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Slope Aspects and Elevation Influenced Herbaceous Diversity and Soil Characteristics in Tropical Forests of Indian Desert

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors contributed to field data collection, laboratory analysis, data interpretation, manuscript writing and approval. Both authors read and approved the final manuscript.

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ABSTRACT

Aim: Understanding the interactive effects of aspects and elevation on soil properties and vegetation diversity in hill forests of the desert environment is essential for devising strategies to restore such degraded hills.
Place and Duration: Observations were recorded from September to October months of both 2017 and 2018 in a hill forest area in Thar Desert of Rajasthan, India.
Methodology: Three-hundred-twenty plots of 1 m^2 (clustered at sixty-four positions based on eight slope aspects and eight elevations) were studied for herbaceous diversity and soil properties by sorting vegetation to species level and soil sampling in each plot. Community population (P), height, soil water content (SWC), pH and organic carbon (SOC) were measured and species-richness (R), Shannon-Weiner diversity (H'), dominance (D) and evenness (J') were calculated.
Results: Out of 174 species recorded from 34 families and 122 genera, 163 species showed IVI <5. Highest number of species (48) were from family Poaceae. Soil pH, SWC, SOC, P and height were greater in 2017, whereas R, H' and J' were greater in 2018. Soil pH, vegetation height and D were lowest in northeast and highest (1.04-1.54-fold) in west to southeast. SOC, SWC, R and J'

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were 1.16-2.35-fold greater in northeast than south aspect. P, height and H′ showed a reverse trend with 1.15-1.53-fold variation. SOC, height, R and H' increased by 1.30-2.35-fold with an increase in elevation from <230m to >600m, whereas D and pH showed a decreasing trend. The highest values of SWC, P and J' were in 800-900m, 700-800m and 600-700m respectively. Though varied with aspects, <230m area was dominated by xeric species, middle by *Aristida adscensionis* and higher ones by *Apluda mutica*/*Heteropogon contortus*.

Conclusion: Altitude had stronger impact on all variables except SWC, which was influenced strongly by aspects making southern slopes drier than the northern slopes and influenced species structure and composition. Such areas require effective conservation, but aspect and elevation should be given due importance in devising restoration strategies for efficient management of biodiversity and mitigating climate change.

Keywords: Arid zone; herbaceous vegetation; isolated hills; soil organic carbon; soil water; species dominance.

1. INTRODUCTION

Topography shows significant impacts on the abundance, distribution, and diversity of vegetation in mountainous regions by influencing micro-climate, vegetation establishment, water movement, nutrient distributions, and soil erosion [1,2]. Elevation along with aspect and slope determines the microclimate and thus large-scale spatial distribution and patterns of vegetation dynamics [3,4]. Each mountain face shows contrasting characteristics with respect to insolation, light intensity, soil moisture, soil pH, humidity, etc [5]. The north-facing slope retain moisture and is more cold and humid than the south-facing slope in the northern hemisphere thereby offering a better habitat for regeneration and growth of diverse vegetation [6,7]. The elevation is another factor influencing temperature, evapotranspiration, humidity, wind speed, rainfall [8,9], and species richness [10], whereas north and south aspects have been observed as the main ecological drivers in altitudinal species richness [7].

Global patterns of species ranges and richness are the product of many interacting factors such as environmental conditions, competition, geographical setting, and evolutionary development [11,12]. For instance, vegetation in arid regions adapt by changing structural characteristics like a fleshy leaf, assimilating shoots, lots of epidermal hairs, thick cuticle, etc., to improve their water use efficiency in the existing environment [13]. Favourable climatic conditions particularly high precipitation promotes species richness and belowground biomass, which shows a consistently positive effect on soil water, organic carbon storage and pH [14]. SOC acts as a medium of sorption to hold water and improve soil aggregation and nutrient cycling [15]. Increased nutrient availability plays a variable role in seed germination, seedling establishment and species dominance along an altitudinal gradient [16,17,18]. SOC also helps improve water availability leading to higher species richness in contrast to the effects of increased nutrient availability [19]. Soil pH influences trace element mobility and nitrogen cycling [20]. Therefore spatial variation in slope aspect, elevation and soil characteristics appear determinant of vegetation pattern, species distribution and ecosystem processes. It would be more imperative to study the environment-vegetation relationships in the arid environment particularly in the Thar Desert [21].

The Thar Desert covers about 200,000 km^2 areas bordering irrigated Indus plain to the west, the Punjab plain in north and northeast, the Aravalli range in the southeast, and the Rann of Kutch in the south [22]. Archean gneiss, Proterozoic sedimentary rocks and more-recent alluvium are geological features [23]. The surface consists of aeolian sand accumulated over the past 1.8 million years. The soils consist of desert soils, red desertic, sierozems, the red and yellow soils in the foothills, the saline soils of the depressions, and the lithosols (shallow weathered soils) and soft loose soils (regosols) in the hills [22]. Because of varying topographical features like saline depressions, sand dunes, sandy plains and rock outcrops, gravelly pediments and isolated hills, this region harbours a variety of flora and fauna [24,25,26]. Most of the isolated hills are surrounded by sandy ravines developed by wind and water erosion in the region [27]. These hills support a wide variety of flora ranging from desertic in foothills to deciduous flora of Aravalli on hillslopes and top [24]. However, increasing pressure of livestock grazing coupled with climatic harshness leads to depletion of flora and requires effective management strategies to restore such degraded hills. There is a lack of knowledge and understanding of how the slope aspect and elevation interact to influence soil characteristics and vegetation composition in such mountainous areas of Thar Desert. Thus, determining the relationship between topography, vegetation and soils is an essential factor for devising restoration plan [28].

Therefore, objectives of this study were: (i) to study vegetation composition and diversity in different physiographic positions of Siwana-complex area; (ii) to estimate soil pH, water storage and organic carbon in different elevation and aspects; and (iii) to find out the relationship between diversity indices and soil factors for help in devising restoration strategies.

2. MATERIALS AND METHODS

2.1 Study Site

The study was conducted in Haldeswar Mahadevji hill forest of Siwana complex area of Barmer district (Thar Desert) in western Rajasthan. This forest block is situated between 25° 32'N to 25° 36' N Latitude and 72° 17' E to 72° 24' E Longitude covering over 5000 ha area. Elevation varies from 230 to 950 meters above mean sea level (amsl) and comes under high altitude hot desert region surrounded by seasonal rivers system and the sandy plain to sandy ravenous area (Fig. 1). The annual rainfall of Siwana tehsil during 2009-2018 was 243.4 mm. In this, the year 2013 received the highest rain of 752 mm, whereas the lowest was 172 mm in 2018 (Fig. 1). In the year 2017, a total of 622 mm rain was received in 25 days. The annual mean minimum and maximum temperatures of Siwana were 23.7 °C and 34.15 °C respectively. Average relative humidity was 30.5-36.4% and wind speed was 10.8-15.8 k hr^{-1}. Windblown soils deposited on the hilltops are also visible in patches. The soil of the area is slightly alkaline in reaction and low in soil organic carbon (0.40-0.76%) and nitrogen (0.12-0.16%).

