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*Full Length Research Paper*

# Vegetation zonation along the geological and geo-morphological gradient at Eastern slope of Sulaiman range, Pakistan

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**The vegetation of gypsiferous strata of Sulaiman range (30°33′ N to 30°41′30″ north latitude and 70°32′ E to 70°41′30″ east longitude, annual rainfall more than 100 mm) was analyzed using ordination (DECORANA) and classificatory cluster analysis techniques. Four plant associations were recognized in the study area. The application of the classification to the ordination allowed an interpretation of vegetation distribution in terms of topography and redistribution of rainwater, the nature of soil, bed rock and geological strata. The pattern of plant communities along the first ordination axis suggested that beside the landscape, substrate plays an important role in determining the boundaries between the plant communities. The assessment of the floristic suggested that there were three classes of plants: first there are plants of alluvial sandy plains (psymophytes), secondly; those of permanent water courses (hydrophytes) and thirdly, there are plants that grow on rocky hard strata (xerophytes/lithophytes). The observed pattern in available soil calcium seems related to long term redistribution of water that occurs during rainfall events because soil calcium, magnesium and moisture content have similar distributions along the transect. High calcium content for rocky strata was due to its parent geological gypsiferous formation. Although the boundaries across the landscape were associated with down slope movement of water, soil particles and cations, it was difficult to assess the relative importance of these factors in comparison with landscape level. The vegetation patterns revealed are discussed in relation to environmental factors and problems of plant assemblage in vegetation of the area.**

**Key words:** Vegetation analysis, plant communities, Sulaiman range, Pakistan.

## INTRODUCTION

Each desert habitat has distinct type of plant community associated with it. The nature of the habitat determines the precise manner in which plants are able to exploit its potential. Dasti and Agnew (1994) working in sandy deserts of Pakistan found that each habitat has a distinct community associated with it and each community is generally dominated by one species, which gives it its visual uniformity. In these deserts, the frequency of large communities is affected by the severity of habitat conditions and because the same few species occur over and over again, the repetition of particular environment encourages a repetition of its characteristic associated species. In sandy deserts, minor differences in surface level and edaphic conditions govern the species diversity and influence the overall community composition (Herwitz and Young, 1994; Gale, 2000). In rocky deserts with patches of soil, the situation is quite different and has strong spatial differentiation as compared to sandy deserts. In these deserts, vegetation closely follows the topographic sequence and the most important environmental gradients and boundaries across the landscape are associated with down slope movement of water, soil particles and organic

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matter (Dasti and Malik, 1998). Redistribution of rainfall water by run-off from some areas and concentration in other (run-on) depends on relief, on rainfall intensity and occurrence of rocky surface. In these deserts, there is a drastic ecological contrast between run-on and run-off habitats. Beside the rainfall intensity, topographic heterogeneity, geological and landscape heterogeneity and rainfall patchiness and surface stability appear to be the important factors that govern the spatial variations in habitats and associated plant communities. One of the enduring challenges in ecology is to identify those factors that explain pattern of biodiversity and community composition across large spatial scale (Bready et al., 2006; May, 1986; Hubbel, 2001; Ricklefs, 2004). Species distribution with respect to environmental gradients have been documented at various scale in numerous plant communities worldwide (Christopher and Cushman, 2007; Engelbrecht et al., 2007; Liza et al., 2007; Tilman, 1982; Tilman and Pacala, 1993; Silvertown, 2004).

The knowledge of the relationship between vegetation and environment in arid and semi-arid areas of Pakistan in particular and in general the deserts of the world is based on the subjective descriptions of ecological conditions from field experience and interpretation (Kassas and Imam, 1954; Rafi, 1965). Detailed species distribution and its interaction with topographic and edaphic variation are poorly known. Investigators often neglect to identify the underlying suit of abiotic factors which provide important keys to understanding the distribution patterns of plant communities and species across an arid landscape (Dasti and Malik, 1998;)

Gradient have been successfully used to understand many aspects of plant ecology as they provide an ideal opportunity to study natural variation in aboitic factors that may drive community changes (Callway, 1997; Dasti and Agnew, 1994; Dasti and Malik, 1998; Dasti et al., 2007; Grime, 1977; Tilman, 1988). Gradient analyses and other modern synecological methods of data analysis provide an opportunity to reduce the complexity of field data set and then relate the results to environmental information (ter Braak, 1987). Such objective approaches have rarely been applied to the vegetation data of Pakistan.

The present aim was to relate vegetation distribution to topography and soils along abiotic gradient and to examine some environmental factors for their correlation with the pattern of vegetation of the study area. It was hypothesize that local aboitic factors are likely to play a crucial role in distribution of species and in composition of plant communities along the natural gradients.

## MATERIALS AND METHODS

### Study area

Floristic inventories centered on relatively undisturbed strip of valuable for sand sheet and sand dune stabilization. Succulent sub vegetation between 100 and 485 m elevation on eastern slopes of Sulaiman range forming western boundary of the Great Indus Valley at 30°33′ N to 30°41′ 30″ N latitude and between 70°32′ E to 70°41′ 30″ E longitude (Figure 1). After repeated orientation survey, 20 sites were selected based on vegetational variation, relatively undisturbed landscape, limited variation in exposure and slope aspect, absence of gorges and workable slope inclinations (< 50 %) along the altitudinal transect (East-West).

### Geology

The area is composed of irregular, rugged and steep ridges. The hill ranges were uniform in character consisting of long central ridge, from which many spurs descend, separated from one another by gorges and torrents. All the valleys consist of flat plains of alluvial soil in the centre with pebbly slopes of varying length on either side to the surrounding mountains. The relief of the area is low in Eastern part which slopes down into plains but increases toward the west. Mountains are mostly sandstone massif, delimited from the surrounding landscape by bedrock geology and a surrounding net work of seasonal streams. The area lacks perennial rivers; however, seasonal streams originate from the hilly regions in the west which terminate in the River Indus (Dasti and Malik, 1998). The landscape includes a diversity of geological features. It is composed of sedimentary rocks mainly Jurassic Limestone, Dolomite, Gypsum, Eocene Limestone, Black Shale, Miocene sediments of sandstone called Siwaliks. Sandstones are composed of silica, feldspar, mica, limonite, haematite and calcite as main constituents. The uraniferrous sandstones of the study area are radioactive and produce gamma radiation.

