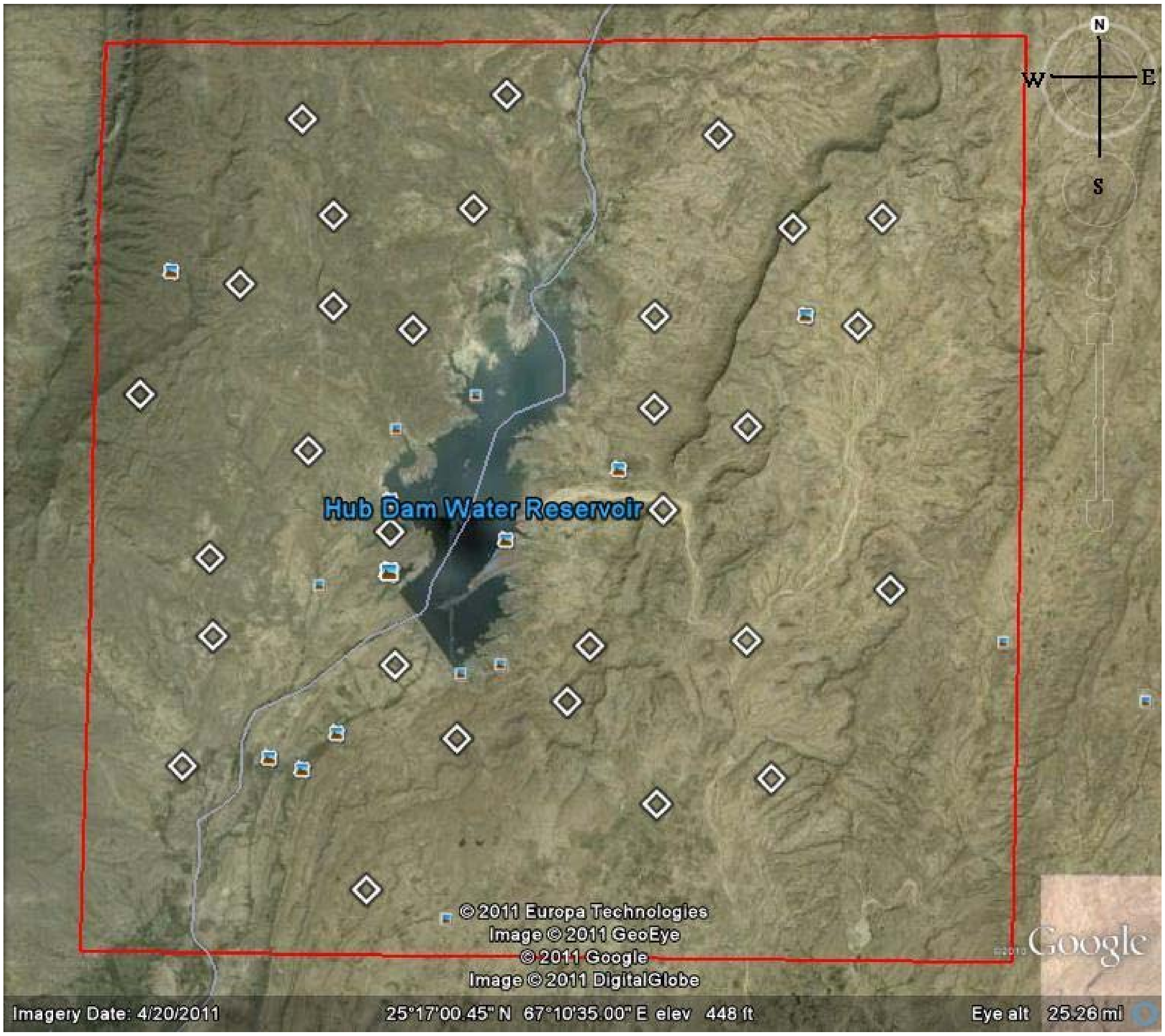

Fig 1. Study area map of the Hub-dam catchment area, Pakistan. Points show the locations of stands sampled.

Detection of spatial pattern of plant population: Table 3 gives the range variance/mean ratio attained by each of the selected species, their average values, range of t-statistic obtained and the number of times the species exhibited significant departure from complete spatial randomness (CSR). The results of variance/mean ratio and that of Morisita's index were closely similar (Tables 3 and 4). Surprisingly, none of the species showed regular distribution but all the species exhibited aggregated pattern in some or most of the stands in which they occurred. *Acacia senegal*, a tree species showed aggregated pattern in seven out of 19 stands in which it was present and was randomly distributed in 12 stands. On the other hand, *Prosopis juliflora* (an invasive tree species) was randomly distributed in 16 stands and contagiously distributed in only three out of 19 stands where it occurred. *Cymbopogon jwarancusa* (a perennial tufted-grass), *Barleria acnthoides*, *Grewia tenax*, *Indigofera oblogifolia*, *Aerva persica*, *Rhazya stricta* and *Iphiona grantiodes* (all shrubs) predominately exhibited aggregated pattern. However, the magnitude of the variance/mean ratio and Moristita's index varied considerably showing low or high intensity of aggregation where significant aggregation was exhibited (Tables 3 and 4). By Contrast, *Calotropis procera* and *Salvadora oleoides* were mostly randomly distributed. *Senna holosericea*, *Zizyphus nummularia* and *Vernonia cinerescens* showed either aggregated or random distribution pattern almost equal number of times in different stands. None of the species exhibited regular distribution. It is noteworthy that both methods of pattern detection and the Monte Carlo simulation tests for both the indices provided closely similar results to those obtained with the observed data thereby confirming the results of the classical tests (results not shown).

Agglomerative cluster analysis of stands: The dendrogram resulting from hierarchical agglomerative cluster analysis of species IV data using Ward's method is shown in Fig. 3. The dendrogram discloses four main groups at a squared Euclidean distance of 3.5×10^4 (information remaining 75%). Table 5 showed the dominance of tree species based on the groups extracted by Ward's cluster analysis. On the basis of four groups extracted by Ward's cluster analysis four groups of environmental variables are developed. With respect to environmental variables the four groups show considerable variability (Table 6).

Table 1. Mean importance value, presence in stands and number of times the species occurred as first, second and third dominant for tree, shrub and perennial herbs recorded from 30 stands of Hub Dam catchment area of Pakistan.

