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TOPOGRAPHIC AND EDAPHIC CONTROL OF ARBOREAL VEGETATION AND THE DISTRIBUTION AND GROWTH OF TREE SPECIES IN MOIST TEMPERATE AREAS OF HIMALAYAN AND HINDUKUSH REGIONS OF PAKISTAN

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Abstract

The role of edaphic and topographic variables on the distribution pattern of conifer species in moist temperate area of western Himalayan and Hindukush region of Pakistan is investigated. Arboreal vegetation of 41 sites was analyzed using point-centered quarter method. Soil samples from 41 different sites were collected to determine the edaphic characteristics and two stratifying variables i.e., elevation and slope were noted. Both classification and ordination methods were used to determine the underlying group structure and vegetation composition. For the purpose of ordination principal component analysis (PCA) and for classification Ward's cluster analysis was employed. Four groups of species were separated on the basis of topographic and edaphic variables by Ward's cluster analysis. Group 1 was dominated by *Pinus wallichiana*, group II & III were dominated by *Abies pindrow* while group IV was compose of two dominant species *Cedrus deodara* and *Pinus wallichiana*. The four groups also differentiated with respect to elevation, slope, salinity and electrical conductivity. The first component of PCA ordination of vegetation was correlated with elevation, soil organic matter (OM), pH, water holding capacity and soil conductivity; the second component exhibited association with elevation, slope, OM and conductivity while the third with slope, soil salinity and conductivity. Four principal component axes were well correlated with topographic and edaphic factors. Axis 1 was highly ($p<0.001$) significantly correlated with pH, organic matter and conductivity while axis 2 showed significant correlation ($p<0.001$) with elevation, slope, pH and conductivity. Axis 3 significantly correlated ($p<0.001$) with salinity and conductivity. Axis 4 exhibited marked relationship ($p<0.001$) with organic matter of soil and slope angle. Correlation coefficient between PCA vegetation and PCA environmental variables was also sought that exhibited significant correlation between components 2.

Introduction

An intrinsic feature of most terrestrial ecosystems is the soil heterogeneity, which are supplied to plant individuals, populations and communities in a patchy manner at different spatial scales (Farley & Fitter 1999). The present investigation attempts to analyze the vegetation composition and structure of moist temperate areas of Pakistan and exposes the regulation of vegetation composition and structure by the topographic and edaphic factors. A number of workers have demonstrated the controlling effect of edaphic factors (Wikum & Wali, 1974; Sollins, 1998) and topographic feature such as elevation (Kim, 2013). The need to evaluate the requirement of edaphic variables of particular plant species is increasing day by day. In Pakistan foresters, silviculturist and ecologists are trying to pay attention to evaluate the status of edaphic variables of selected forest species. One of the major objective of this study is to analyze the distribution of some soil characteristics (water holding capacity, salinity, total dissolved salts, conductivity, organic matter, soil compaction and pH) and topographic factors (elevation and slope) that may control the distribution pattern of the important tree species in the moist temperate area of western Himalayan and Hindukush region of Pakistan.

The nature of soil profile, pH and nutrient cycling between the soils and trees are the important dimensions to determine the site quality (Sheikh & Kumar, 2010). The vegetation influences the physico-chemical properties of the soil to a great extent by improving the soil structure, infiltration rate, water retaining capacity, hydraulic conductivity and aeration (Ilorkar & Totey, 2001; Kumar *et al*., 2004). According to Bates (1971) the diagnosis of nutrient deficiencies, and the prediction of fertilizer requirements from plant analysis, are based on a critical concentration of edaphic variables within the soil, below which growth is restricted.

Tareen *et al.,* (1987) and Tareen & Qadir (1987) stated that vegetation was correlated with edaphic variables during the study of Chiltan and plains of Quetta (Baluchistan). Hussain & Badshah (1998) stated that erosion and deforestation had reduced edaphic variables of soil. Similar studies for other mountainous areas have been reported by Hussain *et al.* (1994) and Hussain *et al*., (1995). Siddiqui *et al.,* (2011) investigated the concentration of soil and foliar nutrients of conifer species in the communities of moist temperate areas of Himalayan and Hindukush region of Pakistan. Besides these individual studies no extensive investigations were carried out to evaluate the status of edaphic variables of soil and dominant plant species in Pakistani forests. In Pakistan researchers have mostly focused on the edaphic variables of forest occurring in small sections of the moist temperate area which often masks the correlations owing to environmental stochastic variability in the concentrations of edaphic variables in various sites. However, no comprehensive study has yet been undertaken to cover a broad region such as the entire moist temperate region of Pakistan. Therefore, a detailed study of the vegetation-environment was conducted in moist temperate conifer forests. Multivariate techniques including cluster analysis (objective classification) and ordination are performed. This is the first attempt in Pakistan to explore the role of topographic and edaphic variables in the distribution and composition of vegetation (*Pinus wallichiana*, *Abies pindrow*, *Cedrus deodara* and *Picea smithiana*) using advance multivariate techniques. Ahmed *et al.,* (2009) accounted almost similar conifer species from different climatic regions of mountainous areas of Pakistan with different aspect.