### Climate

The climate is generally dry and classified as arid and subtropical continental (Athar, 2005). During winter season, climate is intensely cold whereas in summer it is hot. The temperature varies seasonally, touching to almost 48°C in the summer while in the winter, it fluctuates between 5 - 15°C.

The Sulaiman range lies out the reach of monsoon currents and the rainfall is irregular and scanty. No meteorological data from the research site is available. The average rainfall of this tract varies from 200 - 240 mm (Champion et al., 1965). The monsoon (tropical convergence) rainfall occurs between July and August. A couple of showers are received during winter season from December to January.

### Vegetation

Champion et al (1965) describe the study area as dry sub tropical thorn forest. Trees and shrubs were mostly thorny and have leaves of moderate size. There is usually little ground layer vegetation most of the year but during the monsoon, a fairly complete cover of ephemeral grasses and herbaceous plants may develop. The ephemeral grasses almost develop over large stretches of ground and in particular on shallow sand drifts. The predominant species were *Cynodon dactylon*, *Rhazya stricta* and *Zizyphus nummularia* while the herbaceous ephemerals are only found on soft deposits in good locations, where a water supply is preserved even if for only a short while. Beside the ephemerals, there is a permanent flora of perennial species and it includes perennial grasses, succulent shrubs and woody perennials. Perennial grasses are often found on

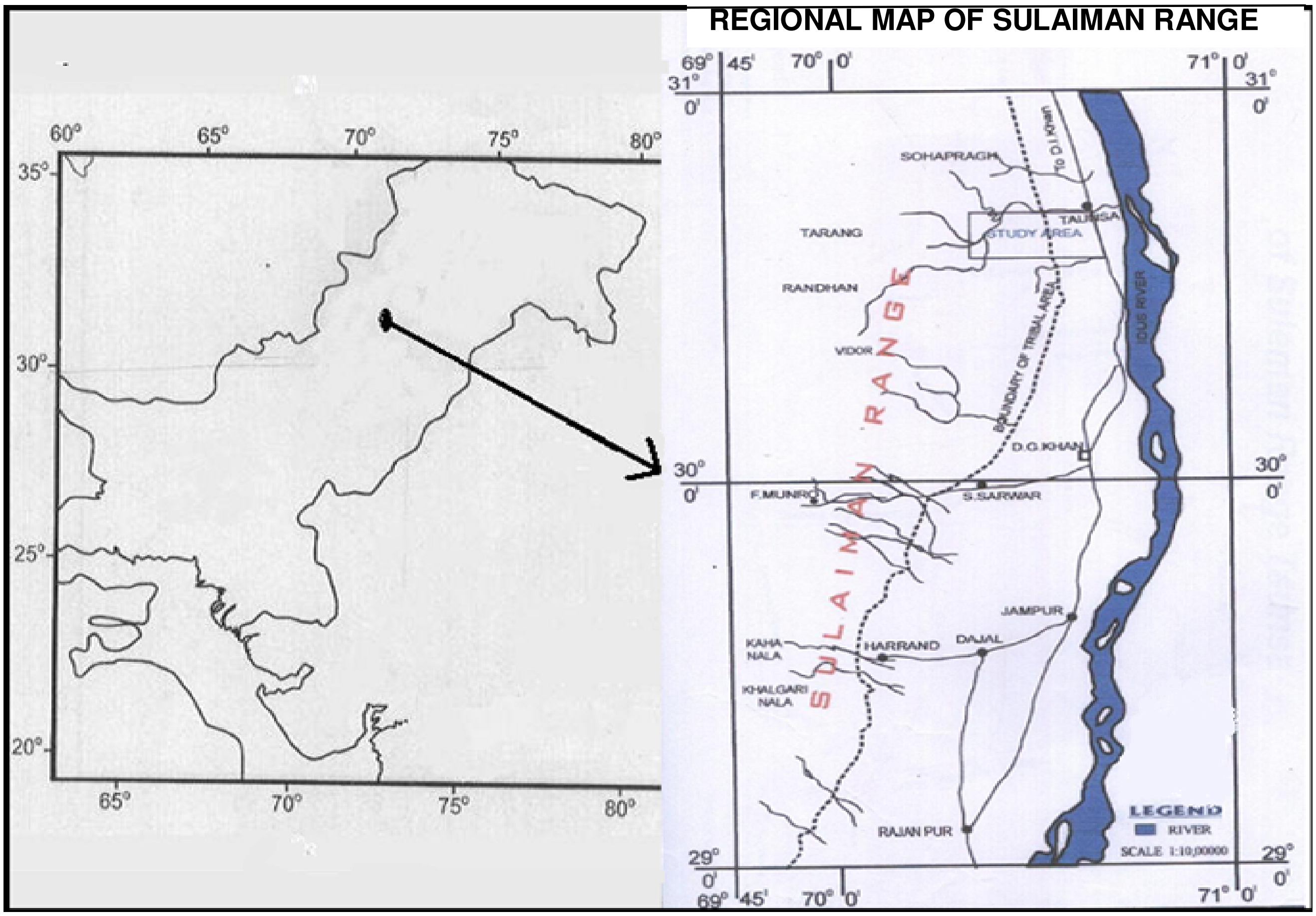


**Figure 1.** Map of Pakistan showing study area.

soils which are capable of storing some water and are particularly shrubs like *Haloxylon salicornicum*, *Salsola baryosma* and *Suaeda fruticosa* are common in salt plays. Scrub land can only be found in good location where there is adequate soil and where, there are mountains around to supply run off water. The dominant plants are *Z. nummularia*, *Tamarix dioica*, *R. stricta*, *Capparis decidua*, *Prosopis juliflora* and *Acacia nilotica*.

After repeated orientation surveys, 50 sites were selected which covered the range of vegetational variation at each site, the vegetation in 10 randomly placed 5 x 5 m quadrats was monitored for the presence and absence of all the vascular plants. Thus a total of 500 samples were obtained containing 83 species.