S. No.	Species	NSPP	Mean IV	Density/ha	Cover m^2/ha	1st dom	2nd dom	3rd dom
1..	*Acacia senegal* (L.) Willd.	19	14.47	154.92	788.14	8	4	2
2.	*Abutilon pakistanicum* Jafri & Ali	2	0.17	9.14	16.27	-	-	-
3.	*Acacia nilotica* (L.) Delile	3	0.60	18.47	182.84	-	-	-
4.	*Aristida mutabilis* Trin. & Rupr.	2	0.20	3.68	0.260	-	-	-
5.	*Aerva persica* (Burm. f.) Merrill	13	2.73	97.55	27.58	-	1	1
6.	*Aerwa pseudotomentosa* Blatt. & Hallb.	2	0.10	8.18	1.32	-	-	-
7.	*Barleria acanthoides* Vahl	17	3.60	89.51	38.28	-	-	1
8.	*Blepharis sindica* Stocks ex T. Anders.	4	2.53	12.83	1.27	-	3	-
9.	*Calotropis procera* (Willd.) R. Br.	11	2.87	79.04	152.91	-		3
10.	*Capparis decidua* (Forssk.) Edgew.	5	1.90	23.40	44.26	-	3	-
11.	*Capparis cartilaginea* Decne.	2	0.33	15.36	29.88	-	-	-
12.	*Cordial gharaf* (Forssk.) Eherenb.	2	0.10	10.18	11.51	-	-	-
13.	*Chloris barbata* Sw.	4	0.13	12.85	1.77	-	-	-
14.	*Cocculus pendulus* (Forsk.) Diels	7	0.90	24.09	19.65	-	-	-
15.	*Commiphora wightii* (Arnott) Bhandari	6	2.97	19.92	42.07	-	3	1
16.	*Convolvulus pluricaulis* Choisy	6	0.87	17.51	2.24	-	-	-
17.	*Chrysopogon aucheri* (Boiss.) Stapf.	4	0.23	12.27	0.87	-	-	-
18.	*Dactyloctenium scindicum* Boiss.	4	0.23	14.75	2.45	-	-	-
19.	*Hochstetteria schimperi* DC.	7	0.97	32.20	1.72	-	1	-
20.	*Euphorbia caducifolia* Haines	7	4.13	21.45	30.89	2	2	2
21.	*Euphorbia granulata* Forssk.	2	0.10	9.30	0.50	-	-	-
22.	*Cymbogon jawarancusa* (Jones) Schult.	18	3.93	126.90	28.25	2	-	1
23.	*Fagonia arabica* L.	3	0.13	7.65	2.46	-	-	-
24.	*Grewia tenax* (Forsk.) Ascher. & Schweinf.	17	5.53	86.31	73.41	-	2	2
25.	*Indigofera oblongifolia* Forsk.	16	5.07	81.43	68.15	1	2	1
26.	*Iphiona grantioides* (Boiss.) Anderb.	10	7.20	68.53	43.59	7	-	-
27.	*Cleome brachycarpa* Vahl	2	0.20	9.25	5.84	-	-	-
28.	*Parkinsonia aculeata* L.	2	0.10	8,79	13.92	-	-	-
29.	*Pentatropis nivilas* (J.F. Gmel.) Field & Wood	3	0.17	6.32	0.87	-	-	-
30.	*Periploca aphylla* Dcne.	3	0.23	9.58	1.73	-	-	-
31.	*Prosopis glandulosa* Torr.	2	0.30	8.45.	14.68	-	-	-
32.	*Prosopis juliflora* DC.	19	12.87	96.05	768.29	7	2	1
33.	*Pteropyrum olivieri* Jaub. & Spach	9	2.37	24.69	20.95	1	-	2
34.	*Rhazya stricta* Decne	11	2.87	58.67	17.61	-	-	2
35.	*Salvadora oleoides* Decne	13	4.27	65.30	169.88	1	2	1
36.	*Salvia santolinifolia* Boiss.	7	0.77	24.63	1.94	-	-	-
37.	*Cenchrus setigerus* Vahl	4	0.23	8.76	3.85	-	-	-
38.	*Senna holosericea* (Fresen.) Greuter	15	4.77	125.84	102.86	-	2	3
39.	*Setaria intermedia* Roem. & Schult.	2	0.33	16.62-	1.07	-	-	-
40.	*Saccharum spontaneum* (L.), Mant.	2	0.17	14.17	2.06	-	-	-
41.	*Solanum surattense* Burm. f.	3	0.40	15.73	2.64	-	-	-
42.	*Tamarix dioica* Roxb. ex Roch,	2	0.43	14.68	2.86	-	-	-
43.	*Tamarix indica* Willd.	2	0.33	16.39	20.63	-	-	-
44.	*Tephrosia subtriflora* Baker	3	0.13	9.45	1.57	-	-	-
45.	*Trianthema pentandra* L.	2	0.10	7.65	1.29	-	-	-
46.	*Vernonia cinerescens* Schultz-Bip.	11	2.13	45.86	33.19	-	-	2
47.	*Zizyphus nummularia* (Burm. f.) Wt. & Arn.	15	5.17	96.08	156.47	1	3	5
48.	*Tribulus terrestris* L.	3	0.36	12.36	2.44	-	-	-
49.	*Digitaria nodsa* Parl.	1	0.14	7.81-	1.92	-	-	-

Key to abbreviations: NSPP = No. of stands in which species was present, IV = Importance value, ha = hectare and dom = dominant

Table 2. Presence of annual species in the 30 stands together with their frequency range and average frequency.

Sr. No.	Species	Presence of sp. in no. of stands	Range of F_1	Average frequency
1.	*Aristida adscensionis* L.	23	31.25-93.75	43.13
2.	*Conyza canadensis* (L.) Cronquist	21	25-68.75	28.54
3.	*Tragus roxburgii* Panigari	20	18.75-56.25	24.79
4.	*Zygophyllum simplex* L.	19	12.5-50	19.79
5.	*Cenchrus biflorus* Roxb.	18	18.75-68.75	17.92
6.	*Digera muricata* (L.) Mart	16	6.25-43.75	15.83
7.	*Rhynchosia minima* (L.) DC.	14	12.5-50	14.79
8.	*Eragrostis ciliaris* (L.) R. Br.	13	12.75-43.75	14.17
9.	*Indigofera cordifolia* Heyne	12	18.75-56.25	16.04
10.	*Achyranthes aspera* L.	12	12.5-50	15.42
11.	*Eragrostis pilosa* (L.) Beauv.	12	6.25-43.75	15.21
12.	*Indigofera hochstetteri* Baker	11	18.75-43.75	13.33
13.	*Pulicaria angustifolia* DC.	11	12.5-56.25	13.75
14.	*Amaranthus lividus* L.	10	18.75-50	14.17
15.	*Cleome scaposa* DC.	10	25-50	13.75
16.	*Dactyloctenium aegyptium* (L.) Beauv.	10	12.5-56.25	13.13
17.	*Euphorbia prostrata* Ait.	9	18.75-43.75	11.88
18.	*Portulaca oleracea* L.	9	18.75-31.25	11.25
19.	*Tephrosia strigosa* (Dalz.) Sant. & Mahesh.	8	12.5-50	9.17
20.	*Aristida funiculata* Trin. & Rupr.	8	6.25-56.25	8.68
21.	*Corchorus trilocularis* L.	7	12.5-56.25	8.33
22.	*Heliotropium subulatum* (DC.) Vatake	7	12.5-50	8.13
23.	*Leucas urticifolia* R. Br.	6	12.5-37.5	6.25
24.	*Glinus lotoides* L.	6	12.5-50	6.88
25.	*Oldenlandia aspera* DC.	6	12.5-56.25	7.08
26.	*Peristrophe bicalyculata* (Retz.) Nees	6	6.25-37.5	5.83
27.	*Schweinfurthia pediceilata* (T. Anders.) Bth. Hk. f.	5	12.5-37.5	4.58
28.	*Puilcaria boissieri* Hk. f.	5	12.5-50	5.42
29.	*Sporobolus coromendelianus* (Retz.) Kunth	5	6.25-56.25	5.21
30.	*Aizoon canariense* L.	5	12.5-62.5	5.63
31.	*Anticharis linearis* (Bth.) Hochst. ex Aschers	4	12.5-50	3.75
32.	*Senna occidentalis* (L.) Link	4	6.25-56.25	3.96
33.	*Elionurus royleanus* Nees es A. Rich.	4	12.5-37.5	4.38
34.	*Cleome gynandra* L.	3	25-31.25	2.71
35.	*Indigofera linifolia* (L. f.) Retz.	3	12.5-43.75	2.5
36.	*Convolvulus scindicus* Stocks	3	12.5-37.5	2.29
37.	*Monosonia heliotropioides* (Cav.) Boiss.	3	18.75-43.75	2.92
38.	*Polycarpaea spicata* Wight and Arn.	3	18.75-56.25	3.54
39.	*Polygala erioptera* DC.	3	18.75-50	3.13
40.	*Cleome viscosa* L.	3	12.5-43.75	3.33
41.	*Oligochaeta ramosa* (Roxb.) Wagenitz.	2	18.75-43.75	2.1
42.	*Chrozophora obliqua* (Vahl) Juss. ex. Spreng.	2	12.5-18.75	1.04
43.	*Convolvulus arvensis* L.	2	6.25-18.25	0.83
44.	*Corchorus tridens* L.	2	6.25-25	1.25
45.	*Glossonema varians* (Stocks) Bth.	2	12.5-25	1.875
46.	*Hibiscus aristivalvis* Garcke	2	18.75-37.5	1.875
47.	*Leucas nutans* Sperng.	2	12.5-37.5	1.67
48.	*Amaranthus viridis* L.	2	18.75-25	1.46
49.	*Physalis minima* L.	2	18.75-25	1.46
50.	*Trichodesma indicum* var. *emplexicaule* (Roth.) Cooke	2	18.75-43.75	2.1
51.	*Sida spinosa* L.	1	6.25	0.21
52.	*Vernonia cinerea* (L.) Less.	1	18.75	0.63
53.	*Corbichonia decumbens* (Forssk.) Exell	1	18.75	0.63
54.	*Xanthium stramarium* L.	1	25	0.83
55.	*Cenchrus pennisetiformis* Hochst.	1	31.25	1.04
56.	*Echinochloa colonum* (L.) Link.	1	37.5	1.25
57.	*Setaria verticillata* (L.) Beauv.	1	43.75	1.46