Material and Methods

Vegetation sampling: Forty-one stands that were of adequate size, visually homogeneous and relatively free from recent anthropogenic disturbance were selected for detailed study of vegetation and environmental factors. The latitude, longitude, slope angle, aspect, altitude and soil compaction of each stand were recorded. The tree vegetation of 41 stands was sampled using point-centered quarter method (Cottam & Curtis, 1956) and various phytosociological attributes including relative and absolute density and basal area of tree species were computed following Mueller-Dombios & Ellenberg (1974); Kent & Kocker (1992) and Ahmed & Shaukat (2012).

Soil samples were collected at 5-30 cm depth from each stand. Five to six soil samples were randomly collected and pooled to obtain a composite soil sample for each site. During the collection of the soil, it was assured that no litter should be added with the soil. Soil samples were stored in labeled polythene bags and brought to the laboratory for analysis. In laboratory the soils were air dried, passed through a 2 mm (10 mesh) sieve size and again stored in clean plastic bottles. Subsequently, these soils were used for different analyses.

Preparation of the soil: 0.4- 0.5g soil sample was digested with the mixture of 6ml $HClO_4$- HF (1:2) on hot plate at about 195ºC till dried. Cool acidified with HNO_3 (2ml) and then distilled water was added. It was warm enough to dissolve all salts and cooled again and the solution was made up to 100 ml with deionized distilled water Cartor & Gregorich (2006).

Edaphic variables of soil: Salinity, pH and Conductivity were measured in the field with the portable instrument, Multiparameter meter [Model Sension TM 105, U.K]. Soil compaction was also measured in the field by portable Analog Soil Compaction gauge. Maximum water holding capacity was determined, following the method of Keen (1931).

Estimation of organic matter of soil: Organic matter of soil was estimated by the loss-on-ignition method of Dean (1974) as follows: In a thoroughly clean crucible 30 g soil (sieved with a 2 mm sieve) was placed in an oven at 90ºC for 5 hours to remove moisture. The soil was weighed and then kept in muffle furnace at 400ºC for 3 hours, subsequently, cooled to room temperature in a desiccators, the loss on ignition, representing the organic matter content. This method was also compared with wet digestion method using potassium dichromate and closely similar results were obtained.

Statistical Analysis: Data were subjected to univariate or multivariate statistical analysis following Orloci and Kenkel (1986), Shaukat & Siddiqui (2005) and Zar (2009). Two main types of multivariate analyses were employed, namely cluster analysis and ordination. For cluster analysis Ward's hierarchical agglomerative method was chosen. For the purpose of ordination, principal component analysis (PCA) was used. Beside simple linear correlation of single environmental variables, synthetic environmental gradients were also correlated with the components of the PCA vegetation ordination. Both Ward's cluster analysis and PCA ordinations were performed using the program-package PC-ORD (Grace and McCune, 2002; McCune & Meford, 2005). Correlation and regression analyses were performed (using SPSS-Package Ver. 12) to seek the relationship between individual environmental variables with the PCA components.

Results and Discussion

Fig. 1 shows the locations of the 41 sampled stands where sampling was conducted. Table 1 gives the site locations, latitude, longitude and topographic characteristics of the moist temperate conifer stands. The study area was located at the elevation of 1600m to 3100m while the slope angle lies between the 5º to 47º. Fourteen stands were located on northerly facing slope, seventeen stands were located southerly, six stands were on westerly side while only two stands were located on east-facing slope. Magnitudes of various soil characteristics are presented in Table 2.

Cluster analysis: Based on Ward's cluster analysis of environmental data, the major groups were extracted. The dendrogram (Fig. 2) discloses four main groups at a squared Euclidean distance of 3.5×10^4 (information remaining 75%). Mean importance value of tree species in each major group is presented in Table 3. Group I comprising of 12 stands, is characterized by the predominance of *Pinus wallichiana* (average importance value = 53.92) with *Cedrus deodara* (average importance value = 29) and *Abies pindrow* (average importance value = 14.5). *Picea smithiana* and *Taxus fuana* is also associated with this group with very low average importance value (1.58 & 0.33 respectively). Group II includes 10 stands is dominated by *Abies pindrow* (average importance value = 48.9) with *Pinus wallichiana* as second dominant (importance value = 37.8). *Cedrus deodara* and *Picea smithiana* were the associated species with this group (average importance value = 7.3 & 3.9 respectively). *Taxus fuana* and *Juglans regia* were found with very low abundance.

Group III comprises of 11 stands is predominated by *Abies pindrow* (average importance value = 45.2) while *Cedrus deodara* occupied as co dominant species (average importance value = 26). *Pinus wallichiana* is also conspicuous (average importance value = 19.4). *Picea smithiana*, *Taxus fauna* and *Juglans regia* has low abundance in this group (average importance value = 6.18, 1.91 & 1.36 respectively). *Cedrus deodara* and *Pinus wallichiana* occupied similar abundance (48.25 and 46.88 average frequency respectively in group IV that consists of eight stands. *Quercus incana* and *Quercus ilex* associated only with this group with very low abundance (average importance value = 1 and 0.65 respectively). *Taxus fauna* and *Juglans regia* is also associated with very low average importance value i.e. 0.375 and 1.13 respectively.