Soil samples (0 - 10 cm depth) were taken from each stand at three different points and mixed into a composite sample for a stand. Soil depth to 2 cm was sampled in the hard clays because the main root zone occurred within the first 2 cm. Sandy soils were sampled up to 10 cm depth because the top layer of soil was very mobile and the rooting zone was deeper. The samples were air-dried and passed through a 2 mm sieve. Three sub-samples were drawn from this composite sample. Soil texture and soil moisture content was determined using standard methods (Hussain, 1989; Richards, 1954). Soil pH was recorded from a pH meter (HM-10K Digital, England). Conductivity was determined using CM-30 ET digital conductivity meter. Calcium and magnesium were determined by versenate method, sodium and potassium by flame photometer method. Phosphorus was determined calorimetrically and carbonates and bicarbonates were determined by titration method.

### Data analysis

Presence or absence data of plant species were used to classify and ordinate for both sites (stands) and species. Rare species (1% or less) were eliminated from the analyses since the presence of these species can severely distort ordinations produced by RA (Dasti and Agnew, 1994; Hacker, 1983). Detrended correspond-dence analysis (DCA) was selected as an appropriate ordination method based on gradient length and preliminary correspondence analyses (Jongman et al., 1995). The default options of the program DECORANA were used for the analyses (Causton, 1988; Hill, 1979). DCA axes 1 and 2 were used to interpret the data.

For cluster analysis of species and sites monothetic information, statistic procedure was used by incorporating the Spearman rank order dissimilarity coefficient (Causton, 1988; Hill, 1979). Scatter of classification groups were plotted on overlays of the ordination axes to assess the compatibility of the two methods of data simplification (Dargie and El Demerdash, 1991; Dasti and Agnew, 1994; Dasti and Malik, 1998).

The differences in soil parameters between the plants communities were estimated by using the analyses of variance (ANOVA). The percent data were normalized by an arcsine transformation prior to analyses of variance. Duncan multiple range tests were used to detect and compare any significant difference between the means of soil parameters of different communities at the 5% level of significance. The relationships between soil characters and DCA axes 1 and 2 were determined using Spearman Rank correlation (Causton, 1988).

## RESULTS

### Classification

The results of classification are presented in Table 1. The first hierarchical level separated the sandy alluvial communities from the rocky massif. As a result of two hierarchical levels four clusters were created (Figure 2). These clusters (groups) delineated four type of vegetation:

1. Sandy alluvial plains (group 1).
2. Solenchalk depressions (group 2).
3. Rocky sand stone riverine deposit strata (group 3).
4. Rocky gypsiferous marine strata (group 4).

### Sandy alluvial plains

Sandy plains were without tree strata and the vegetation was in isolated patches, limited to oases which often receive run off. Here the plant cover developed with the rain. During the rain, a magnificent green carpet spreads on the landscape, giving the appearance of a fine grass land dominated by annuals with an upper strata (> 1 m) of *Cenchrus ciliaris*, *Panicum antidotale*, *Dactyloctenium scindicum*. A middle stratum (50-70 cm) of *Aristida adscensionis*, *Farsetia hamiltonii*, *Heliotropium dasycarpum* and *Sinapsis arvensis* and a lower most stratum of various plants: *Citrullus colocynthis*, *Convolvulus prostratus*, *C. dactylon*, *Euphorbia granulata*, *Heliotropium strigosum*, *Lactuca serriola*, *Launaea procumbens*, *Medicago polymorpha* and *Tribulus terrestris.* In the dry season the annuals disappear leaving behind the perennials that is, *Aerua persica*, *Capparis decidua*, *Crotolaria burhia*, *Withania coagulans* and degraded *A. nilotica*, *Prosopis cineraria* and *Tamarix aphylla.*

### Solenchalk depressions

Solenchalk depressions was distinctive in the combination of high coverage of *Calotropis procera* with shrubby *S. baryosma* and *Fagonia bruguieri*. Grasses like *Cleome viscosa*, *Cirsium arvense*, *C. dactylon*, *Cyperus compressus*, *Eclipta prostrata*, *Festuca ovina* and herbaceous *Eclipta prostrata*, *Mollugo hirta* and *Trianthema portulacastrum* are the characteristic species of this group.

### Rocky sand stone riverine deposit strata

The sand stone plateau surround the sandy plains to the west and because of its topography, it generate run off and even violent storms during the short rainy season (July-August). The plateau with rather scattered vegetation is rich in shrubs of *Acacia jacquemontii* and *Zizyphus mauritiana.* The surrounded sand dunes of this massif had hallowed a number of psaemophytic species: *A. persica*, *Oligomeris linifolia*, *R. stricta* and *T. terrestris.* However the frequency of the species often increases as one move from sandy plain to sand dunes. The clay hollows moistened by rain had relatively dense vegetation consisted of *A. jacquemontii*, *A. nilotica*, *C. burhia*, *H. salicornicum* and *Salvadora oleoides.*

### Rocky gypsiferous marine strata

These strata consist of marine deposits of Siwalik origin and largely composed of lime or gypsum but sometimes it is also gravely. The litho soles consist of undeveloped shallow overlying the sedimentary gypsiferous material. The varying texture from shale to gravy lome with excessive run on. These strata consisted of marine deposits and had diversity of natural sites like humid canyons, springs and permanent water courses that harbors variety of plant species ranging from macrohydrophytes to the true halophytes. The common macrohydrophytes were *Phragmities australis*, *Scirpus maritimus*, *Saccharum bengalense* and *Typha elephantina* along with *T. dioica*. While the halophytes were *Anabasis setifera*, *Hertia intermedia*, *S. fruticosa*, *Physorrhynchus brahuicus* and *H. salicornicum* associated with grasses like *Bromus ramosus* and *C. dactylon*. The rocky and pebble slopes were occupied with *Ajuga bracteosa*, *Capparis spinosa*, *F. bruguieri* and *Salvadora persica*.