Fig. 2. Percentage occurrence of a total of 106 species in various Raunkiaerian Life-form Classes in the Hub-Dam catchment area, Pakistan.
Key to abbreviations: Ph = phanerophyte; Ch= chamaephyt; H= hemicryptophyte; Cr= cryptophytes; Th =therophyte.

Group I comprising of 12 stands, is characterized by the predominance of *Acacia senegal* and *Prosopis juliflora* attained 13.04 and 10.17% average importance value respectively, while *Indigofera oblongifolia, Zizyphus nummularia, Senna holosericea, Fagonia indica, Aerva javanica, Salvadora oleoides, Calotropis procera* and *Barleria acanthoides* (average importance value = 8.67, 8.25, 7.67, 7.42, 5.67, 5.83, 4.42 and 4.17% respectively) also were conspicuously associated in this group. The nitrogen content and the maximum water holding capacity of soil were high while potassium, calcium and magnesium content were lower compared to other groups. Both grazing and harvesting index were moderate for this group.

Group II that includes 7 stands dominated by *Iphiona grantiodes* and *Blepharis sindica* achieved 29.57 and 10.86% average importance value while *Grewia tenax, Rhazya stricta, Indigofera oblongifolia, Senna heloseracia* and *Zizyphus nummularia* (average importance value = 7.86, 6.71, 5.43, 4.87 and 4.71% respectively) showed lower abundance. This community type seems to represent relatively pioneer or pioneer-to-intermediate community. The community generally prevails on flat-tops of the hills or rocky-stony ground. Nitrogen and phosphorus content were lower compared to other groups but exchangeable calcium, magnesium and water holding capacity of soil were high. Grazing and harvesting indices for this community type was low.

Group III which comprises of 7 stands is predominated by *Acacia senegal* (average importance value = 36.71%) while *Euphorbia caducifolia* is also conspicuous (average importance value = 17.71%). *Grewia tenax, Commiphora wightii* and *Salvadora oleoides* has comparatively low abundance (average importance value = 10.86, 9.86 and 7.86% respectively) in this group. Total nitrogen and phosphorus content contents were high but exchangeable magnesium and to some extent exchangeable calcium contents were low. The carbonate content and pH were relatively low. This community type represents most mature, i.e., climax community dominated by the physiographic climax species of the hills in the study area. Grazing and harvesting indices were low for this community type.

Group IV is the smallest group of this study, which comprised of four stands dominated by *Prosopis juliflora* (55% average importance value) while *Capparis decidua, Zizyphus nummularia* and *Acacia senegal* were also associated with the dominant species, attained 12.25, 5.75 and 3.25% respectively. This community type undoubtedly represents a disturbed community, firstly because of the dominance of an invading exotic species *Prosopis juliflora* and also because of the high importance value of *Capparis deciduas* that is usually found with high abundance in disturbed communities, particularly near construction sites. The total nitrogen content of soil, pH and carbonate content were low. On the other hand Phosphorus, exchangeable K, Ca and Na contents were relatively higher. Grazing as well as harvesting indices were recorded to be highest for this community type.

Significance between group differences, using one-way ANOVA (Table 7) was obtained for nitrogen ($p<0.05$), phosphorus ($p<0.001$), potassium ($p<0.1$), exchangeable calcium ($p<0.05$), exchangeable sodium ($p<0.001$) and soil calcium carbonate ($p<0.05$).

Ordination

1. Correspondence analysis: The correspondence analysis (CA) ordination on axes 1 and 2 is shown in Fig. 4. The first axis of CA ordination explained 19.417 percent, the second axis of ordination accounted for 18.877 percent while the third axis explained 12.916 percent of the total variance in the data matrix (Table 8). Together the three axes accounted for 51.21 percent of the total variance inherent in the data set (Table 8). Four groups derived from cluster analysis could readily be superimposed on the two dimensional CA configuration. Furthermore, continuity in vegetation from right to the left of the ordination was depicted. On the right side (group II) the stands are dominated by early successional species, i.e., the undershrubs *Iphiona grantiodes* and *Barleria acanthoides*, in the middle (group I) comprises of mid-successional shrubs *Indigofera oblongifolia, Zizyphus nummularia* and *Senna holosericea*, in addition to climax species *Acacia senegal,* while on the right side of the ordination (group III) the stands are dominated by the climax species *Acacia senegal* (a tree species) and *Euphorbia caducifolia* (a large cactoid shrub) and other large shrubs such as *Grewia tenax* and *Commiphora wightii.*

Ordination axis 1 (Table 9) showed significant correlation with nitrogen ($p<0.05$), exchangeable Mg ($p<0.05$) and water holding capacity ($p<0.05$). Ordination axis 2 did not exhibit correlation with any of the soil variables. The third ordination axis was found correlated with total nitrogen ($p<0.05$), exchangeable sodium ($p<0.01$) and with soil carbonate content (negative correlation, $p<0.05$).

Table 3. The range of variance/mean ratio, average of variance/mean ratio, range of t-statistic, number of times significant aggregation found, number of time random and regular distribution recorded for trees, shrubs and perennial herbs in the stands where they occurred out of 30 stands of the Hub Dam catchment area of Pakistan.