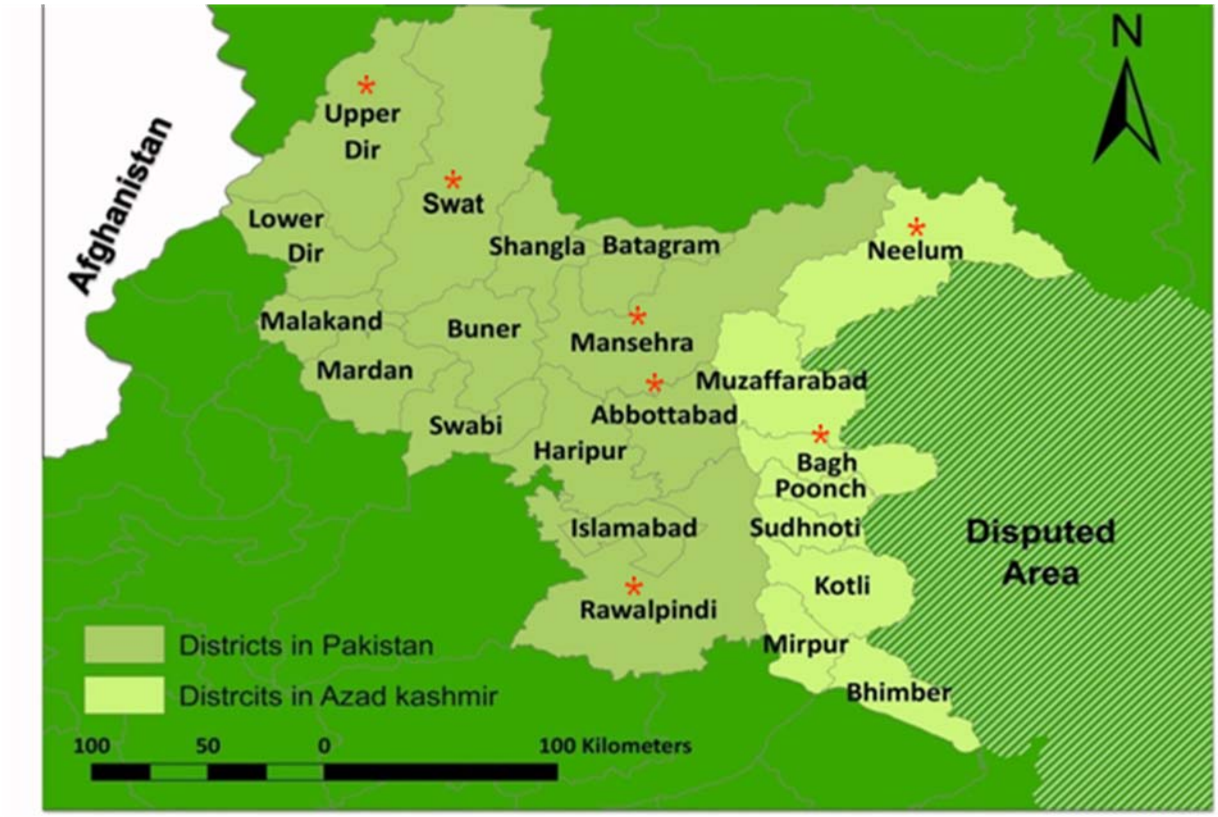

Fig. 1. Study area map. * showing the districts where forests were sampled Siddiqui *et al.*, (2013).