### Soils

ANOVA detected significant differences among the plant communities in physical and chemical properties of their soils (Table 3). The soil of the alluvial plains (Association A-C) was significantly low in sand stone and rich in clay content compared to other plant associations. Interestingly, plant communities confined to the marine strata were significantly higher in organic matter, $Ca^{2+}$ and $Mg^{2+}$ contents than any other association identified by cluster analysis. The concentration of all the salts increased in a sequence that is, from sand dunes to rocky strata. Among the soil parameters, soil texture, % stone cover, % organic matter, $Ca^{2+}$ and $Mg^{2+}$ content, soil pH and EC played important role in the distribution of the species (Table 2).

### Plant distribution

The results indicated that the vegetation closely follow a topographic and geological sequence. The species most abundant in group I (Table 1) were most common in sandy alluvial plains which were occasionally subjected to hill torrents. Most species of this group were virtually

**Table 1.** Frequencies (%) of the species in each association recognized from the normal information statistic.

| S/No | Species name | Group 1 | Group 2 | Group 3 | Group 4 |
|---|---|---|---|---|---|
| 1 | *Abutilon indicum* (L.) Sweet | - | - | 0.35 | 0.43 |
| 2 | *Acacia jacquemontii* Benth. | - | - | 0.095 | - |
| 3 | *Acacia nilotica* (L.) Delile | - | 3.12 | 2.345 | 2.155 |
| 4 | *Aerua persica* (Burm f.) Merril | 4.72 | 5.21 | 7.86 | 1.295 |
| 5 | *Ajuga bracteosa* Wall. ex Bth. | - | - | - | 0.86 |
| 6 | *Anabasis setifera* Moq in DC. | - | - | - | 4.76 |
| 7 | *Aristida adscensionis* L. | 1.89 | - | 0.945 | - |
| 8 | *Atriplex crassifolia* C.A. Mey | 1.89 | - | - | - |
| 9 | *Bothriospermum tenellum* (Hornem) Fisch and C.A.M. | 1.89 | - | - | - |
| 10 | *Bromus ramosus* Huds. | - | - | - | 0.43 |
| 11 | *Calotropis procera* (Willd.) R.Br. | 2.83 | 6.25 | 6.675 | 0.035 |
| 12 | *Capparis cartilaginea* Dcne. | - | - | - | 0.43 |
| 13 | *Capparis decidua* (Forssk.) Edgew | - | 3.12 | 3.845 | - |
| 14 | *Capparis spinosa* L. | - | - | 1.885 | 0.86 |
| 15 | *Cenchrus ciliaris* L. | 1.89 | 2.08 | 1.295 | - |
| 16 | *Chenopodium murale* L. | 0.94 | - | - | - |
| 17 | *Cirsium arvense* (L.) Scop | - | 1.04 | - | - |
| 18 | *Citrullus colocynthis* (L.) Schard | 5.66 | - | 0.7 | - |
| 19 | *Cleome viscosa* L. | - | 1.04 | - | - |
| 20 | *Convolvulus arvensis* L. | 0.94 | - | - | - |
| 21 | *Convolvulus prostratus* Forssk. | 4.72 | 1.04 | 1.05 | - |
| 22 | *Convolvulus spinosus* Burm f. | - | - | 0.35 | - |
| 23 | *Conyza bonariensis* (L.) Cronqist | 0.94 | 1.04 | - | - |
| 24 | *Cotoneaster nummularia* Fisch and Mey. | - | - | - | 0.86 |
| 25 | *Crotolaria burhia* Ham. ex Bth. | 2.83 | - | 1.295 | - |
| 26 | *Cymbopogon jawarancusa* (Jones) Schult | - | - | - | 0.86 |
| 27 | *Cynodon dactylon* (L.) Pers. | 7.55 | 6.25 | 10.205 | 10.81 |
| 28 | *Cyperus compressus* L. | - | 1.04 | - | - |
| 29 | *Dactyloctenium scindicum* Boiss. | 2.83 | - | - | - |
| 30 | *Desmostachya bipinnata* (L.) Stapf. | - | - | - | 2.175 |
| 31 | *Dichanthium annulatum* (Forssk.) Stapf. | 0.94 | - | - | - |
| 32 | *Eclipta prostrata* (L.) L. | - | 1.04 | - | - |
| 33 | *Euphorbia granulata* Forssk. | 2.83 | 2.08 | - | - |
| 34 | *Fagonia bruguieri* DC | 4.72 | 6.25 | 1.645 | 3.445 |
| 35 | *Farsetia hamiltonii* Royle | 3.77 | - | 3.285 | 0.43 |
| 36 | *Festuca ovina* L. | - | 2.08 | - | - |
| 37 | *Haloxylon multiflorum* (Moq.) Bunge. | - | - | 1.885 | - |
| 38 | *Haloxylon salicornicum* (Moq.) Bunge. ex Boiss. | 4.72 | 1.04 | 9.155 | 4.76 |
| 39 | *Heliotropium dasycarpum* Ledeb. | 1.89 | 1.04 | 0.7 | - |
| 40 | *Heliotropium eichwaldi* L. | 0.94 | 6.25 | 0.7 | - |
| 41 | *Heliotropium strigosum* Willd. | 2.83 | 1.04 | 0.35 | - |
| 42 | *Hertia intermedia* (Boiss.) O. Ktze. | - | - | - | 4.74 |
| 43 | *Kochia indica* Wight | - | - | 0.945 | - |
| 44 | *Lactuca serriola* L. | 1.89 | - | - | 0.43 |
| 45 | *Launaea procumbens* (Roxb.) Rammaya and Rajagopal | 2.83 | 1.04 | 0.7 | - |
| 46 | *Leptadenia pyrotechnica* (Forssk.) Dcne. | - | - | 0.945 | - |
| 47 | *Medicago polymorpha* L. | 1.89 | - | - | - |
| 48 | *Melilotus albus* Desr. | 0.94 | 1.04 | - | - |
| 49 | *Melilotus indicus* (L.) All. | 1.89 | 1.04 | - | - |
| 50 | *Mollugo hirta* Thunb. | - | 1.04 | - | - |
| 51 | *Oligomeris linifolia* (Vahl.) Macbride | 0.94 | 2.08 | 0.35 | - |