2.2 Experimental Design and Observation Recording

The total area was divided into eight slope aspects and 8 elevation categories. The slope aspects were North (N), Northeast (NE), East (E), Southeast (SE), South (S), Southwest (SW), West (W) and Northwest (NW). Eight elevation positions were <230m, 230-300m, 300-400m, 400-500m, 500-600m, 600-700m,700-800m and 800-900 m amsl. The slope aspect was measured clockwise starting from North (0°). The compass direction facing the slope was the slope aspect and flat terrain with no slope was considered no aspect. Elevations were measured in meters (m) amsl. The geographical coordinates (latitude and longitude) and the elevation were recorded with the help of the Geographic Information System (GPS). Percent slope was calculated by dividing the difference between the elevations of two points (rise) by the distance between them (run) multiplied by 100. Sixty-four sites were identified based on the slope aspect and elevation (8 × 8). At each site, five sampling plots (cluster sampling) of 1 m × 1 m size were laid out as replicates. In this one plot was in the central position and the other four were at each corner of the central plot with a distance of 45 m from the center of the central plot to the center of the other plots. Vegetation study was conducted after the monsoon period, i.e. during September to October months of 2017 and again in 2018. This is the time when the chances of availability of herbaceous species are highest in the region. Herbaceous vegetation was studied in 320 plots (8 aspects × 8 elevations × 5 sampling plots) following the standard method [29]. The above-ground vegetation from 1-m^2 area quadrates was clipped just above the surface and sorted to species. All herbaceous vegetation was identified as per taxonomic classification using local and regional flora of Jodhpur and Rajasthan [24,26]. These species were counted manually and categorized into several species and their population. The phytosociological analysis included diversity variables like species richness (R), Shannon-Wiener diversity index (H'), species evenness (J'), and Simpson's diversity index (D), were calculated following standard procedures [30,31,32,33]. Height and diameter were recorded for 5 representative plants of each species using measuring tape and vernier caliper. The Importance Value Index (IVI) was calculated as the sum of relative frequency, relative density and relative dominance [34]. The height of the herbaceous vegetation in a sampling plot was calculated using equation $H = \Sigma n_i h_i / N$. Here H is the height of the herbaceous vegetation, ni is the population of its species, hi is the average height of its species and N is the population of all species in the sampling plot [35].

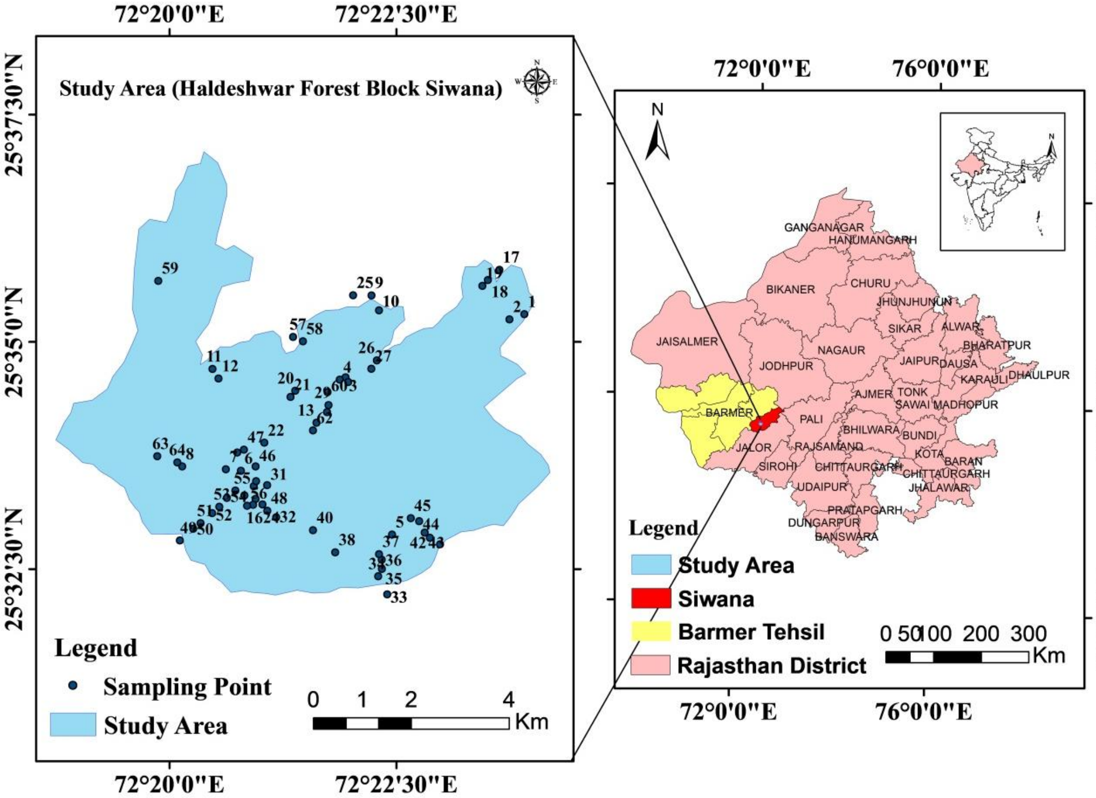

Fig. 1. Study site in haldeshwar mahadev forest block area of siwana ring complex in Barmer district of Rajasthan, India

2.3 Laboratory Analysis of Soil

Soil samples were collected in 0-30 cm (or available depth) soil layer during vegetation study in 2017 and again in 2018. Soil samples were packed thoroughly in polythene bags to avoid moisture losses and brought to the laboratory for further analysis. Air-dried soil samples were grounded and passed through a 2 mm sieve and used for soil pH and soil organic carbon (SOC) estimation. Soil pH was determined in 1:2 soils: water suspension using pH (Deluxe pH meter-101) [36]. Percent soil organic carbon (SOC) was determined by the wet digestion method of Walkley and Black [37]. Per cent soil water content (SWC) was determined gravimetrically after oven drying the samples at 105°C for a constant weight.