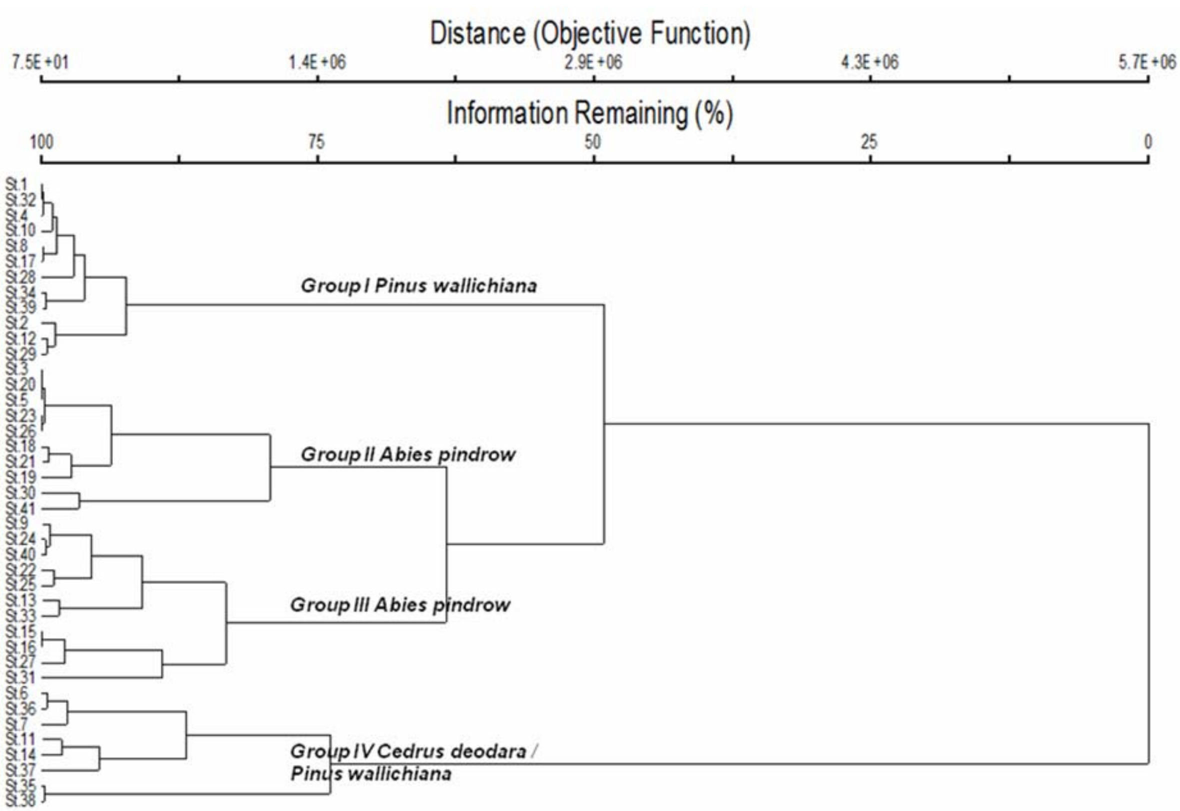

Fig. 2. Dendrogram derived from Ward's cluster analysis of edaphic and topographic variables of moist temperate area of Pakistan.

Table 1. Summary of topographic variables and site characteristics of studied moist temperate area of Himalayan and Hindukush region of Pakistan, modified Siddiqui *et al.*, (2013).

S. No.	Location and sites	Latitude (N)	Longitude (E)	Elevation (m)	Slope (°)	Aspect
	1. Dir Upper (district), Malakand Division					
1.	Kumrat	35° 54'	72° 14'	2400	5	R. Top
2.	Pana Kot	35° 16'	71° 50'	2200	40	W
	2. Swat (district), Malakand Division					
3.	Malam Jabba 1	35° 12'	72° 81'	2600	34	W
4.	Malam Jabba 2	35° 20'	72° 40'	2350	30	N W
5.	Miandam	35° 09'	72° 30'	2600	49	N
	3. Neelam (district), Azad Kashmir					
6.	Keran	34° 56'	73° 12'	1960	30	N E
	4. Bagh (district), Azad Kashmir					
7.	Chikar	34° 54'	73° 10'	1930	28	N W
8.	Sudhan Gali 1	34° 20'	73° 22'	2450	22	E
9.	Sudhan Gali 2	34° 22'	73° 28'	2500	32	N
10.	Sudhan Gali 3	34° 19'	73° 25'	2420	38	W
	5. Murree (district), Rawalpindi Division					
11.	Ghora Gali	33° 52'	73° 20'	2100	29	N
12.	Patreata Top 1	33° 50'	69° 56'	2300	40	S E
13.	Patreata Top 2	33° 50'	69° 56'	2300	25	S W
14.	Nia, Near Patriata	33° 52'	69° 57'	2000	39	S
15.	Kashmir Point	34° 54'	73° 24'	2500	39	S
	6. Abbot Abad (district), Hazara Division					
16.	Ghora Dhaka 1	34° 02'	73° 26'	2500	36	N E
17.	Ghora Dhaka 2	34° 04'	73° 24'	2500	32	S E
18.	Ghora Dhaka 3	34° 07'	73° 25'	2800	40	S W
19.	Ghora Dhaka 4	34° 09'	73° 27'	2800	40	W
20.	Ghora Dhaka 5	34° 11'	73° 28'	2600	37	S W
21.	Khaira Gali	33° 57'	73° 23'	2730	42	S E
22.	Changla Gali 1	33° 59'	73° 23'	2650	47	W
23.	Changla Gali 2	33° 59'	73° 23'	2670	35	S
24.	Kuzah Gali 1	34° 02'	73° 24'	2560	5	R. Top
25.	Kuzah Gali 2	34° 02'	73° 24'	2560	28	S E
26.	Nathiagali, Lalazar 1	34° 54'	73° 46'	2640	35	S
27.	Nathiagali, Lalazar 2	34° 54'	73° 46'	2630	33	N W
28.	Thandyani 1	34° 14'	73° 22'	2320	31	S
29.	Thandyani 2	34° 14'	73° 22'	2300	38	S
	7. Mansehra (district), Kaghan Valley					
30.	Paye	34° 47'	73° 30'	3100	38	S
31.	Sri	34° 47'	73° 30'	2900	39	N
32.	Shogran 1	34° 37'	73° 28'	2400	27	S W
33.	Shogran 2	34° 37'	73° 28'	2400	23	S
34.	Shogran 3	34° 37'	73° 28'	2500	33	S
35.	Paras,Malkandi Pine Park	34° 41'	73° 35'	1600	20	N E
36.	Khanian	34° 47'	73° 32'	2000	35	E
37.	Shinu 1, Near Jurait Park	34° 38'	73° 26'	1900	39	N W
38.	Shinu 2, Near Jurait Park	34° 38'	73° 26'	1650	43	W
39.	Naran, River Belt 1	34° 53'	73° 39'	2500	5	N W
40.	Naran, River Belt 2	34° 53'	73° 39'	2500	5	N W
41.	Lalazar (Naran)	34° 53'	73° 39'	3000	45	N W

Key to abréviations: R. Top = Ridge top, E = East, W = West, N = North, S = South

Table 2. Values of edaphic variables from 41 stands of moist temperate area of Himalayan and Hindukush region of Pakistan.