**Table 1.** Contd.

| | | | | | |
|---|---|---|---|---|---|
| 52 | *Panicum antidotale* Retz. | 0.94 | 3.12 | - | - |
| 53 | *Phoenix sylvestris* Roxb. | - | - | 0.945 | 4.345 |
| 54 | *Phragmities australis* (Cav.) Trin. ex Steud. | - | - | - | 4.345 |
| 55 | *Phyllanthus niruri* L. | - | - | 0.35 | - |
| 56 | *Physorrhynchus brahuicus* HK | - | - | - | 1.29 |
| 57 | *Prosopis cineraria (L.)* Druce | 4.92 | 4.17 | 2.445 | - |
| 58 | *Prosopis juliflora* Swartz. | - | 1.04 | 0.7 | 4.775 |
| 59 | *Rhazya stricta* Dcne. | 5.96 | - | 8.805 | 3.88 |
| 60 | *Saccharum bengalense* Retz. | - | - | - | 4.345 |
| 61 | *Salsola baryosma (R. and S.)* Dandy | 0.94 | 5.21 | 5.275 | 4.31 |
| 62 | *Salvadora oleoides* Dcne. | - | 1.04 | 1.295 | - |
| 63 | *Salvadora persica* L. | - | - | - | 6.055 |
| 64 | *Salvia farinacea* Bth. | - | 1.04 | - | - |
| 65 | *Schismus arabicus* Nees. | - | 1.04 | - | 2.175 |
| 66 | *Scirpus maritimus* L. | - | - | - | - |
| 67 | *Sinapsis arvensis* L. | 1.89 | - | - | - |
| 68 | *Solanum miniatum Bernh.* ex Willd. | - | 1.04 | - | - |
| 69 | *Solanum surattense* Burm f. | 2.83 | 4.17 | 0.35 | - |
| 70 | *Sonchus asper (L.)* Hill. | 1.89 | 1.04 | - | - |
| 71 | *Suaeda fruticosa (L.)* Forssk. | - | - | - | 6.07 |
| 72 | *Tamarix aphylla (L.)* Karst. | - | 4.17 | 0.7 | 2.605 |
| 73 | *Tamarix dioica Roxb.* ex Roth. | - | - | 5.525 | 4.345 |
| 74 | *Tecomella undulata (Sm.)* Seem. | - | - | 0.35 | - |
| 75 | *Trianthema portulacastrum* L. | - | 3.12 | - | - |
| 76 | *Tribulus terrestris* L. | 1.94 | 2.08 | 0.35 | - |
| 77 | *Typha elephantina* Roxb. | - | - | - | - |
| 78 | *Volutarella divaricata* Benth. | - | 2.08 | - | - |
| 79 | *Withania coagulans* Dunal | 2.83 | 1.04 | 2.795 | 5.62 |
| 80 | *Withania somnifera (L.)* Dunal | - | 2.08 | - | -- |
| 81 | *Xanthium strumarium* L. | - | 1.04 | - | - |
| 82 | *Zizyphus mauritiana* Lam. | - | 1.04 | 3.39 | - |
| 83 | *Zizyphus nummularia (*Burm f.) Wight and Ann. | 1.89 | 2.08 | 4.58 | 3.035 |

absent from the other groups. These might be tolerant to the disturbances from seasonal hill torrents and periodic aridity. Alluvial depressions mostly have occupied *P. cineraria*, *S. baryosma* and *T. aphylla* along with *P. antidotale* and *T. portulacastrum*. Most of these species are exploited for fire wood. Gravel is generally absent in areas with more soil deposition. Such places have small annuals like *C. compressus*, *Euphorbia granulata* and *T. terrestris* which quickly utilize the temporary moisture in surface sand during the rainy season. In the upper rocky zone, the soils are usually shallow and may over lie a great variety of geological formation from lime stone, shales or crystalline rock to uraniferrous sandstones. The rocky strata supports scatter xeromorphic species like *H. intermedia*, *Leptadenia pyrotechnica*, *P. brahuicus* and *S. persica* and many others. The eroded sand stones in rocky habitat has sparse *A. jacquemontii*, *C. decidua* and *P. cineraria* with patches of herbaceous or shrubby plants in between. *A. jacquemontii*, *C. decidua* vegetation (Group 3) is common on the sand stone riverine strata and shares the range of environmental condition of the first group with a bias toward rocky marine strata. The localize depres-sion were dominated by the species most abundant in group 2. The governing factor in these plant association, therefore, appear to be rock and soil type which affect the water run off and its availability to plants.

## Gradient analysis

Site and species ordination in the plane of first two axes are presented in Figures 3 and 4, respectively. It is much more difficult to verbally describe the results of an ordi-nation in broad outlines. The graphical results resemble

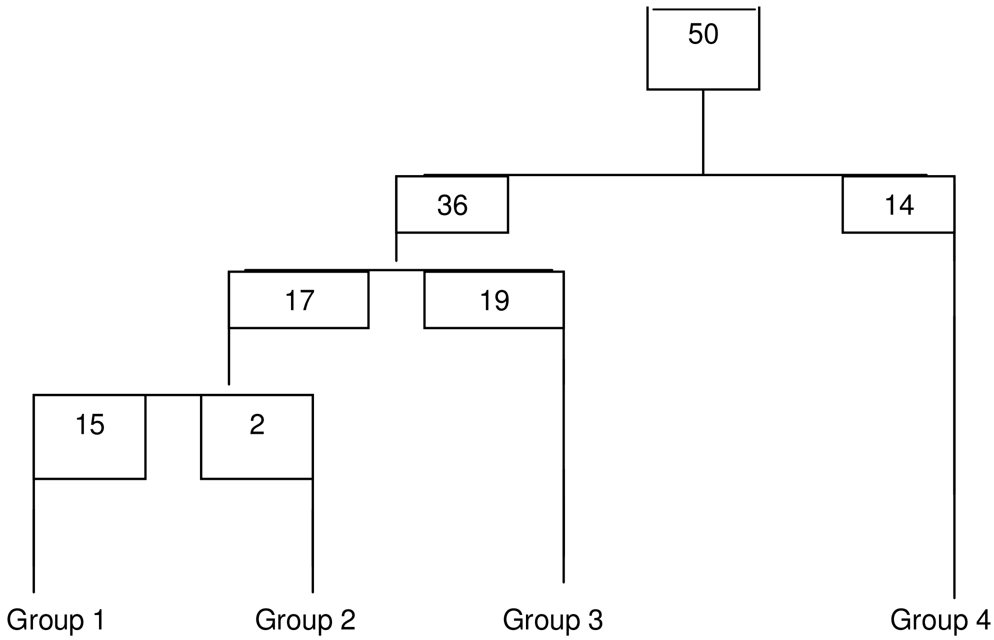


**Figure 2.** The hierarchy of classification of 50 stands from the Sulaiman Range by the monothetic divisive technique. The number of stands in each association are given in boxes.