2.4 Statistical Analysis

All data were subjected to statistical analysis using SPSS statistical package version 17.0 for Windows. Since the data on SWC, SOC, pH, vegetation height and different diversity variables were recorded repeatedly for two years, i.e. 2017 and 2018, these data were analysed using Repeated Measure ANOVA (RAMNOVA). The year was 'Tests of Within-Subjects Effects', whereas slope aspects and elevations were 'Tests of Between-Subjects Effects'. Duncan Multiple Range Tests (DMRT) were applied to group different variables into homogeneous subsets based on slope aspect and elevation at $P < 0.05$ levels. Pearson correlation was also employed to obtain correlation between different soil and vegetation variables and elevations. Regression analyses were also done to find out relationships among different diversity variables and soil parameters.

3. RESULTS AND DISCUSSION

3.1 Phytosociology

A total of 174 herbaceous species from 122 genera and 34 families were identified indicating significant number of species in the area. The most dominant family was Poaceae (48 species) followed by Asteraceae (17 species) and Fabaceae (15 species) as reported in the existing literature on Thar Desert [24]. About

85% of study sites were dominated by grass species belonging to family Poaceae. The most dominant species were *Apluda mutica*, *Aristida adscensionis* and *Oropetium thomaeum* showing >10 IVI and *Heteropogon contortus, Dichanthium annulatum*, *Lepidagathis trinervis*, *Tephrocea purpurea*, *Actinopteris radiata*, *Borreria pusila*, *Brachiaria ramosa* and *Cenchrus ciliaris* with IVI of 5-10. Other species with IVI values <5 require appropriate conservation measures (Annexure 1). Frequently observed species were in order: *A. adscensionis>B. ramosa>M. jacquemontii>A. mutica>D. annulatum>C. ciliaris>H. contortus*, etc. The most dominant species was *O. thomaeum* in NE, E (600-700m also), SE and NW, *D. verticillata/P. paniculata/ C. benghalensis* in N and W, *Panicum turgidum* in S, and *C. arenarius* in SW in <230m elevation. This indicates the availability of more xeric species in S and SW aspects in foothills (<230m elevation). In middle altitude, *A. adscensionis* dominated in 230-600m range in NW, N, E and SE, 230-300m in SW and 230-700m in S and W aspects. *L. trinervis* dominated in NE aspect in 230-400m, *Urginea indica/Zornia gibosa* in N and *D. scindicum* in SE in 600-700m elevation and *B. pusilla* in W aspect in 700-800m elevation (Annexure 2). The rest of the elevation and aspects were dominated by *A. mutica/H. contortus.* Such differences in the dominance of different species in different locations/positions was because of variation in edaphic and environmental condition like soil pH, SWC, SOC and soil nutrient influenced by slope aspects and elevation, which showed high degree of impact on the species composition particularly in N and W aspects in the northern hemisphere [38,39].

3.2 Temporal Effects

Repeated Measure ANOVA showed significant (P < 0.01) variations in all soil and vegetation parameters between years of data recording, i.e. 2017 and 2018. Soil water content (SWC), pH, SOC, population density, vegetation height and D were highest in 2017 as compared to 2018, whereas R, H' and J' were highest in 2018. Though less in concentration, SOC was relatively greater in the present study as compared to the reported values of 0.12-0.43% in forests and 0.04-0.49% in agricultural lands [40,41]. Greater rainfall in 2017 enhanced SWC by 17% as compared to that in 2018 and promoted vegetation population, height and D as observed earlier [35,42]. It was also supported by a positive correlation (r=0.144, P < 0.01) between SWC and vegetation height. However, lesser SWC and SOC in 2018 was the impact of species-richness, H' and J', particularly of grass species. For instance, topsoil in plots containing grasses (or species-rich) have been observed drier as compared to legumes in the long-term Jena experiment [43]. Significant (P < 0.01) interactions of year × aspect for all, year × elevation for population density, R and H', and years × aspect × elevation for SWC, population density, R, H', D and J' showed the combined effects of these factors on soil and vegetation diversity variables.

3.3 Effects of Slope Aspects

We observed significant vegetation differences between slope aspects in species composition, vegetative structure, and biodiversity pattern. All variables like slope gradient, SWC, pH, SOC, population density, vegetation height and diversity variables (R, H', D and J') varied significantly (P < 0.01) due to slope aspects (Table 3). Northeast aspect exhibited highest values of SWC and SOC (2.35-fold and 1.90-fold than in South aspect) as well as J', and lowest values of soil pH indicating their favourable effects on species evenness. An increase in SOC enhanced the water holding capacity of the soil showing a conducive environment promoting species richness in north facing slopes [44]. Soil pH ranged between 7.17 in NE and 7.46 in the west and was related inversely to SWC and SOC. However, the highest population, height and D in southern slopes (SE and S) and their lowest values in NE were similar to the observations of Louhaichi et al. [45]. Because of maximum population and dominance of grass species in order: *A. adscensionis >A. mutica >Panicum turgidum >O. thomaeum >C. martini>D. scindicum >Dichanthium annulatum* in southern slopes, efficiently utilized soil water and SOC (via decomposition and nutrient release) resulting in the lowest values of SWC and SOC in these aspects. Earlier reports also indicated the dominance of the family Poaceae, Fabaceae and Asteraceae in the Indian desert [24,46]. The greatest slope gradient and soil pH with low SWC and SOC in the south aspect was due to greater exposure to solar radiation and salt concentration. However, greater vegetation height in this aspect appeared related with vegetation to characteristics, i.e. high altitude grasses. It was also shown by negative and positive correlations (P < 0.01) of slope gradient with soil pH and vegetation height. The highest values of H', R and J' in northern slopes (N and NE) were because of high SWC, SOC, low