S. No.	Location and sites	Organic matter (%)	pH	WHC (%)	Salinity (%)	Conductivity (mmhos/cm)	Soil compaction (PSI)
1.	Kumrat	10.5	5.8	65.4	0.34	215	165
2.	Pana Kot	9.9	6.64	62.5	0.1	230	150
3.	Malam Jabba 1	5.5	5.4	49.7	0.1	237	175
4.	Malam Jabba 2	3.9	5.2	51.8	0.1	197.6	200
5.	Miandam	3.4	5.7	55.2	0.1	226	150
6.	Keran	7.2	6.85	48.1	0.1	204	250
7.	Chikar	5.0	6.39	45.4	0.13	120.1	150
8.	Sudhan Gali 1	3.8	6.02	50.2	0.23	220	200
9.	Sudhan Gali 2	4.3	5.65	56.5	0.2	395	130
10.	Sudhan Gali 3	5.1	6.51	54.4	0.1	276	110
11.	Ghora Gali	3.8	6.8	60.2	0.2	359	150
12.	Patreata Top 1	5.2	6.59	61.5	0.1	322	210
13.	Patreata Top 2	7.9	6.62	59.8	0.3	570	110
14.	Nia, Near Patriata	7.2	6.32	54.7	0.3	475	150
15.	Kashmir Point	5.2	6.9	51.2	0.3	688	150
16.	Ghora Dhaka 1	4.3	6.7	56.6	0.4	732	130
17.	Ghora Dhaka 2	3.8	6.52	47.8	0.1	203	170
18.	Ghora Dhaka 3	6.7	6.31	57.3	0.2	391	180
19.	Ghora Dhaka 4	5.6	5.62	50.8	0.1	239	220
20.	Ghora Dhaka 5	8.4	6.77	58.7	0.1	242	170
21.	Khaira Gali	8.0	5.89	61.8	0.1	345	120
22.	Changla Gali 1	6.7	6.98	47.2	0.2	452	180
23.	Changla Gali 2	6.7	6.65	53.4	1.3	234	150
24.	Kuzah Gali 1	3.4	6.15	48.5	0.34	348	210
25.	Kuzah Gali 2	4.4	6.18	52.7	0.2	534	210
26.	Nathiagali, Lalazar 1	8.6	6.31	62.4	0.1	246	160
27.	Nathiagali, Lalazar 2	3.8	6.8	63.5	0.3	714	190
28.	Thandyani 1	5.6	6.75	40.6	0.14	109	140
29.	Thandyani 2	5.1	5.3	46.5	0.1	260	140
30.	Paye	3.8	5.23	32.5	0.1	317	250
31.	Sri	4.4	5.55	42.6	0.3	615	90
32.	Shogran 1	4.0	6.74	58.4	0.31	223	170
33.	Shogran 2	7.7	6.87	63.4	0.2	488	190
34.	Shogran 3	3.4	6.91	61.2	0.1	58.6	150
35.	Paras,Malkandi Pine Park	4.4	6.82	48.6	0.23	80	160
36.	Khanian	5.1	6.61	59.7	0.1	275	195
37.	Shinu 1, Near Jurait Park	6.7	6.75	54.3	0.3	611	180
38.	Shinu 2, Near Jurait Park	3.8	6.7	56.2	0.11	34.7	120
39.	Naran, River Belt 1	3.8	6.44	43.6	0.32	132	190
40.	Naran, River Belt 2	3.8	5.62	48.5	0.35	297	170
41.	Lalazar (Naran)	8.7	5.21	62.7	0.12	164.2	150

Key to abbreviations: WHC = Water holding capacity, PSI = Pounds per square inch

Table 3. The four groups derived from Ward's cluster analysis of 41 stands based on environmental data in Matrix 1 while their average tree species composition (average importance value for each group) are presented.

S. No.	Tree species	Group I	Group II	Group III	Group IV
1.	*Pinus wallichiana*	53.92	37.8	19.36	46.88
2.	*Abies pindrow*	14.5	48.9	45.18	*
3.	*Cedrus deodara*	29	7.3	26	48.25
4.	*Picea smithiana*	1.58	3.9	6.18	*
5.	*Taxus fuana*	0.33	0.8	1.91	0.375
6.	*Juglans regia*	*	1.3	1.36	1.13
7.	*Quercus incana*	*	*	*	1
8.	*Quercus ilex*	*	*	*	0.625

* Absent

Four groups of topographic and edaphic variables are also formulated on the basis of groups extracted by Ward's cluster analysis (Table 4) which showed mark heterogeneity because of difference in vegetation composition. Group I is characterized by medium elevation, medium slope angle, low salinity and conductivity levels. Group II is characterized by higher elevation, greater slope, higher salinity and conductivity and high soil compaction. Group III is associated with slightly high elevation, medium slope, high salinity and conductivity while Group IV is characterized by low elevation, slightly high slope angle, low salinity and conductivity.

Soils of the study area showed considerable variability with respect to different sampling sites. Such soil heterogeneity has been noticed by other workers (Garcia-Palacios *et al.*, 2012; Tittonell *et al.*, 2013). The vegetation of studied forests is clearly demarcated into four groups on the basis of vegetation composition and was well correlated with environmental factors.

Principal component analysis: PCA technique is capable of extracting the synthetic axes called principal components which are linear combination of original variables such that the successive components are orthogonal to each other. The results of principal component analysis (PCA) of topographic and edaphic data are summarized in Table 5. The first, second, third and fourth components (axes) of PCA ordination explained 23%, 19%, 16% and 13% of the total variation in the environmental data while the four components together explained 71% of the total variance inherent in the environmental data set. The first PCA axis was primarily a function of water holding capacity (WHC), organic matter (OM), soil pH and soil compaction. The second component was basically regulated by elevation, pH, slope and soil conductivity.