**Table 2.** Spearman rank correlation coefficients between Detrended Correspondence Analysis (DCA) first and second axis scores and soil parameters.

| Factors | Axis 1 | Axis 2 |
|---|---|---|
| Clay % | - 0.61** | - 0.35 |
| Sand % | 0.004 | 0.08 |
| Stone % | 0.72** | 0.33 |
| Moisture % | 0.47* | - 0.51* |
| pH | - 0.12 | 0.58* |
| EC(µS) | 0.33 | - 0.40* |
| Organic matter % | - 0.09 | - 0.71** |
| Bicarbonates (ppm) | - 0.34 | - 0.06 |
| Calcium (ppm) | 0.58* | - 0.37 |
| Magnesium (ppm) | 0.43* | - 0.49* |
| Sodium (ppm) | 0.20 | - 0.24 |
| Potassium (ppm) | - 0.08 | - 0.26 |
| Phosphate (ppm) | 0.04 | 0.31 |

*P<0.05, **P<0.01.

more closely the discontinuous nature of vegetation as do the grouping produced by classification. Therefore it is easy and profitable to describe the salient features of the stands and species in the association with ordination.

The first DCA axis of the normal data set had an Eigen value of 0.536. The Eigen value for the second axis was 0.330. Further axes each explained the low Eigen value and thus were ignored. In the present study, it was found that the sites belonging to sandy planes with low scores on axis-1 were towards the left and the sites with rocky substrate with high scores were towards the right end of the ordination diagram (Figure 3). Stone fraction of the substrate increased with increase in score along the DCA axis 1. The results suggested that the relative dominance of the species like *C. procera*, *C. dactylon*, *H. salicornicum* and *Z. nummularia* increased with decrease in clay content or otherwise increase in stone fraction in the substrate. A large bulk of species appeared to be the substrate

**Table 3.** Mean values and standard deviation (S.D.) for all soil variables for six association types identified by the Normal Information Statistic divisive hierarchical process.

| Soil variables | | A | B | C | D | E | F |
|---|---|---|---|---|---|---|---|
| % wt. of clay | Mean | 47.05 | 74.45 | 44.40 | 24.87 | 28.95 | 24.21 |
| | S.D. | 31.78 | 7.97 | 26.35 | 23.28 | 0.00 | 13.13 |
| % wt. of sand | Mean | 50.87 | 25.10 | 52.91 | 73.12 | 33.20 | 29.23 |
| | S.D. | 30.31 | 6.91 | 26.15 | 22.61 | 0.00 | 1.44 |
| % wt. of stone | Mean | 1.99 | 1.61 | 2.30 | 2.26 | 37.85 | 46.57 |
| | S.D. | 2.75 | 0.88 | 1.60 | 1.58 | 0.00 | 13.93 |
| Moisture (%) | Mean | 2.28 | 5.17 | 2.74 | 3.15 | 17.38 | 6.39 |
| | S.D. | 0.75 | 0.86 | 1.57 | 1.48 | 0.00 | 4.30 |
| pH | Mean | 5.18 | 8.09 | 8.19 | 8.18 | 7.96 | 8.18 |
| | S.D. | 0.10 | 0.10 | 0.08 | 0.16 | 0.00 | 0.19 |
| EC (µS) | Mean | 197 | 836 | 580 | 1139 | 2400 | 1618 |
| | S.D. | 231 | 268 | 264 | 1194 | 0 | 2168 |
| Organic matter (%) | Mean | 2.09 | 3.11 | 2.11 | 2.30 | 4.58 | 1.71 |
| | S.D. | 0.71 | 0.04 | 0.63 | 1.52 | 0.00 | 1.00 |
| Bicarbonate (ppm) | Mean | 101.11 | 149.33 | 88.61 | 83.72 | 64.97 | 88.79 |
| | S.D. | 19.28 | 55.65 | 28.04 | 26.05 | 0.00 | 19.28 |
| Calcium (ppm) | Mean | 33.75 | 16.26 | 38.08 | 76.29 | 288.00 | 122.11 |
| | S.D. | 13.91 | 5.26 | 24.13 | 123.93 | 0.00 | 116.01 |
| Magnesium (ppm) | Mean | 9.08 | 9.73 | 7.64 | 7.76 | 43.38 | 13.02 |
| | S.D. | 1.06 | 2.30 | 1.98 | 6.68 | 7.07 | 5.45 |
| Sodium (ppm) | Mean | 11.40 | 10.93 | 11.15 | 42.94 | 26.94 | 48.97 |
| | S.D. | 3.45 | 2.50 | 2.87 | 78.56 | 0.00 | 98.02 |
| Potassium (ppm) | Mean | 6.88 | 4.49 | 5.88 | 5.52 | 5.60 | 5.99 |
| | S.D. | 2.35 | 1.96 | 2.12 | 4.54 | 0.00 | 4.17 |
| Phosphate (ppm) | Mean | 1.43 | 0.57 | 1.21 | 1.15 | 0.01 | 1.38 |
| | S.D. | 0.36 | 0.53 | 1.15 | 0.73 | 0.00 | 0.41 |

specialists. The species such as *A. perisca*, *C. ciliaris*, *C. colocynthis*, *C. prostratus*, *L. procumbens*, *O. linifolia*, *P. cineraria*, *T. portulacastrum T. terrestris* and *Z. mauritiana* were confined to run-on alluvial plains with sandy substrate, whereas, *A. setifera*, *C. spinosa*, *Haloxylon multiflorum*, *H. intermedia*, *S. persica* and *S. fruticosa* occupied the runoff rocky mountains.