Sr. No.	Species	Range of V/M ratio	Avg. of V/M ratio	Range of t-value	No. of times significant aggregation	No. of time random	No. of time regular
1.	*Acacia senegal*	1.007-1.922	1.456	0.224-2.67	7	12	0
2.	*Prosopis juliflora*	0.912-1.681	1.321	0.126-2.361	3	16	0
3.	*Cymbogon jwarancusa*	1.226-2.473	1.912	0.783-5.105	15	3	0
4.	*Barleria acanthoides*	1.75-3.642	2.195	1.61-7.321	16	1	0
5.	*Grewia tenax*	1.486-2.137	1.789	1.665-3.939	14	3	0
6.	*Indigofera oblongifolia*	1.68-2.442	2.048	2.365-4.996	16	0	0
7.	*Senna holosericea*	1.179-2.362	1.665	0.621-4.718	8	7	0
8.	*Zizyphus nummularia*	1.021-1.961	1.5334	0.07-3.33	7	8	0
9.	*Aerva persica*	1.641-2.638	2.036	2.43-5.677	13	0	0
10.	*Salvadora oleoides*	1.137-2.326	1.422	0.849-2.416	5	8	0
11.	*Calotropis procera*	1.181-1.596	1.326	0.629-2.106	2	9	0
12.	*Rhazya stricta*	1.453-2.631	1.658	1.405-2.718	7	4	0
13.	*Vernonia cinerescens*	0.562-2.385	1.435	1.079-4.866	5	6	0
14.	*Iphiona grantioides*	1.235-2.418	1.644	1.220-3.816	7	3	0

Table 4. The range of Lloyd's and Morisita's index and their respective variances and the number of times significant aggregation found for trees, shrubs and perennial herbs in the stands where they occurred out of 30 stands of the Hub Dam catchment area.

Sr. No.	Species	Lloyd Index (range)	Variance (range)	Morisita Index (range)	Variance (range)	No. of times significant aggregation
1.	*Acacia senegal*	1.375-2.3	0.0115-0.0988	0.496-1.851	0.019-0.2166	5
2.	*Prosopis juliflora*	1.012-1.941	0.024-0.144	0.944-2.225	0.015-0.367	3
3.	*Cymbogon jwarancusa*	1.44-2.894	0.059-0.32	1.132-2.136	0.0205-0.3122	11
4.	*Barleria acanthoides*	1.666-2.208	0.066-0.404	1.438-2.826	0.11-1.149	14
5.	*Grewia tenax*	1.23-2.411	0.0626-0.135	0.367-2.564	0.083-1.001	13
6.	*Indigofera oblongifolia*	1.41-2.384	0.057-0.364	1.468-2.569	0.06-0.673	13
7.	*Senna holosericea*	1.692-2.333	0.04-0.236	0.460-2.367	0.019-0.242	8
8.	*Zizyphus nummularia*	1.459-1.923	0.0492-0.106	1.013-1.923	0.023-0.235	6
9.	*Aerva persica*	1.411-2.733	0.069-0.422	1.480-2.356	0.116-0.551	10
10.	*Salvadora oleoides*	1.391-2.572	0.0549-0.386	0.711-2.219	0.105-0.798	3
11.	*Calotropis procera*	0.823-2.052	0.063-0.182	1.21-1.500	0.035-0.188	0
12.	*Rhazya stricta*	1.015-2.414	0.0522-0.118	1.398-2.416	0.025-0.224	7
13.	*Vernonia cinerescens*	1.454-2.514	0.0173-0.196	1.343-2.279	0.014-0.236	4
14.	*Iphiona grantioides*	1.592-2.661	0.0148-0.159	1.478-2.630	0.011-0.382	6

2. Canonical correspondence analysis: The eigenvalues, percentage explained variance and cumulative percentage variance for the first three canonical axes are given in Table 10. Together the first three canonical axes accounted for 24.2 percent of the total variance. The Pearson correlation between the first canonical pair (U_1, V_1) was 0.887 while Kendall's rank correlation was 0.724 indicating that the vegetation composition is amply correlated with soil characteristics. The Pearson correlation between the second canonical pair (U_2, V_2) was 0.852 while rank correlation was 0.655. The Pearson correlation between the third canonical pair (U_3, V_3) was 0.650 while the rank correlation was 0.503. The CCA biplot presented in Fig. 5 shows correlation of maximum water holding capacity and magnesium with the first canonical axis while $CaCO_3$, total nitrogen, potassium and phosphorus exhibit correlation with the second canonical axis. Similar relationships are shown in Table 11 that gives the correlations between soil variable and the three canonical axes of the vegetation data. The first canonical axis was negatively correlated with Mg^{++} and maximum water holding capacity ($p<0.01$). The second axis was positively correlated with nitrogen and carbonate ($p<0.01$ and $p<0.001$ respectively) and negatively correlated with P, K+, Ca^{++}, Mg^{++} and Na (P at the most 0.01). The third canonical axis did not exhibit correlation with any of the soil variables.

Diversity analysis: General species diversity (H) and equitability (J) were lowest for group IV (Table 12) which represents a disturbed community. The highest, diversity, equitability and species richness were recorded for group I which is *Acacia senegal* and *Prosopis juliflora* dominated community. Diversity, equitability and species richness were intermediate for groups II and III which represent flat hill top and hill slope (climax) communities respectively. In general, dominance (D) was high when diversity (H) was low and vice *versa*.

Table 5. The four groups of vegetation derived from Ward's cluster analysis of 30 stands of Hub Dam catchment area and their average species composition (average importance value of species for each group).