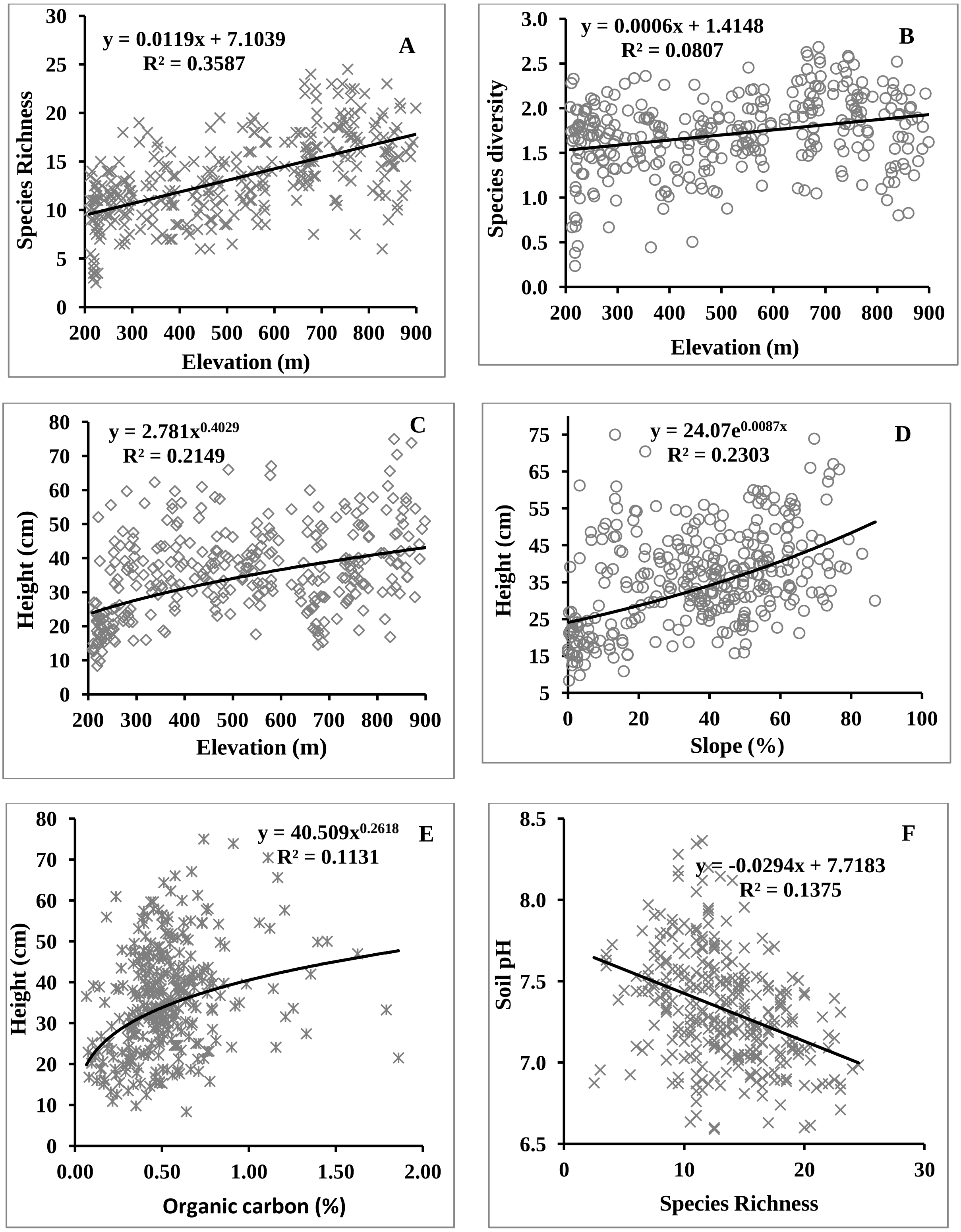

Fig. 2. Relationships among different topographical features, diversity indices and soil parameters. (a) Species richness, (b) Species diversity and (c) plant height with elevation, (d) slope (%) vs. plant height, (e) soil organic carbon vs. height and (f) species richness vs. soil pH

Table 1. Effect of years of data recording on soil and vegetation variables in a hill forest area of Indian Desert. Values are mean±1SE of 320 replicates

Variable‡	Year		F values of Repeated Measure ANOVA						
			Tests of Within-Subjects Effects				Tests of Between-Subject Effects		
	2017	2018	Year	Y × A	Y × E	Y × A × E	Aspect	Elevation	A × E
Slope (%)	36.83±0.03	36.83±0.03	-	-	-	-	15.33**	101.45**	10.45**
SWC (%)	2.01±0.06^b	1.75±0.06^a	54.31**	3.76**	1.27ns	1.74**	31.93**	25.01**	3.14**
pH	7.38±0.02^b	7.28±0.02^a	37.95**	4.29**	1.73ns	0.89ns	11.52**	50.28**	3.85**
SOC (%)	0.54±0.02^b	0.51±0.02^a	7.49**	3.26**	1.91ns	1.24ns	12.90**	14.36**	2.38**
Population (nos m^{-2})	202.02±6.86^b	173.15±5.64^a	17.92**	2.48*	2.53*	1.75**	5.20**	18.10**	2.14**
Height (cm)	41.44±0.89^b	29.93±0.78^a	209.32**	3.44**	1.53ns	1.18ns	2.70**	25.43**	2.38**
R	12.79±0.25^a	13.75±0.29^b	19.38**	7.34**	5.17**	2.65**	6.11**	56.01**	5.19**
H’	1.64±0.03^a	1.78±0.03^b	25.50**	5.30**	3.05**	1.77**	3.56**	13.00**	4.06**
D	0.32±0.01^b	0.28±0.01^a	15.85**	3.69**	1.75ns	1.48*	3.50**	6.22**	3.86**
J’	0.66±0.01^a	0.69±0.01^b	13.53**	2.59*	1.52ns	1.53*	4.97**	3.23**	2.54**

‡SWC: Soil Water Content, SOC: Soil Organic Carbon; PD: Population Density, H: Vegetation Height, R: Species Richness, H': Shannon-Wiener Diversity Index, D: Simpson Dominance, J': Evenness Index, df: degree of freedom year 1, year × aspect (A) 7, year × elevation (E) 7, year × aspect × elevation 49, aspect 7, elevation 7, aspect x elevation 49. Similar alphabets as superscript in a row indicates not significant (P>0.05) difference

Table 2. Correlation coefficient (*r*) showing relationships between different physiographic, soil parameters, diversity and growth variables of Haldeshwar forest area in Barmer, Rajasthan (n=320)

Variable‡	Topographic		Herbaceous variables						Soil parameter		
	Aspect	Elevation	Population	Height	R	H'	D	J’	SWC (%)	pH	SOC (%)
Slope (%)	ns	0.252**	ns	0.345**	ns	ns	ns	ns	ns	-0.242**	0.233**
SWC (%)	-.214**	0.369**	ns	0.144**	0.098*	ns	ns	ns	-	-0.351**	0.519**
pH	ns	-0.553**	-0.162**	-0.162**	-0.316**	-0.157**	ns	ns	-0.351**	-	-0.355**
SOC (%)	-.188**	0.338**	ns	0.209**	0.122**	ns	ns	ns	0.519**	-0.355**	-
Population(nos m^{-2})	ns	0.342**	-	0.242**	0.332**	-0.137**	0.194**	-0.372**	ns	-0.162**	ns
Height (cm)	ns	0.336**	0.242**	-	ns	-0.275**	0.310**	-0.408**	0.144**	-0.162**	0.209**
Richness	ns	0.520**	0.332**	ns	-	0.699**	-0.508**	0.257**	0.098*	-0.316**	0.122**
Diversity	ns	0.239**	-0.137**	-0.275**	0.699**	-	-0.942**	0.829**	ns	-0.157**	ns
Dominance	ns	-0.139**	0.194**	0.310**	-0.508**	-0.942**	-	-0.505**	ns	ns	ns
Evenness	ns	ns	-0.423**	-0.412**	0.246**	0.843**	-0.915**	-	ns	ns	ns

‡As in Table 1.