Beside the texture of the substrate, the DCA axis I was significantly influenced by the soil chemistry. The concentration of bivalent cations such as $Ca^{2+}$ and $Mg^{2+}$ increased with increase in score along the ordination axis I. The soils of the stands located in the rocky zone of the transect have more cations than the sandy alluvial plains. This difference is probably a geological one but is sufficient to control the distribution of the species. Species such as *Capparis cartilaginea*, *C. spinosa*, *C. nummularia*, *D. bipinnata*, *H. multiflorum*, *H. intermedia*, *Kalimeris indica*, *L. pyrotechnica*, *S. persica* and *S. fruticosa* were the characteristic of rocky mountains and were altogether absent in the alluvial plains.

The ordination axis II was significantly influenced by the soil pH and organic matter (Table 2). The sites on gypsiferous strata (with the highest score along the axis II) had lower values of organic matter than the permanent water courses (located at bottom of diagram with lowest score along axis II). These water courses were occupied by hydrophytes such as *P. australis*, *S. bengalense* and *S. maritimus*.

The species ordination provides a summary of distribution of species along the geomorphological gradient of the study area. The distribution of species along the DCA axes suggested that most of the species were associated with broad habitat and followed the configuration similar to that evident for site ordination. However there were some species like *C. procera*, *C. dactylon*, *F. bruguieri*, *H. salicornicum* and *S. baryosma* that do not follow the site distribution suggesting that they were largely unaffected by underlying topographic or edaphic factors.

The species having high score along the DCA axis I were widely distributed in sandy plains with deep sandy soils. These species include *C. ciliaris*, *C. colocynthis*, *C. burhia*, *F. hamiltonii*, *Medicago polymorpha* and *Oligomeris linifolia*. On the other hand, the species with high score along DCA axis I were confined to rocky desert, shallow

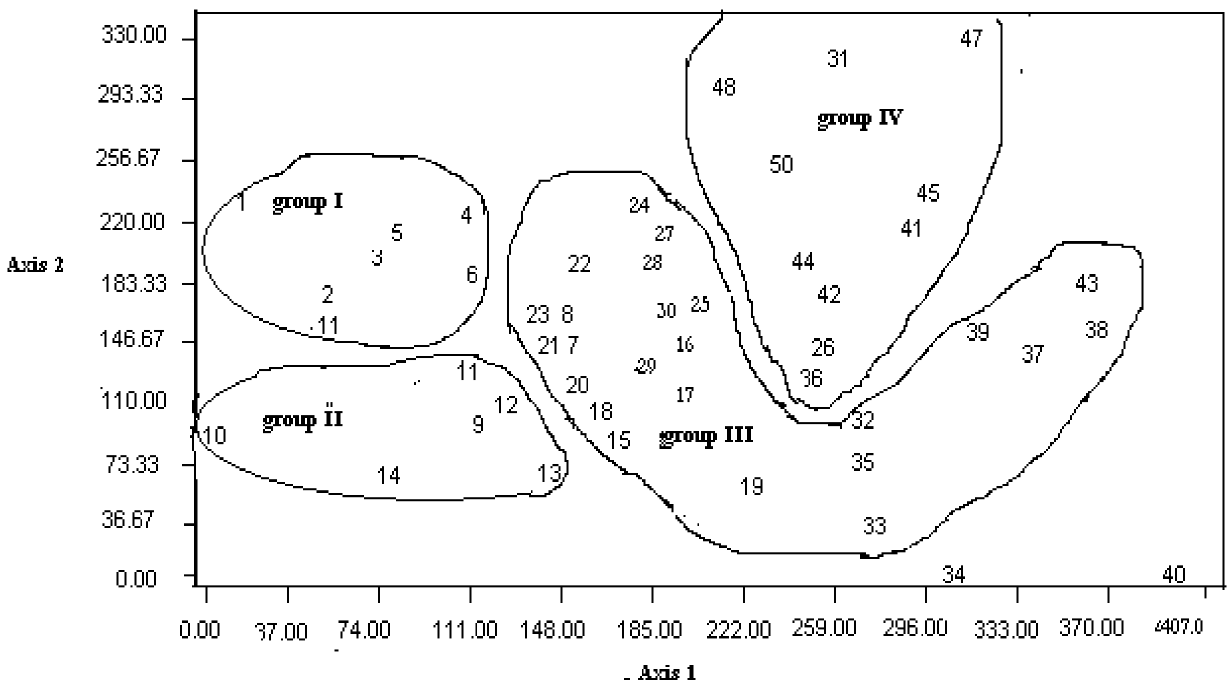


**Figure 3.** Results of detrended correspondence analysis of the sites grouped by the associations produced by cluster analyses.

depressions or in pockets of soil, for example, *C. spinosa*, *P. brahuicus S. persica* and *C. nummularia*. *S. persica* was associated with loose stony areas and banks of wadis with little soil on the surface. Similarly, *C. spinosa* were found on rocks and cliffs of deep wadis. The species like *P. australis*, *S. bengalense* and *Scirpus maritimus* were confined to the channels of natural drainage system or around the springs where the surface was largely covered with course material.