Table 4.The four groups of environmental variables (topographic and edaphic variables) are formulated on the basis of Ward's cluster analysis. (Mean ± SE).

Sr. No.	Environmental variable	Group I Mean ± SE	Group II Mean ± SE	Group III Mean ± SE	Group IV Mean ± SE
1.	Elevation (m)	2386.7 ± 27.48	2754 ± 55.4	2545.5 ± 46.1	1892.5 ± 62.5
2.	Slope (º)	28.4 ± 3.52	39.5 ± 1.52	28.46 ± 3.99	32.88 ± 2.66
3.	Organic matter (%)	5.34 ± 0.69	6.55 ± 0.61	5.1 ± 0.48	5.4 ± 0.5
4.	pH	6.29 ± 0.166	5.91 ± 0.18	6.37 ± 0.17	6.66 ± 0.071
5.	MWHC	53.66 ± 2.35	54.45 ± 2.85	53.68 ± 2.1	53.4 ± 1.94
6.	Salinity	0.17 ± 0.029	0.232 ± 0.12	0.281 ± 0.21	0.184 ± 0.03
7.	Conductivity	203.85 ± 21.15	264.12 ± 21.1	530.3 ± 44.92	270 ± 71.3
8.	Soil compaction	166.25 ± 8.64	172.5 ± 11.91	160 ± 12.28	169.4 ± 14.1

SE = Standard error & MWHC = Maximum water holding capacity

Table 5. Results of PCA of topographic and edaphic characteristics of the 41 stands of moist temperate area of Pakistan.

Component	Eigen value	% Variance explained	Cumulative variance %	Eigenvector co-efficient	Associated variables
1	1.823	22.782	22.782	2.234	WHC
				1.725	OM
				1.716	pH
				-1.441	Soil comp.
				-0.897	Conductivity
				-0.866	Elevation
2	1.510	18.878	41.659	-2.587	Elevation
				1.791	pH
				-1.696	Slope
				-1.275	Conductivity
				-0.819	OM
				0.575	Soil Comp.
3	1.294	16.169	57.829	-2.875	Salinity
				-1.915	Conductivity
				1.309	Slope
				-0.789	Elevation
				0.733	OM
				-0.603	pH
4	1.040	13.005	70.834	-2.239	OM
				1.987	Slope
				-1.517	Soil Comp.
				-1.208	WHC
				1.068	Conductivity
				0.817	pH

Key to abbreviations: OM = Organic matter, WHC = water holding capacity, Conduct. = Conductivity and Soil comp. = Soil compaction

The third component is chiefly related to salinity, conductivity, slope and elevation while the fourth component is mainly a function of organic matter, slope, soil compaction and water holding capacity.

Two dimensional Principle component analysis (PCA) ordination (Fig. 3) of environmental data set showing the distribution of stand on right side (axes 1 &2), tree species in different directions and topographic and edaphic variables are also in different directions, showed marked influence in the vegetation composition in moist temperate area of Pakistan. On axes 2 & 3 exhibited the distribution of stands on left upper side and almost similar situation of species distribution and environmental variables.

Two dimensional Principle component analysis (PCA) ordination (Fig. 4) of vegetation data set (axes 1 & 2) showing the distribution of stand on upper left side, tree species are distributed in different directions that showed the effect of environmental variables in vegetation composition.