*NS: non-significant,*P<0.05 and **P<0.01*

Table 3. Effect of slope aspects on soil physicochemical properties and vegetation diversity in a hilly forest area of Indian Desert. Values are mean±1SE of 16 replications

Variable‡	Aspect (degree)								
	N (0°)	**NE (45°)**	**E (90°)**	**SE (135°)**	**S (180°)**	**SW (225°)**	**W (270°)**	**NW (315°)**	**Mean**
Slope (%)	36.55±3.42^{b}	43.30±3.23^{cd}	29.21±3.70^{a}	39.13±3.69^{bc}	46.72±3.70^{d}	34.94±3.28^{b}	30.00±2.84^{a}	34.79±3.00^{b}	36.83±1.22
SWC (%)	2.27±0.09^{d}	2.82±0.13^{e}	1.91±0.11^{c}	1.20±0.06^{a}	1.20±0.08^{a}	1.59±0.13^{b}	2.04±0.10^{c}	2.01±0.09^{c}	1.88±0.04
pH	7.20±0.04a	7.17±0.04^{a}	7.44±0.04^{c}	7.38±0.04^{bc}	7.39±0.05^{bc}	7.24±0.05^{a}	7.46±0.04^{c}	7.34±0.03^{b}	7.33±0.01
SOC (%)	0.57±0.03^{d}	0.76±0.05^{e}	0.53±0.03^{cd}	0.43±0.02^{ab}	0.40±0.02^{a}	0.47±0.03^{abc}	0.48±0.02^{bc}	0.56±0.02^{d}	0.53±0.01
P (nos m^{-2})	202.66±14.04^{cd}	140.36±10.53^{a}	194.06±13.2b^{cd}	215.26±16.44^{d}	208.78±12.16^{d}	200.7±9.17^{cd}	171.44±12.4^{abc}	167.44±9.94^{ab}	187.59±4.47
Height (cm)	36.35±2.00^{abc}	33.21±1.63^{a}	38.34±1.98^{bc}	34.23±1.40^{ab}	40.45±1.89^{c}	34.01±1.39^{ab}	34.17±1.82^{ab}	34.74±1.99^{ab}	35.69±0.63
R	14.69±0.69^{d}	12.54±0.52^{ab}	13.0±0.41^{abc}	12.13±0.48^{a}	14.09±0.51^{cd}	14.09±0.44^{cd}	13.49±0.65^{bc}	12.15±0.55^{a}	13.27±0.19
H'	1.71±0.07^{ab}	1.82±0.04^{bc}	1.64±0.05^{a}	1.62±0.06^{a}	1.69±0.06^{ab}	1.87±0.05^{c}	1.72±0.06^{ab}	1.62±0.06^{a}	1.71±0.02
D	0.32±0.02^{b}	0.24±0.01^{a}	0.32±0.02^{b}	0.33±0.02^{b}	0.31±0.02^{b}	0.25±0.01^{a}	0.30±0.02^{b}	0.32±0.02^{b}	0.30±0.01
J'	0.65±0.02^{a}	0.74±0.01^{c}	0.64±0.02^{a}	0.65±0.02^{a}	0.65±0.02^{a}	0.72±0.01^{bc}	0.68±0.02^{ab}	0.66±0.02^{a}	0.68±0.01

‡*As in Table 1*

Table 4. Effect of elevation on soil physicochemical properties and vegetation diversity in a hilly forest area of Indian Desert. Values are mean±1SE of 16 replications

Variable‡	Elevation (m)								
	<230	**230-300**	**300-400**	**400-500**	**500-600**	**600-700**	**700-800**	**800-900**	**Mean**
Slope (%)	2.54±0.32^{a}	39.95±2.98^{cd}	47.28±2.44^{f}	44.84±2.23^{ef}	52.73±2.49^{g}	28.59±3.06^{b}	41.81±2.35^{e}	36.91±3.59^{c}	36.83±1.22
SWC (%)	1.55±0.13^{ab}	1.62±0.12^{ab}	1.51±0.08^{a}	1.44±0.07^{a}	1.76±0.10^{b}	2.17±0.1^{c}	2.12±0.09^{c}	2.86±0.14^{d}	1.88±0.04
pH	7.73±0.05^{e}	7.46±0.03^{d}	7.50±0.03^{d}	7.34±0.04^{c}	7.26±0.03^{bc}	7.19±0.04^{b}	7.07±0.03^{a}	7.07±0.03^{a}	7.33±0.01
SOC (%)	0.31±0.03^{a}	0.53±0.04^{cd}	0.44±0.02^{b}	0.49±0.02^{bc}	0.56±0.02^{cd}	0.56±0.03^{cd}	0.60±0.03^{d}	0.71±0.04^{e}	0.53±0.01
P (nos m^{-2})	156.34±10.17^{a}	147.11±11.11^{a}	147.64±9.43^{a}	168.06±9.98^{a}	177.79±10.87^{a}	179.54±8.76^{a}	263.2±17.56^{b}	261.03±13.24^{b}	187.59±4.47
Height (cm)	19.16±1.07^{a}	32.95±1.52^{b}	38.21±1.63^{c}	38.84±1.57^{c}	39.32±1.55^{c}	32.84±1.84^{b}	39.14±1.52^{c}	45.05±1.98^{d}	35.69±0.63
R	9.19±0.42^{a}	10.95±0.31^{b}	11.73±0.44^{b}	11.56±0.42^{b}	13.39±0.40^{e}	16.13±0.52^{d}	17.69±0.55^{e}	15.54±0.53^{d}	13.27±0.19
H'	1.52±0.07^{a}	1.60±0.05^{ab}	1.61±0.05^{ab}	1.55±0.05^{a}	1.77±0.04^{c}	1.98±0.06^{d}	1.97±0.05^{d}	1.70±0.06^{bc}	1.71±0.02
D	0.34±0.03^{a}	0.32±0.02^{a}	0.32±0.02^{c}	0.33±0.02^{a}	0.27±0.01^{a}	0.24±0.02^{a}	0.23±0.01^{bc}	0.32±0.02^{ab}	0.30±0.01
J'	0.70±0.02^{c}	0.68±0.02^{bc}	0.67±0.02^{abc}	0.65±0.02^{ab}	0.69±0.01^{bc}	0.71±0.02^{c}	0.69±0.01^{bc}	0.62±0.02^{a}	0.68±0.01

‡*As in Table 1*

population density and less evapotranspiration [47,48,49]. The study of Pandita et al. [38] also showed that NE and NW faces are rich in terms of the herbaceous than pure north slopes. Thin and scattered vegetation along with weaker soil development with higher erosion rates in south facing sunny slope supported drought and radiation-resistant vegetation like grasses [50] and hence low in diversity and SOC [51].