Sr. No.	Species	Group I	Group II	Group III	Group IV
1.	*Acacia senegal* (L.) Willd.	**13.04**	1.14	**36.71**	**3.25**
2.	*Abutilon pakistanicum* Jafri & Ali	0.17	0.43	*	*
3.	*Acacia nilotica* (L.) Delile	0.67	0.43	1.00	*
4.	*Aristida mutabilis* Trin. & Rupr.	0.33	0.29	*	*
5.	*Aerva persica* (Burm. f.) Merrill	**5.67**	0.43	0.57	1.75
6.	*Aerwa pseudotomentosa* Blatt. & Hallb.	0.17	0.14	*	*
7.	*Barleria acanthoides* Vahl	**4.17**	**7.57**	0.71	*
8.	*Blepharis sindica* Stocks ex T. Anders.	0.00	**10.86**	*	*
9.	*Calotropis procera* (Willd.) R. Br.	**4.42**	1.86	*	5
10.	*Capparis decidua* (Forssk.) Edgew.	0.25	0.71	*	**12.25**
11.	*Capparis cartilaginea* Decne.	0.42	*	0.71	*
12.	*Cordial gharaf* (Forssk.) Eherenb.	0.25	*	*	*
13.	*Chloris barbata* Sw.	0.17	0.14	0.14	*
14.	*Cocculus pendulus* (Forsk.) Diels	0.83	*	2.43	*
15.	*Commiphora wightii* (Arnott) Bhandari	0.50	2.00	**9.86**	*
16.	*Convolvulus pluricaulis* Choisy	1.42	0.71	0.57	*
17.	*Chrysopogon aucheri* (Boiss.) Stapf.	0.42	*	0.29	*
18.	*Dactyloctenium scindicum* Boiss.	0.00	0.14	0.86	*
19.	*Hochstetteria schimperi* DC.	2.25	0.29	*	*
20.	*Euphorbia caducifolia* Haines	*	*	**17.71**	*
21.	*Euphorbia granulata* Forssk.	0.08	0.29	*	*
22.	*Cymbogon jwarancusa* (Jones) Schult.	**7.42**	2.57	*	2.75
23.	*Fagonia arabica* L.	0.17	0.14	0.14	*
24.	*Grewia tenax* (Forsk.) Ascher. & Schweinf.	2.92	**7.86**	**10.86**	*
25.	*Indigofera oblongifolia* Forsk.	**8.67**	**5.43**	*	2.5
26.	*Iphiona grantioides* (Boiss.) Anderb.	0.67	**29.57**	*	0.25
27.	*Cleome brachycarpa* Vahl	0.50	*	*	*
28.	*Parkinsonia aculeata* L.	*	0.43	*	*
29.	*Pentatropis nivilas* (J.F. Gmel.) Field & Wood	*	0.00	0.71	*
30.	*Periploca aphylla* Dcne.	0.33	0.43	*	*
31.	*Prosopis glandulosa* Torr.	0.00	0.00	*	2.25
32.	*Prosopis juliflora* DC.	**10.17**	2.43	3.86	**55**
33.	*Pteropyrum olivieri* Jaub. & Spach	3.75	0.71	3.00	*
34.	*Rhazya stricta* Decne	2.75	**6.71**	0.86	*
35.	*Salvadora oleoides* Decne	**5.83**	0.43	**7.86**	*
36.	*Salvia santolinifolia* Boiss.	1.08	1.43	*	*
37.	*Cenchrus setigerus* Vahl	0.50	0.14	*	*
38.	*Senna holosericea* (Fresen.) Greuter	**7.67**	**4.57**	0.71	3.5
39.	*Setaria intermedia* Roem. & Schult.	0.17	1.14	*	*
40.	*Saccharum spontaneum* (L.), Mant.	0.08	0.00	*	1
41.	*Solanum surattense* Burm. f.	0.58	0.71	*	*
42.	*Tamarix dioica* Roxb. ex Roch,	*	*	*	3.25
43.	*Tamarix indica* Willd.	0.42	*	*	1.25
44.	*Tephrosia subtriflora* Baker	0.08	0.29	*	0.25
45.	*Trianthema pentandra* L.	*	0.43	*	*
46.	*Vernonia cinerescens* Schultz-Bip.	3.08	3.29	0.57	*
47.	*Zizyphus nummularia* (Burm. f.) Wt. & Arn.	**8.25**	**4.71**	*	**5.75**
48.	*Tribulus terrestris* L.	**0.35**	*****	*	**0.42**
49.	*Digitaria nodsa* Parl.	*****	**0.16**	*	*****

* Absent

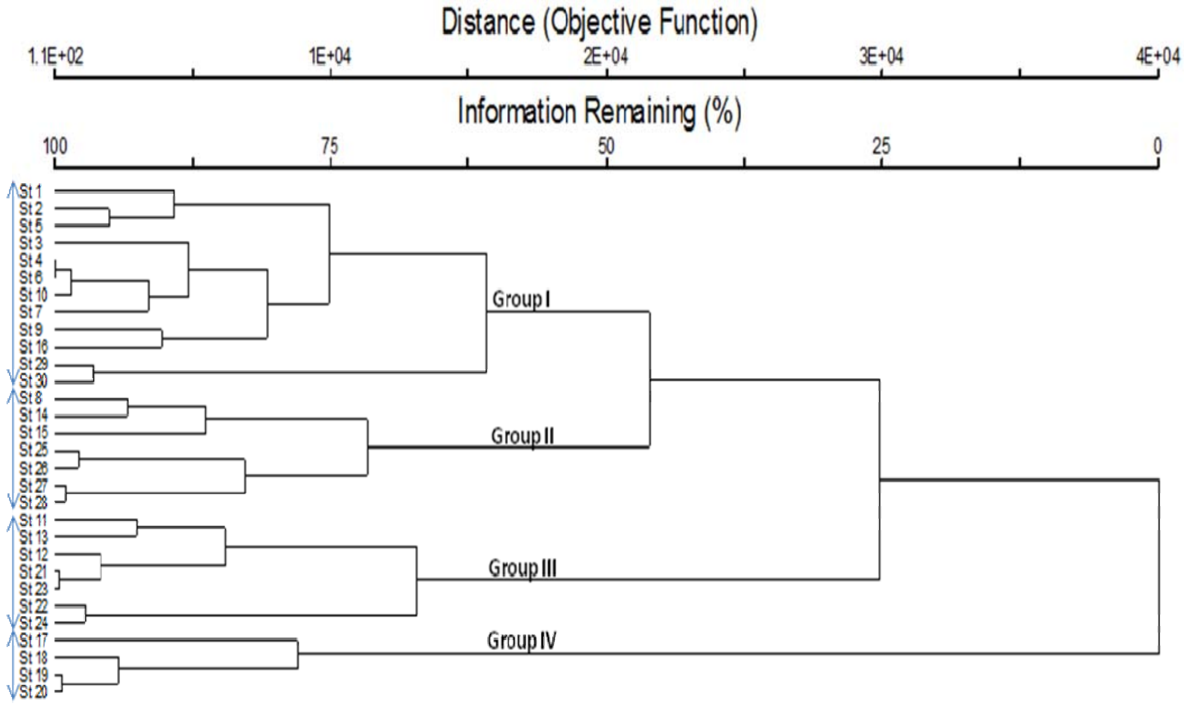

Fig. 3. Dendrogram derived from Ward's cluster analysis using perennial species data of 30 stands of Hub Dam catchment area. Stand numbers are shown at the base.

Table 6. The mean values of edaphic variables, grazing and harvesting index based on the four groups obtained from Ward's method of cluster analysis using vegetation data of 30 stands of Hub dam catchment area of Pakistan (Mean ± SE).

Sr. No.	Variables	Group I Mean ± SE	Group II Mean ± SE	Group III Mean ± SE	Group IV Mean ± SE
1.	N	0.17 ± 0.02	0.14 ± 0.017	0.1843 ± 0.015	0.105 ± 0.012
2.	P	9.0 ±0.89	13.143 ± 1.078	15.143 ± 1.455	16.5 ± 0.646
3.	K^+	11.08 ± 1.23	16.14 ± 0.63	15.714 ± 0.747	16.5 ± 0.646
4.	Ca^{++}	33.25 ± 3.48	46.429 ± 3.565	41.143 ± 2.61	48 ± 2.94
5.	Mg+	16.67 ± 1.103	20 ± 1.29	17.0 ± 0.436	18.75 ± 1.601
6.	Na^+	51.58 ± 2.64	62.57 ± 4.07	66.0 ± 2.75	72.75 ± 1.797
7.	CO_3	22.0 ± 1.82	16.84 ± 2.04	14.53 ± 1.40	16.46 ± 0.1.32
8.	pH	7.9 ± 0.076	7.6 ± 0.101	7.6 ± 0.031	7.8 ± 0.048
9.	WHC	22.45 ± 0.76	24 ± 0.643	26.1 ± 0.522	21.5 ± 1.01
10.	Grazing index	1.13	0.78	0.67	1.42
11.	Harvesting index	1.25	0.50	0.86	1.65

Key to abbreviation: SE = Standard error and WHC = water holding capacity

Table 7. Single factor analysis of variance (ANOVA) of the soil variables for the four groups derived from Ward's method of cluster analysis of the vegetation of Hub dam catchment area.