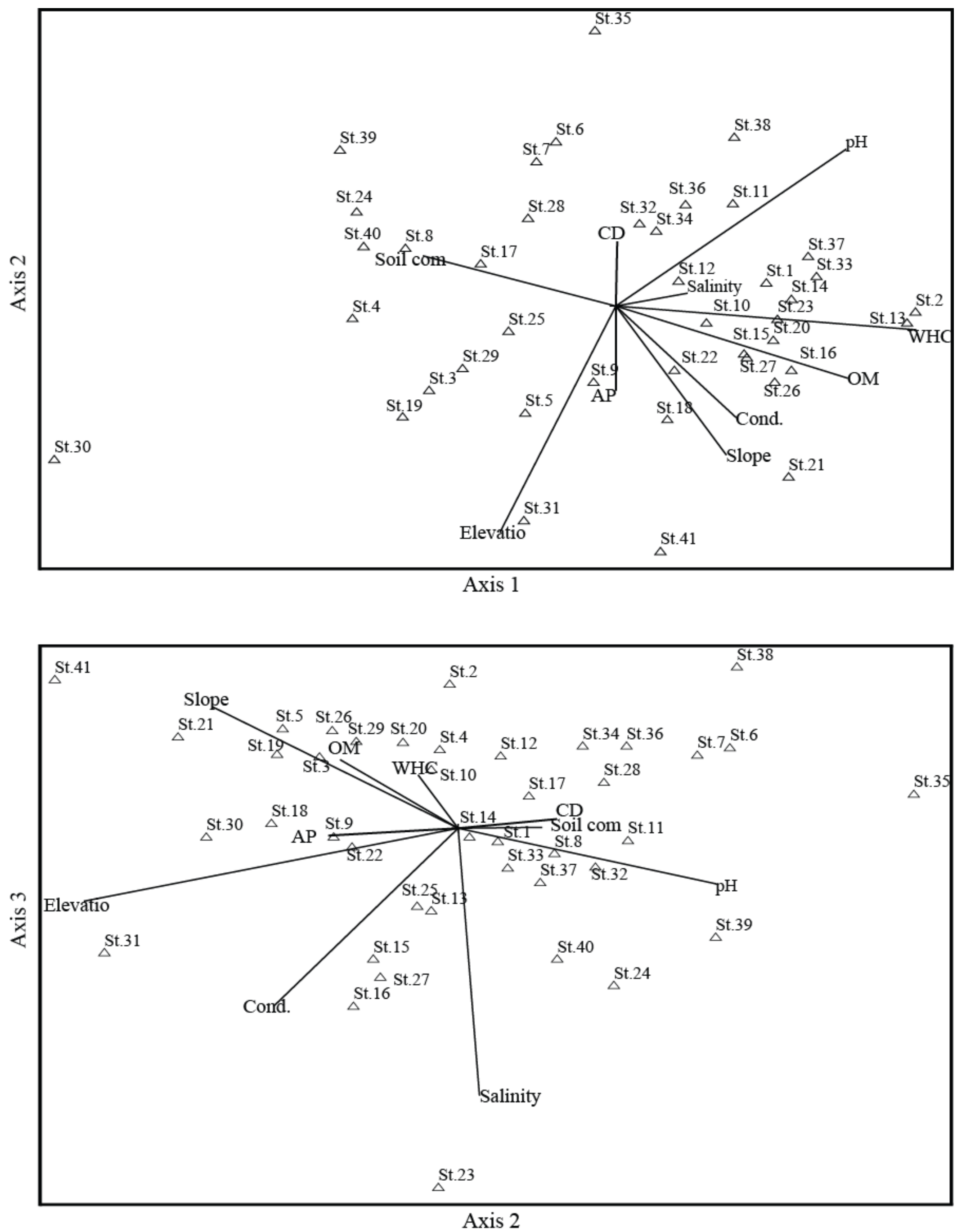

Fig. 3. Two dimensional Principle component analysis (PCA) ordination of environmental data set showing the distribution of stand in moist temperate area of Pakistan.