3.4 Effects of Elevation

All soil and vegetation variables differed significantly ($P < 0.05$) due to elevation. Soil pH and species dominance were highest ($P < 0.01$) in <230m elevation and decreased by 0.66 units and 32% respectively in elevation range 800-900m (Table 3). This elevation range showed the lowest slope gradient, SOC, vegetation height, species richness and H' dominated by *A. adscensionis* as observed in other xeric environments including Thar Desert [52,53]. Vegetation of more xeric characteristics was also recorded on low elevations S-facing slopes as compared to N-facing slopes on high elevations [52]. It was also shown by a negative correlation between soil pH and SOC, which increased to the highest values of 0.71% (2.29-fold) in 800-900 m elevation [54]. The highest SOC and SWC at high elevation areas was because of reduced temperature and improvement in climatic condition, vegetation status and soils conditions as compared to those in foothill areas [55,56]. However, lowest values of soil pH at high altitude was because of washing out of salts and their accumulation in foothill area resulting in high pH in <230 m elevation [57,58]. The highest H' and J' in middle-top elevation (600-700 m), R and vegetation population in 700-800 m and vegetation height in 800-900 m were because of species characteristics particularly high altitude tall grasses (*A. mutica*, *C. martini*, *H. contortus*, etc.) supported by highest concentration of SOC and SWC [59,60]. An earlier study [61] also indicated an increase in the mean coverage of grasses with elevation. Regression analyses also showed a linear increased in diversity (R^2 = 0.083, $F_{1/318}$ =28.655, $P < 0.01$) and species richness (R^2 = 0.356, $F_{1/318}$ = 175.97, $P < 0.01$) with increase in elevation (Fig. 2). However, vegetation height showed an increasing trend with elevation by a power relationship (R^2 = 0.275, $F_{1/318}$ = 120.848, $P < 0.01$). SOC increased linearly with vegetation height (R^2 = 0.114, $F_{1/318}$= 40.715, $P < 0.01$) and species dominance a similar to the observation recorded earlier [42]. Many studies showed similar trend between elevation and H' and R, which were observed low in lower altitude and increase with an increase in elevation [62,63].

Soil properties and vegetation diversity were partly under the influence of elevation. Soil pH decreased linearly with an increase in altitudinal species richness (R^2 = 0.238, $F_{1/318}$ = 99.242, $P <$ 0.01), though the correlation was stronger with species richness in the north than in other aspects [64]. Likewise, north-facing slopes appeared connected with higher vegetation coverage, height and H' than the south-facing slopes at high altitude [50,65]. Because of more moisture and less livestock grazing at higher elevations, vegetation cover and diversity was significantly higher than in lower altitude area [28,66]. Thus altitude appeared dominant factor affecting R and H'. The slope aspect indirectly affected R and H' by creating a dry or moist environment (variation in SWC) and altering the rate of litter production and decomposition.

4. CONCLUSION AND RECOMMENDATIONS

Both slope aspects and elevation influenced soil characteristics and herbaceous diversity, but the impact of altitude was stronger than the aspect except for soil water. Results of this study indicated the dominance of grass species in herbaceous vegetation, where SWC and SOC had beneficial effects on vegetation growth and development particularly in the NE aspect. Low available SWC in the south-facing slopes affected height growth particularly in lower altitude areas that support xeric vegetation. Increased elevation had a significant positive impact on soil fertility and SWC, which promoted species rich vegetation at high altitudes as compared to xeric species in foothills. However, out of 174 species, 163 species showed an importance value index <5. Conclusively, high elevations in north-facing slopes are more favourable for regeneration and conservation. Selecting low elevation south-facing slopes areas require additional inputs of soil resources like water and nutrients. Our recommendations will be to conserve this area to avoid species extinction and adopt soil and water conservation and protection measures from overgrazing and overexploitation of vegetation and using suitable species in restoring degraded hills particularly in southern aspects of the foothill areas.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Annexure 1. Herbaceous species, their habits and importance value index (IVI) across years, aspects and elevations in Siwana hills forest area of Barmer, Rajasthan, India