## DISCUSSION

The presence/absence data (qualitative data) was analyzed to elucidate the compositional similarities/ dis-similarities and to establish the boundaries of the plant communities along the geological gradient. The four associations produced by cluster analysis were plotted on the first two axes as a scatter diagram (Figure 3). Two procedures (classification and ordination) of data simplification can be seen to have given much similar results. The analysis and assessment of pattern and zonation along the first ordination axis suggested that two factors seems to be operative: landscape level and substrate. The importance of land scale level is not surprising but is closely associated with rainfall and redistribution of rainfall water. The upper piedmont and plains gain water from run on while the lower ones loose water to run off. This run off will be distributed in a moisture gradient along which vegetation change will be gradual. The down slope movement of water play an important role in determining the zonation along the ordination axis. The first ordination axis represent a gradient from rocky zone (with high score group 3) to alluvial plains (with low score in Groups 1 and 2). Vegetation of the sandy landscape consists of large number of deciduous sclerophyllous shrubs like *A. perisca*, *P. cineraria*, *Z. mauritiana* or psymohyllous grasses and herbs *C. colocynthis*, *C. ciliaris*, *C. prostratus*, *Heliotropium* sp., *L. procumbens*, *O. linifolia* and *T. terrestris*. *T. portulacastrum* and *M. hirta* were confined to solanchalk depressions and were not found in rocky strata whereas *Anabasis setifera C. spinosa*, *H. multiflorum*, *H. intermedia* and *S. fruticosa* were confined to the rocky strata.

## Conclusion

The pattern of plant communities along the first ordination axis suggested that beside the landscape, substrate play an important role in determining the boundaries between the plant communities. The assessment of the floristic suggested that there were three classes of plants. First, there are plants of alluvial sandy plains (psymophytes), second those of permanent water courses (hydrophytes) and thirdly, there are plants that grow on rocky hard strata (xerophytes/lithophytes).

Apart from the fact that the substrate variables are indeed relevant for explaining the main vegetation types, the correspondence between the results of the cluster

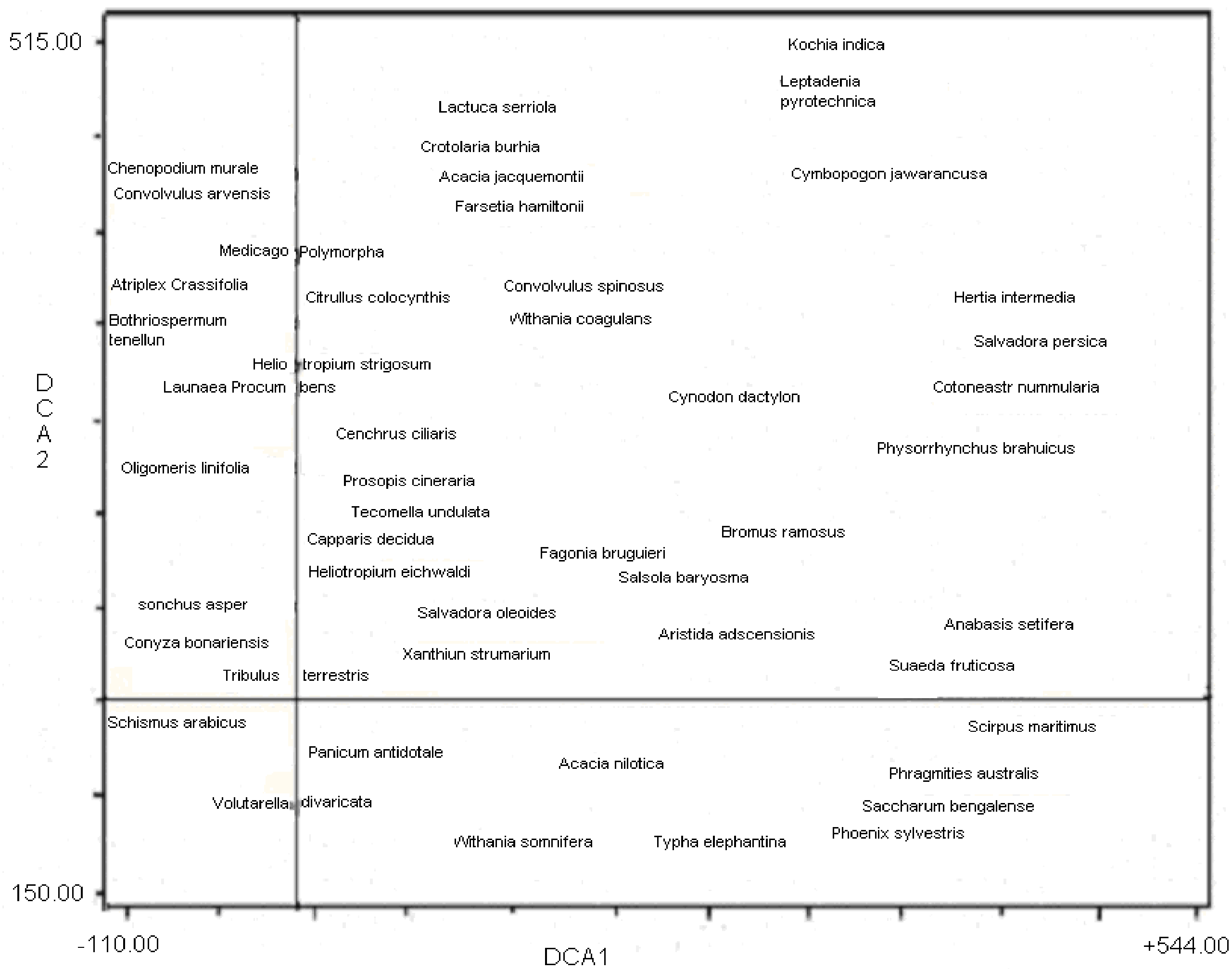


**Figure 4.** Results of detrended correspondence analysis (DCA) for the distribution of the species included in the vegetation analyses.

analysis and DCA planes permit a direct interpretation of scores of stand data in DCA plane in relation to soil variables. The observed pattern in available soil calcium seems related to long term redistribution of water that occurs during rainfall events because soil calcium, magnesium and moisture content have similar distributions along the transect. High calcium content for rocky strata is due to its parent geological gypsiferous formation. Although the boundaries across the landscape are associated with down slope movement of water, soil particles and cations, it is difficult to assess the relative importance of these factors in comparison with landscape level. The correlation between DCA axis and substrate variables suggest that some combine effect is important. Support for this interpretation comes from both the ordination and classification. Classification procedure ordered groups on the basis of their floristic composition in a sequence that correlated most closely with landscape level and topography. The reasons for these correlations must be hydrological; particularly the pattern of run off generation and redistribution of organic matter of the study area (Dasti and Agnew, 1994; Dasti and Malik, 1998).

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