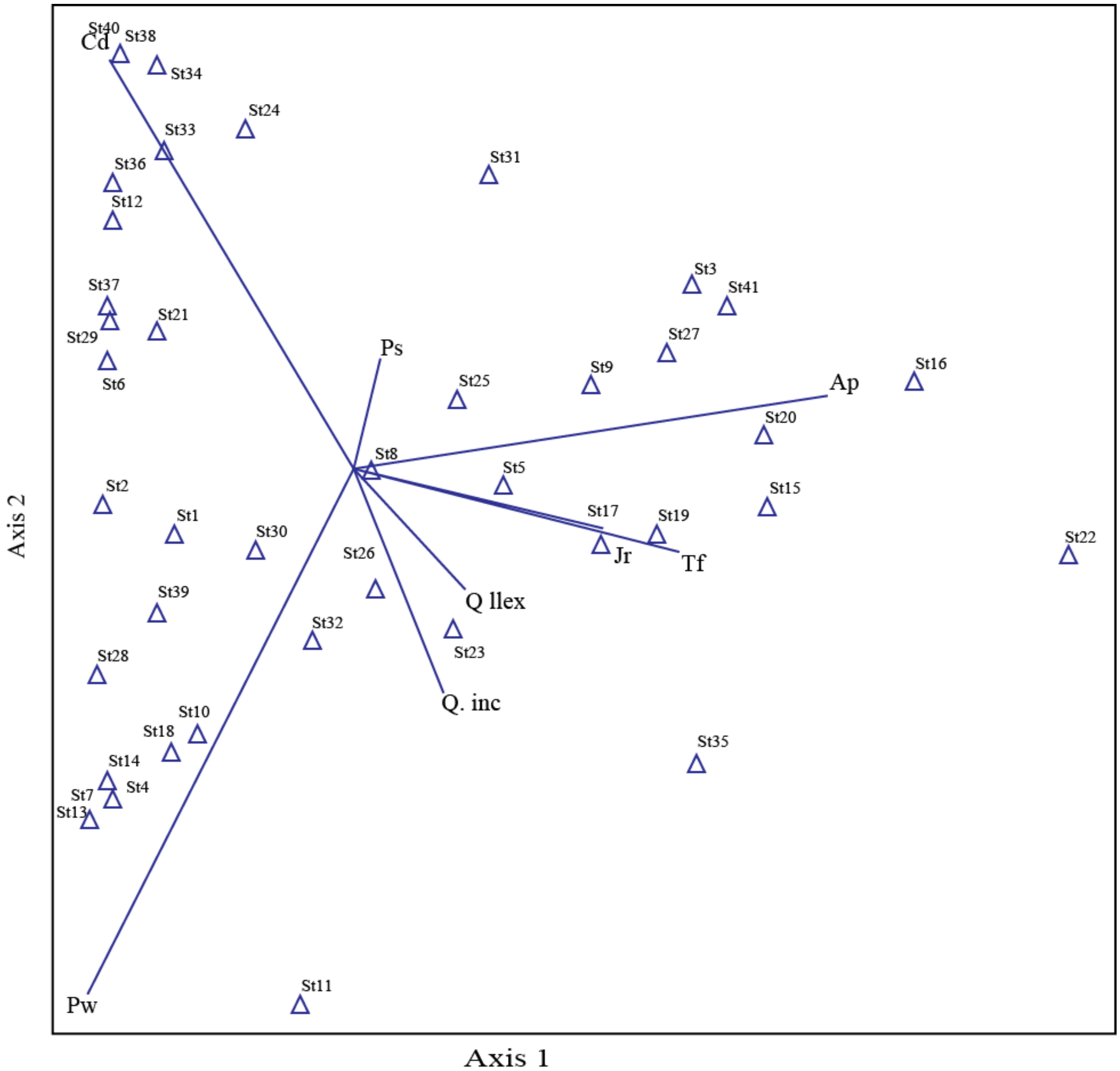

Fig. 4. Two dimensional Principle component analysis (PCA) ordination of vegetation data matrix showing the stands sampled in the moist temperate area of Pakistan.

First four components of PCA ordination axes showed many significant correlations with the environmental variables (Table 6). Axis 1 showed highly significant correlation ($p<0.001$) with organic matter of soil, pH and water holding capacity (WHC) while conductivity and soil compaction exhibited correlation at $p<0.01$. Axis 2 was found correlated with elevation, slope and soil pH at: $p<0.001$ while conductivity and organic matter showed the correlation at ($p<0.01$) and ($p<0.1$) respectively. On the other hand, axis 3 was significantly correlated with slope ($p<0.01$), conductivity ($p<0.001$), and salinity ($p<0.001$). Lastly, axis 4 was correlated with slope ($p<0.001$), organic matter ($p<0.001$), water holding capacity of soil ($p<0.01$), conductivity ($p<0.1$) and soil compaction ($p<0.01$). The first component of PCA (vegetation data) seems to represent an amalgam of soil and topographic factors contributing the moisture regime as well as soil chemical factors that regulate the availability of nutrients. Likewise, components 2 and 3 also represent a combination of moisture status (viz. degree of slope that controls water run-off/retention) and chemical factors. The fourth component seems to represent predominately soil chemical factors. Siddiqui *et al.*, (2010) observed similar type significant correlation between DCA ordination axes with environmental variables.

Table 7 shows correlation coefficients between components derived from the PCA of vegetation data set with those derived from the PCA of environmental data set. The second vegetation component was highly significantly correlated ($p<0.001$) with the first PCA component of the environmental data set. The first environmental component was primarily a function of maximum water holding capacity, organic matter and soil compaction. Likewise, the second vegetation component exhibited a significant negative correlation with the second environmental component ($p<0.01$). The second component resulting from PCA of environmental data set is largely governed by elevation, pH, slope and soil compaction.

Table 6. Correlation coefficient between the PCA axes with topographic and edaphic variables of moist temperate areas of Himalayan and Hindukush region of Pakistan.

Sr. No.	Nutrients	Axis 1	P value	Axis 2	P value	Axis 3	P value	Axis 4	P value
1.	Elevation	-0.297	p<0.1	-0.808	p<0.001	-0.228	ns	-0.206	ns
2.	Slope	0.281	p<0.1	-0.529	p<0.001	0.378	p<0.01	0.515	p<0.001
3.	OM	0.588	p<0.001	-0.258	p<0.1	0.211	ns	-0.582	p<0.001
4.	pH	0.589	p<0.001	0.559	p<0.001	-0.174	ns	0.212	ns
5.	WHC	0.766	p<0.001	-0.086	ns	0.164	ns	-0.313	p<0.01
6.	Salinity	0.182	ns	0.047	ns	-0.831	p<0.001	-0.149	ns
7.	Conduct.	0.308	p<0.01	-0.398	p<0.01	-0.553	p<0.001	0.277	p<0.1
8.	Soil com.	-0.494	p<0.01	0.179	ns	0.0035	ns	-0.393	p<0.01

Table 7. Correlation coefficients between PCA vegetation and PCA environmental components.

PCA vegetation components	PCA environmental components		
	Component 1	Component 2	Component 3
Component 1	0.066 ns	0.019 ns	-0.068 ns
Component 2	0.549***	-0.359*	-0.099 ns
Component 3	0.116	-0.200	0.022 ns

* = p< 0, 01, *** = p<0.001

Normal growth and development of plants depends upon the continuous supply of nutrients and soil moisture. Water holding capacity, organic matter of soil, salinity, conductivity, total dissolved salts, pH and soil compaction showed marked association with the distribution and abundance of vegetation. The present communication highlights how soil heterogeneity modulates plant responses in terms of growth and distribution. Multivariate methods including agglomerative cluster analysis (Ward's method) and principal component ordination were employed to seek the influence on individual environmental factors as well as factor complexes in terms of PCA components that are heavily weighed on particular environmental variables. In addition to developing the PCA ordinations of the environmental and vegetation data sets an attempt was made to unfold the multidimensional relationships inherent in the vegetation-environmental data sets by correlating the PCA components of vegetation data set with PCA components derived from the environmental data matrix. PCA was chosen for ordinations because it does not require formal assumptions (James and McCulloch, 1990). Furthermore, the environmental variables used in this study are linear or monotonic and satisfy the condition of linearity necessary to obtain linear combinations of variables or the principal components. Thus the multivariate approach employed in this study seems to be adequately robust and successfully discloses the vegetation-environmental pattern, particularly the distribution pattern of individual tree species, despite the long history of anthropogenic disturbances.

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