SNo.	Name of species	Habit	Family name	IVI
1	*Abelmoschus moschatus* (L.) Medic	Herb	Malvaceae	0.41
2	*Acalypha ciliata* Forssk.	Herb	Euphorbiaceae	0.86
3	*Acanthospermum hispidum* DC.	Herb	Asteraceae	1.76
4	*Achyranthes aspera* L.	Herb	Amaranthaceae	2.20
5	*Acrachne racemosa* (B.Heyne ex Roem. & Schult.) Ohwi.	Grass	Poaceae	1.13
6	*Actiniopteris radiata* (J. Konig ex Sw.) Link.	Small fern	Pteridaceae	5.32
7	*Adiantum lunulatum* Burm. f.	Small fern	Pteridaceae	3.11
8	*Alternanthera paronychioides* St. Hil., Voy.	Decumbent herb	Amaranthaceae	0.17
9	*Alysicarpus monilifer* (L.) DC.	Herb	Fabaceae	0.51
10	*Alysicarpus rugosus* (Willd.) DC.	Prostrate herb	Fabaceae	0.34
11	*Amaranthus viridis* L.	Herb	Amaranthaceae	0.32
12	Andrographis echioides (L.) Nees.	Herb	Acanthaceae	1.26
13	Anisochilus carnosus (L.f.) Wall.	Herb	Lamiaceae	0.57
14	Anisomeles indica (L.) Kuntze	Herb	Lamiaceae	0.42
15	*Apluda mutica* L.	Grass	Poaceae	22.86
16	*Aristida adscensionis* Linn.	Grass	Poaceae	22.06
17	*Aristida funiculata* Trin. & Rupr.	Grass	Poaceae	0.55
18	*Aristida mutabilis* Trin. & Rupr.	Grass	Poaceae	0.60
19	*Artemisia scoparia* Waldst. & Kit.	Herb	Asteraceae	0.16
20	*Arthraxon lanceolatus* (Roxb.) Hochst.	Grass	Poaceae	1.77
21	*Arthraxon lancifolius* (Trin.) Hochst.	Grass	Poaceae	1.25
22	*Bidens pilosa* L.	Herb	Asteraceae	1.60
23	*Blainvillea acmella* (L.) Philipson	Herb	Asteraceae	2.91
24	*Blepharis maderaspatensis* (L.) B.Heyne ex Roth	Procumbent herb	Acanthaceae	1.03
25	*Blumea mollis* (D. Don) Merr.	Herb	Asteraceae	0.32
26	*Blumea virens* DC.	Herb	Asteraceae	0.39
27	*Boerhavia diffusa* L.	Prostrate herb	Nyctaginaceae	1.67
28	*Boerhavia erecta* L.	Herb	Nyctaginaceae	2.81
29	*Borreria pusilla* (Wall.) DC.	Herb	Rubiaceae	5.46
30	*Brachiaria ramosa* (L.) Stapf.	Grass	Poaceae	5.58
31	*Cardiospermum halicacabum* L.	Climbing vine	Sapindaceae	1.19
32	*Catharanthus pusillus* (Murr.) G. Don .	Herb	Apocynaceae	0.18
33	*Celosia argentea* L.	Glabrous herb	Amaranthaceae	1.11
34	*Cenchrus biflorus* Roxb.	Grass	Poaceae	0.24
35	*Cenchrus ciliaris* L.	Grass	Poaceae	5.55
36	*Cenchrus pennisetiformis* Hochst. & Steud.	Grass	Poaceae	1.00
37	*Cenchrus prieurii* (Kunth) Maire	Grass	Poaceae	0.75
38	*Ceropegia bulbosa* Roxb. var. *lushii* (Grah.) Hook.f.	Twiner herb	Apocynaceae	0.48
39	*Chamaecrista absus* (L.) H.S. Irwin &	Herb	Caesalpiniaceae	0.80
40	*Chamaecrista pumila* (Lamk.) K. Larsen,	Herb	Caesalpiniaceae	1.74
41	*Chloris barbata* Sw.	Grass	Poaceae	0.53
42	*Chloris dolichostachya* Lagasca,	Grass	Poaceae	0.91
43	*Citrullus colocynthis* (L.) Schrad	Trailing vine	Cucurbitaceae	0.33
44	*Cleome gracilis* Edgew.	Herb	Capparaceae	0.54
45	*Cleome viscosa* L.	Herb	Capparaceae	1.43
46	*Clitoria annua* J. Graham ·	Herb	Fabaceae	0.57
47	*Coccinia grandis* (L.) Voigt	Climber	Cucurbitaceae	0.16
48	*Commelina benghalensis* L.	Herb	Commelinaceae	0.77
49	*Commelina erecta* L.	Decumbent herb	Commelinaceae	2.93
50	*Commelina forskaolii* Vahl.	Prostrate herb	Commelinaceae	0.20
51	*Commicarpus boissieri* (Heimerl.) Cufod.	Decumbent undershrub	Nyctaginaceae	1.06
52	*Corallocarpus epigaeus* (Rottl.) C.B.Clark	Climbing Herb	Cucurbitaceae	0.16
53	*Corbichonia decumbens* (Forssk.) Exell	Procumbent herb	Molluginaceae	0.90
54	*Corchorus aestuans* L.	Herb	Tiliaceae	0.85
55	*Corchorus depressus* (L.) Stocks	Prostrate herb	Tiliaceae	0.34
56	*Corchorus tridens* L.	Herb	Tiliaceae	0.68
57	*Crinum pratense* Herb.	Herb	Amaryllidaceae	1.89
58	*Crotalaria mysorensis* Roth	Tall herb	Fabaceae	0.65
59	*Cucumis maderaspatanus* L.	Climbing Herb	Cucurbitaceae	1.99
60	*Cyanotis fasciculata* (B.Heyne ex Roth) Schult. & Schult.f.	Glabrous Herb	Commelinaceae	0.88
61	*Cymbopogon jwarancusa* (Jones) Schult.	Grass	Poaceae	1.41
62	*Cymbopogon martinii* (Roxb.) Watson	Grass	Poaceae	4.64
63	*Cynodon dectylon* (L.) Pers.	Grass	Poaceae	0.71
64	*Cyperus arenarius* Retz.	Perennial herb	Cyperaceae	1.14