Sr. No.	Soil variables	F-value	P-value	Significance-level
1.	Nitrogen	3.21956	0.03905	<0.05
2.	Phosphorus	9.22069	0.00025	<0.001
3.	Potassium	6.37623	0.00220	<0.01
4.	Calcium	3.78405	0.02237	<0.05
5.	Magnesium	1.84592	0.16365	ns
6.	Sodium	7.8925	0.0007	<0.001
7.	CO_3	3.81131	0.02178	<0.05
8.	pH	0.1673	0.9174	ns
9.	WHC	1.5134	0.2344	ns

Table 8. Eigenvalues, percentage variance explained and cumulative % variance obtained in Correspondence Analysis (CA) of the vegetation of Hub dam catchment area of Pakistan.

Serial No.		Axis 1	Axis 2	Axis 3
1.	Eigenvalue	0.5757	0.5597	0.3237
2.	% of variance explained	19.417	18.877	12.916
3.	Cumulative % explained	19.41792	38.294	51.21

Total variance ("inertia") in the species data: 2.9650

Table 9. Correlation coefficients between the CA axes and the soil variables of the Hub dam catchment area of Pakistan.

Sr. No.	Soil variables	Axis 1	p value	Axis 2	p value	Axis 3	p value
1.	N	-0.349	P<0.05	-0.145	ns	-0.223	ns
2.	P	-0.063	ns	-0.061	ns	0.43	P<0.05
3.	K^+	0.131	ns	-0.106	ns	0.281	ns
4.	Ca^{++}	0.271	ns	-0.114	ns	0.249	ns
5.	Mg^{++}	0.445	P<0.05	-0.106	ns	0.013	ns
6.	Na^+	-0.108	ns	0.013	ns	0.506	P<0.01
7.	CO_3	-0.092	ns	0.085	ns	-0.328	P<0.05
8.	pH	-0.1	ns	0.125	ns	0.109	ns
9.	WHC	0.35	P<0.05	-0.149	ns	-0.252	ns

Table 10. Canonical correspondence analysis (CCA) of the vegetation data and the soil variables of the Hub dam catchment area.

Sr. No.		Axis 1	Axis 2	Axis 3
1.	Eigenvalue	0.417	0.191	0.143
2.	% of variance explained	13.4	6.1	4.6
3.	Cumulative % explained	13.4	19.6	24.2
4.	Pearson correlation	0.887	0.852	0.650
5.	Kendall (Rank) correlation	0.724	0.655	0.503

Table 11. Inter-set correlations for 9 soil variables of the Hub dam catchment area with the corresponding vegetation axes.

Sr. No.	Soil variables	Axis 1	p value	Axis 2	p value	Axis 3	p value
1.	N	0.284	ns	0.507	P<0.01	0.311	ns
2.	P	0.144	ns	-0.664	P<0.001	0.14	ns
3.	K^+	-0.089	ns	-0.481	P<0.01	0.17	ns
4.	Ca^{++}	-0.247	ns	-0.695	P<0.001	0.168	ns
5.	Mg^{++}	-0.473	p<0.01	-0.495	P<0.01	0.199	ns
6.	Na^+	0.227	ns	-0.503	P<0.01	-0.109	ns
7.	CO_3	0.046	ns	0.729	P<0.001	-0.192	ns
8.	pH	0.149	ns	0.157	ns	-0.291	ns
9.	WHC	-0.444	p<0.05	0.018	ns	0.323	ns

Table 12. Averages of species diversity (H), equitability (J), species richness (d_1) and Simpson's dominance (D) values formulated on the basis of four groups obtained by Ward's cluster analysis of vegetation data.

Groups	Species diversity (H)	Equitability (J)	Species richness (d_1)	Dominance (D)
Group I	2.276	0.902	1.307	0.120
Group II	2.019	0.859	1.037	0.256
Group III	1.667	0.805	0.814	0.239
Group IV	1.137	0.683	0.848	0.345

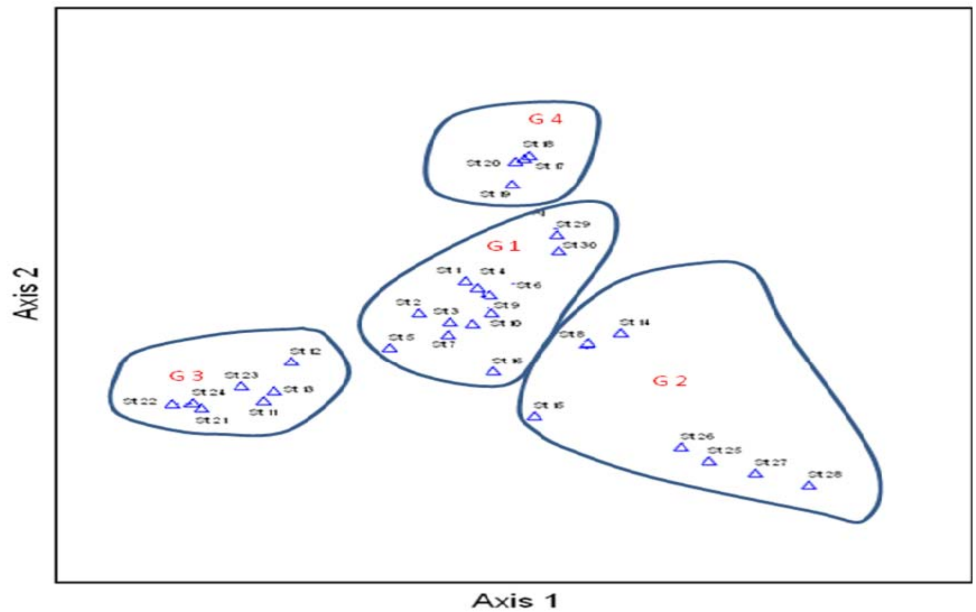

Fig. 4. Two-dimensional correspondence analysis (CA) ordination of 30 stands based on 49 perennial species in the vegetation of Hub-Dam catchment area. Four groups derived from Ward's cluster analysis are superimposed on the ordination plane. G1 to G4 represent the four groups.

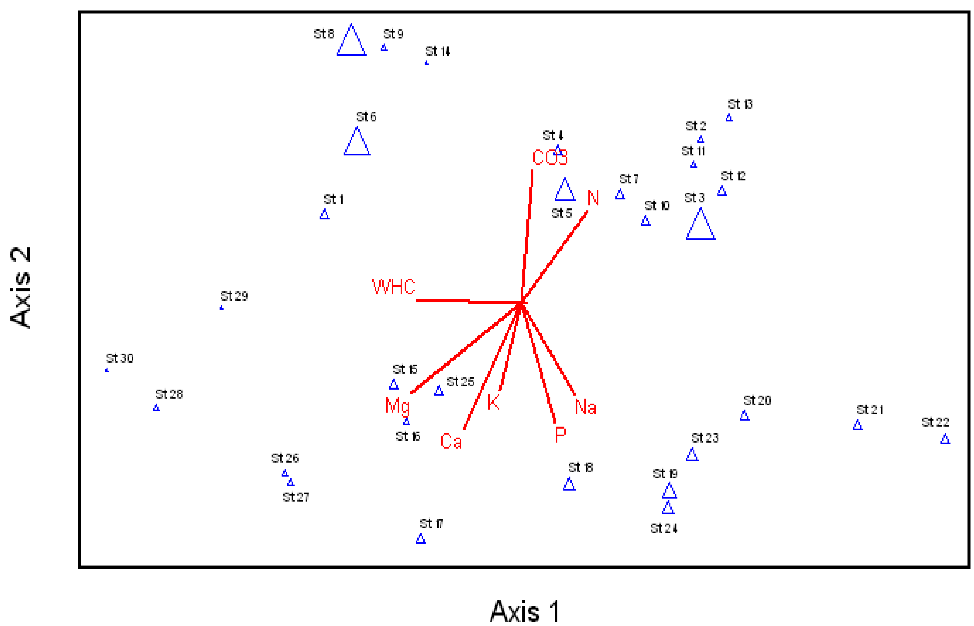

Fig. 5. Two dimensional canonical correspondence analysis (CCA) biplot showing stand and the correlations (directed lines) with the soil variables. The size of triangles (points) corresponds directly to soil pH.

Discussion

The vegetation of the Hub Dam area was found to be fairly rich in species diversity as a total of 49 perennial herbs, shrubs and trees while a total of 57 annuals were recorded from the area. The dominant species in terms of IV% in the area were: *Acacia senegal*, *Barleria acanthoides*, *Fagonia indica*, *Grewia tenax*, *Prosopis juliflora*, *Senna holosericea*, *Zizyphus nummularia* and *Indigofera oblongifolia*, Most of the plant species belonged to the Saharo-Sindian element (Anon., 1997; Stewart, 1972). According to Wickens (1976) Saharo-Sindian region extends from Morocco and Mauritania eastwards to Sinai and extra-tropical Arabia, south Iraq. Iran, Baluchistan, desert of Sindh and the Punjab (Pakistan). Although the part of area surveyed lies in the province of Baluchistan we found that a vast majority of the floral element comprised of species common in the province of Sind. Such species extend eastward to Indian desert of Jodhpur (Sen, 1982). No endemic species was found in the area but some interesting species were recorded including *Capparis cartilaginea* (that has become a rare species on calcareous hills) and annuals that have become rare within the last two decades, such as *Oligochaeta ramosa*, *Chrozophora obliqua* and *Glossonema varians.*

The results of spatial pattern analysis of shrubs and the perennial herb (*C. jwarancusa*) populations disclosed predominately aggregated patterns. Such aggregated patterns in arid-land (or desert) shrubs and trees have been observed by many workers (Wright & Howe, 1987; Skarpe, 1991; Haase, 1995; Hegazy & Kabiel, 2007; Shaukat *et al.,* 2012). When the two measures of pattern detection were significant they showed variation in the magnitude, indicating the low or high degree of aggregation. Miriti *et al.,* (1998) also observed such variation in the value of Morisita index (see below). The principal causes of aggregated pattern observed for shrubs and the grass appear to be environmental heterogeneity i.e., patchy distribution of soil resources (Schenk *et al.,* 2003; Tirado & Pugnaire, 2003; Perry *et al.,* 2008) such as soil nitrogen (Schlesinger *et al.,* 1996) and soil moisture (Evans & Ehleringer, 1994), limited seed dispersal (shrubs and the grass) and vegetative reproduction (*Zizyphus nummularia*) (Monzeglio, 2007; Alvarez *et al.,* 2011). If soil resources are heterogeneous within a stand, as observed here (data not shown) and in other studies (Tirado & Pugnaire, 2003; Schurr *et al.,* 2004) seed germination and seedling survival is higher in some microsites (Holmgren *et al.,* 1997), this alone could create spatial aggregation of shrubs. On the other hand, *Calotropis procera*, a large shrub and the invasive tree species *Prosopis juliflora* that are known to colonize disturbed open sites (or sites with gaps) predominately exhibited random distribution. In the colonizing phase most species are randomly distributed. Moreover, *Calotrpis procera* has small plumed seeds that have anemochoric dispersal and seeds tend to fall randomly and germinate in the gaps (created by disturbance) because of greater chances of availability of safe sites at such locations. Whereas, *Prosopis juliflora* that has zoochoric /endozoochoric mode of dispersal and is dispersed by livestock and wild animals (Mworia *et al.,* 2011). The physiographic climax tree species *Acacia senegal* showed aggregated pattern in 7 out of 19 stands. Miriti *et al.,* (1998), Miriti (2007) and Kenkel *et al.,* (1997) demonstrated that the spatial pattern is not static and changes over time. As a consequence of random thinning the aggregated pattern can gradually change to random and subsequently to regular (Kenkel *et al.,* 1997; Miriti *et al.,* 1998). This would explain the aggregated as well as random patterns exhibited by the physiographic climax tree *Acacia senegal* which presumably changes its pattern with the passage of time (in ecological time scale) because of differential mortality and different phases of competition (cf. Kenkel *et al.,* 1997; Maestre, 2006). Furthermore, the community composition and structure could be influenced by individual species tolerances to abiotic conditions and the competitive or facilitative interactions that individuals exert over their neighbors (Miriti, 2007). This mechanism elegantly explains why the aggregated and random patterns are observed for some of the shrub species equally often. Various stands sampled are not in the same stage of succession (see below) and because of facilitative/competitive processes operating in the community and owing to temporal changes in abiotic conditions and soil heterogeneity the spatial patterns change over time (Skarpe, 1991; Miriti *et al.,* 1998; Miriti, 2007; Callaway, 1995; Callaway *et al.,* 2002; Tirado & Pugnaire, 2003 and Maestre, 2006). In particular, moisture regime in arid regions changes frequently and often drastically (Evans & Ehleringer, 1994) also accumulation of leaf litter and consequently nutrients (Tirado & Pugnaire, 2003). This would easily sway the balance between facilitation and competition (Miriti, 2007) and as a consequence act as a driving force for the change in the spatial pattern of shrubs. Thus, both climatic and biotic regulation of under and over-dispersed spatial patterns, regulated by facilitation and competition respectively, have been observed (Larrea-Alcazar & Soriano, 2006; Miriti, 2007) for most of the species. Surprisingly, none of the species showed regular pattern, though a number of workers have demonstrated uniform distribution of shrubs in arid/semi-arid areas or deserts (Cox, 1987; Wright & Howe, 1987). Such regular patterns are attributed to competition, particularly for soil moisture (Evans & Ehleringer; 1994).

The results of cluster analysis and ordination, together with the vegetation-environmental relationships (CCA) provided a distinctive picture of the landscape, the associated communities and their environmental correlates. The agglomerative cluster analysis was performed by Ward's method using Euclidean distance as the resemblance function. This method is one of the sequential, agglomerative, hierarchical non-overlapping (SAHN) strategies that yield spherical group structure and being a homogeneity optimizing strategy results in fairly homogeneous groups. The cluster analysis revealed 4 distinct broad groups. Group I represented *Acacia senegal* and *P. juliflora* community type in which *A. senegal* generally occurs as a tree species while *P. juliflora* occurs either as a small tree or a large shrub. This community is associated with the relatively less disturbed steep slopes (30-38º) of calcareous hills. This community type represents more or less early community. The stands belonging to Group II, dominated by *Iphiona grantioides* and *Blepharis sindica* together with a number of shrub species were found associated with either flat hill tops or stony-rocky ground with shallow sandy soil having low water retaining capacity. This community type represent early-to-intermediate vegetation in the successional chronosequence in the area. Group III dominated by *Acacia senegal* and *Euphorbia caducifolia* was supported by relatively undisturbed hill slopes with 10-30 cm soil depth. This community seems to represent the most mature vegetation that presumably forms physiographic climax of the area (sensu Oosting, 1956; Mueller-Dumbois and Ellenberg, 1974). Group IV predominated by *Prosopis juliflora* and exotic, invasive species of South American origin, and *Calotropis procera* is associated with disturbed plains, subjected to greater anthropogenic activity. Cation and phosphorus concentrations in this community were higher presumably because of plenty of leaf litter of *P. juliflora* which presumably decomposes and thereby cations are released from the clay particles. Litter decomposition of *P. juliflora* or its leachates also releases phytotoxins (allelochemicals) that may inhibit the germination and growth of many other species (Khan and Shaukat, 2005). Hence reduced diversity was observed for this community.

Correspondence analysis (CA) was chosen as the suitable ordination method in the current study. The advantage of CA over the popular technique of principal component analysis (PCA) is that CA does not suffer as adversely as PCA with respect to arch or horse-shoe effect. CA is also less susceptible to involution of gradient's ends sample clusters and outlier samples (Gauch, 1982; McCune & Grace, 2002). Furthermore, CA was preferred over DCA (detrended Correspondence Analysis) because some authors have noted lack of robustness and erratic performance of DCA (Minchin, 1987; Jackson & Somers, 1991). The choice of axis segmentation is arbitrary and artificial which may substantially affect the interpretation and hence the utility of higher dimensions generated with DCA (Jackson and Somers, 1991; McCune and Grace, 2002). On the other hand, the major advantage of Canonical Correspondence analysis (CCA) technique that was employed to expose vegetation-environment inter-relationships, is that it provides biplots that directly exhibit the correlations of environmental variables with the canonical axes (Shaukat *et al.,* 2005) and basically is an extension of CA hence it retains most of the advantages of CA ordination. Though the results of CA and CCA were similar to a great extent, but slight differences were noted. In CA total soil nitrogen was correlated with the first ordination axis while in CCA nitrogen was found correlated with the second canonical axis. Carbonate content of soil showed high correlation with the second canonical variate in CCA but it exhibited a negative correlation with the third axis in CA. In general, we believe that the application of CA and CCA in combination provides an effective evaluation of vegetation pattern and the underlying relationships with the environmental complex.

Shaukat *et al.,* (1981a) described a lithosere succession of the vegetation of calcareous hills in the vicinity of Karachi (Southern Sind) where the pioneer stage of the lithosere was represented by various lichens and some exochomophytic herbs, the intermediate stages were dominated by shrubs such as *Commiphora wightii*, *Grewia tenax* and *Euphorbia caducifolia* while the physiographic climax was represented by the tree species *Acacia senegal.* This successional sequence was well correlated with edaphic characteristics, including increasing soil depth, relatively finer soil texture, greater water holding capacity and nutrients, and decreasing pH and $CaCO_3$ content of soil. Based on the results of the current study, however, no pioneer or early intermediate stage was observed. Nevertheless, late intermediate stages where *A. senegal* begins to gain prominence and the physiographic climax stage where *A. senegal* attained dominance (or shared the dominance) were found and examined. In the Kirthar National Park, located close to the study area about 10-30 km north, Enright *et al.,* (2005) found considerable floristic overlap in the vegetation of the hills from location to location and were unable to recognize clear-cut successional sequence as the species showed broad distribution patterns with wide environmental tolerances. Further, they noted that variation in substrate conditions regulating water availability is probably more important deriving force for the observed vegetation patterns rather than the successional processes. Many ecologists, however, believe that the successional processes on xeric sites eventually lead to better moisture regime, and processes of succession (mostly autogenic processes) themselves alter the soil properties (Novak & Parch, 2003; Walker & del Moral, 2003). In the present study, we have found that the climax stage, dominated by *Acacia senegal* is supported by less steeper hill slopes with soils having greater depth, increased water retaining capacity, higher levels of nutrients and overall better soil moisture regime. It shows either aggregated or random pattern as the pattern changes with time depending on density dependent competition and mortality, as described above. The heterogeneity in the soil properties from location to location also regulates the pattern. Most of the associated shrubs, therefore, depicted usually aggregated pattern. This implies that at this stage in the chronosequnce there was greater degree of intraspecific competition than interspecific competition. This would readily explain greater observed diversity for these communities. The succession on the hills seems to represent not only a vegetation sequence (although with considerable stochasticity) but also an associated progression of environmental characteristics ,i.e., gradual soil formation, greater water retaining capacity and increase in soil nutrients (P and K), decrease in pH, resulting eventually in more and more conducive conditions for the climax species to persist with time. Despite cutting and grazing the two climax species *Acacia senegal* and *Euphorbia caducifolia* seem to dominate the climax stage forming a stable community with greater stress tolerance as well as withstanding greater environmental fluctuations. Therefore, the theory of physiographic succession of the vegetation on the slopes of the hills in the Hub dam area still seems to be well supported by the observed data.

General species diversity (H), equitability (J) and species richness were lowest for group 4 which represents a highly disturbed community type where *Prosopis juliflora* is predominant. Since *P. juliflora* is also an allelopathic species as mentioned earlier (Khan & Shaukat, 2005) its phytotoxins or allelochemicals present in the soil inhibit the germination and growth of many plant species that consequently results in reduced diversity. In addition, due to excessive grazing and trampling certain species are eliminated. The highest, diversity, equitability and species richness were recorded for group I which represent a mid-successional community containing a number of shrubs of mid-sere as well as containing the climax species *Acacia senegal*. The climax community (group IV) showed intermediate levels of diversity and equitability which corresponds with the previous results that the diversity slightly declines in the climax stage as a result of competition and stress tolerance while representing the monopolization of resources in the stable, terminal communities (Shaukat *et al.,* 1981b). Dominance and diversity were inversely related, which accords with the findings of previous workers (Shaukat *et al.,* 1981b, Sapkota *et al.,* 2010).

Overgrazing by sheep and goats could have immense impact with respect to decreasing the abundance of some perennial species (palatable species e.g., *Zizyphus nummularia*, *Senna holosericea*) and increase in the importance value of the unpalatable or stress tolerant species. Batanouny (1987) recorded increased abundance of the unpalatable shrub *Rhazya stricta* in heavily grazed sites in the Arab Gulf countries. Interestingly, in the present study, *Rhazya stricta* was one of the abundant species.

Conclusion

In conclusion, four community types were objectively recognized that were associated with particular biotic and abiotic factors. Among the abiotic factors, soil moisture regime played a pre-eminent role in the distribution of vegetation. Therophytes and chamaephytes were the major life-forms in the vegetation. The vegetation revealed a lithosere chronosequence in which the physiographic climax was attained by *Acacia senegal* and *Euphorbia caducifola* while the earl to intermediate stages were dominated by under-shrubs or small shrubs. The successional sequence was associated with amelioration of soil moisture and nutrient regimes. The community type which included many mid-succession elements depicted high species diversity while the community having excessive disturbance showed low diversity. Most perennial shrubs and a grass showed aggregated spatial pattern which has great implications in community stability and dynamics. The stratification progressively developed with the onward march of succession. Grazing/harvesting indices were high for the disturbed community.

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