SNo.	Name of species	Habit	Family name	IVI
65	*Cyperus difformis* L.	Glabrous herb	Cyperaceae	0.17
66	*Cyperus rotundus* L.	Perennial herb	Cyperaceae	1.16
67	*Dactyloctenium aegyptium* (L.) Willd.	Grass	Poaceae	1.58
68	*Dactyloctenium scindicum* Boiss.	Grass	Poaceae	2.36
69	*Desmodium triflorum* (L.) DC.	Prostrate herb	Papilionaceae	0.98
70	*Dichanthium annulatum* (Forsk.) Stapf.	Grass	Poaceae	7.02
71	*Dichanthium foveolatum* (Delile) Roberty	Grass	Poaceae	1.30
72	*Dichanthium huegelii* (Hack.) S.K.Jain & Deshp.	Grass	Poaceae	0.66
73	*Dicliptera verticillata* (Forssk.) C. Christensen	Herb	Acanthaceae	1.07
74	*Dicoma tomentosa* Cass.	Herb	Asteraceae	0.56
75	*Digitaria pennata* (Hochst.) T.Cooke	Grass	Poaceae	4.81
76	*Digitaria sanguinalis* (L.) Scop.	Grass	Poaceae	0.37
77	*Digitaria bicornis* (Lam.) Roem. & Schult.	Grass	Poaceae	2.55
78	*Dipteracanthus patulus* (Jacq.) Nees	Pubescent herb	Acanthaceae	4.01
79	*Eclipta alba* (L.) Hassk.	Herb	Asteraceae	0.18
80	*Elyonurus royleanus* Nees ex A.Rich	Grass	Poaceae	1.56
81	*Enneapogon persicus* Boiss.	Grass	Poaceae	1.05
82	*Eragrostiella bifaria* (Vahl) Bor	Grass	Poaceae	3.42
83	*Eragrostis cilianensis* (All.) Janch.	Grass	Poaceae	0.54
84	*Eragrostis ciliaris* (Linn.) R.Br.	Grass	Poaceae	0.95
85	*Eragrostis minor* Host.	Grass	Poaceae	1.98
86	*Eragrostis tenella* (Linn.) P Beauv.	Grass	Poaceae	0.93
87	*Eragrostis tremula* (Lam.) Hochst. ex Steud.	Grass	Poaceae	0.55
88	*Euphorbia granulata* Forssk.	Prostrate herb	Euphorbiaceae	0.32
89	*Euphorbia hirta* L.	Herb	Euphorbiaceae	0.88
90	*Euphorbia indica* Lam.	Herb	Euphorbiaceae	0.50
91	*Evolvulus alsinoides* var. *alsinoides* (L.) L.	Herb	Convolvulaceae	3.04
92	*Evolvulus alsinoides* var. *linifolius* (L.) Kuntze	Herb	Convolvulaceae	0.38
93	*Galactia tenuiflora* (Willd.)Wight & Arn.	Climbing herb	Fabaceae	0.53
94	*Glinus lotoides* L.	Prostrate herb	Molluginaceae	0.16
95	*Glossocardia bosvallea* (L.f) DC	Herb	Asteraceae	1.08
96	*Heliotropium marifolium* Retz.	Herb	Boraginaceae	1.08
97	*Heteropogon contortus* (L.) P. Beauv. Ex Roem. & Schult	Grass	Poaceae	7.58
98	*Hibiscus micranthus* L.f.	Subshrubs	Malvaceae	1.40
99	*Hibiscus palmatus* Forsk.	Herb	Malvaceae	0.16
100	*Indigofera cordifolia* Heyne ex Roth.	Herb	Fabaceae	4.13
101	*Indigofera hochstetteri* Baker	Spreading herb	Fabaceae	0.26
102	*Indigofera linifolia* (L.f.)Retz.	Prostrate herb	Fabaceae	0.38
103	*Indigofera linnaei* Ali	Prostrate herb	Fabaceae	0.70
104	*Ipomoea dichroa* Hochst. ex Choisy.	Climbing Herb.	Convolvulaceae	1.23
105	*Ipomoea eriocarpa* R. Br.	Twining herb	Convolvulaceae	0.51
106	*Ipomoea indica* (Burm. f.) Merr.	Vine herb	Convolvulaceae	0.32
107	*Ipomoea nil* (L.) Roth	Annual herb vine	Convolvulaceae	0.97
108	*Ipomoea pes-tigridis* L.	Twining herb	Convolvulaceae	0.84
109	*Ipomoea sindica* Stapf.	Twining herb	Convolvulaceae	0.51
110	*Justicia simplex* D. Don	Herb	Acanthaceae	1.40
111	*Justicia heterocarpa* T.Anderson	Herb	Acanthaceae	1.07
112	*Kickxia ramosissima* (Wall.) Janchen	Prostrate herb	Scrophulariaceae	0.49
113	*Launaea procumbens* L	Decumbent herb	Asteraceae	0.74
114	*Lavandula bipinnata* (Roth) Kuntze	Slender herb	Lamiaceae	1.75
115	*Lepidagathis cristata* willd.	decumbent herb	Acanthaceae	2.44
116	*Lepidagathis trinervis* Wall. ex. Ness	Suffruticose herb	Acanthaceae	6.71
117	*Leptothrium senegalense* (Kunth) Clayton	Grass	Poaceae	0.55
118	*Leucas aspera* (Willd.) Link	Herb	Lamiaceae	1.23
119	*Leucas urticaefolia* (Vahl) R. Br.	Herb	Lamiaceae	0.59
120	*Lindenbergia indica* (L.) Vatke	Herb	Orobanchaceae	0.70
121	*Linum mysorense* Heyne ex Benth.	Herb	Linaceae	0.18
122	*Macrotyloma uniflorum* Lam.	Twining herb	Fabaceae	0.87
123	*Melanocenchris jacquemontii* Jaub. & Spach	Grass	Poaceae	4.28
124	*Mollugo nudicaulis* Lam.	Herb	Molluginaceae	1.01
125	*Momordica dioica* Roxb. ex Willd.	Climbing Herb	Cucurbitaceae	0.33
126	*Nepeta bombaiensis* Dalzell	Herb	Lamiaceae	1.46
127	*Nothosaerva brachiata* (L.) Wight	Herb	Amaranthaceae	0.22
128	*Ocimum canum* Sims	Herb	Lamiaceae	0.67
129	*Oligochaeta ramosa* (Roxb.) Wagenitz.	Herb	Asteraceae	0.16
130	*Oropetium roxburghianum* (Steud.) S.M.Phillips	Grass	Poaceae	1.09
131	*Oropetium thomaeum* (L. f.) Trin.	Grass	Poaceae	16.12
132	*Panicum turgidum* Forsk.	Grass	Poaceae	3.40
133	*Pedalium murex* Linn	Herb	Pedaliaceae	0.19
134	*Pennisetum orientale* L.C. Rich.	Grass	Poaceae	0.20

SNo.	Name of species	Habit	Family name	IVI
135	*Pentanema indicum* (L.) Ling	Herb	Asteraceae	0.51
136	*Peristrophe paniculata* (Forsk.) Brummitt	Herb	Labiatae	2.70
137	*Perotis indica* (L.) Kuntze.	Grass	Poaceae	0.48
138	*Phyllanthus amarus* Schum. & Thonn.	Herb	Euphorbiaceae	0.50
139	*Physalis minima* L.	Herb	Solanaceae	0.65
140	*Poloygala erioptera* DC.	Herb	Polygaleaceae	1.17
141	*Polygala irregularis* Boiss.	Herb	Polygalaceae	0.34
142	*Portulaca oleracea* L.	Herb	Portulacaceae	0.16
143	*Portulaca pilosa* L.	Herb	Portulacaceae	0.57
144	*Portulaca tuberosa* Roxb.	Herb	Portulacaceae	0.20
145	*Pulicaria wightiana* D. C. Clarke.	Herb	Asteraceae	0.16
146	*Pupalia lapacea* (L.) Juss	Subshrub	Amaranthaceae	3.09
147	*Rhincosia minima* (Camb.) Barker	Prostrate climbing herb	Fabaceae	0.93
148	*Sclerocarpus africanus* Jacq.	Herb	Asteraceae	1.04
149	*Sehima nervosum* (Rottler) Stapf.	Grass	Poaceae	2.49
150	*Senecio hewrensis* Hook. F.	Herb	Asteraceae	1.78
151	*Sesamum indicum* L.	Herb	Pedaliaceae	0.50
152	*Setaria geniculata* P.Beauv.	Grass	Poaceae	0.19
153	*Sida cordata* (Brum. F.) Bross	Herb	Malvaceae	0.87
154	*Sida cordifolia* L.	Herb	Malvaceae	0.49
155	*Sorghum halepense* (L.) Pers.	Grass	Poaceae	1.04
156	*Sporobolus coromandelianus* (Retz.) Kunth	Grass	Poaceae	0.67
157	*Sporobolus diander* (Retz.) P.Beauv.	Grass	Poaceae	2.59
158	*Striga angustifolia* (D. Don) C.J. Saldanha	Herb	Orobanchaceae	0.72
159	*Striga gesnerioides* (Willd.) Vatke.	Herb	Orobanchaceae	0.95
160	*Tephrosia purpurea* (Linn.) Pers.	Suffruticose herb	Fabaceae	6.44
161	*Tephrosia strigosa* (Dalzell) Santapau & Maheshw	Herb	Fabaceae	1.81
162	*Tephrosia uniflora* Pers. ssp. *petrosa* (Blatt. & Hall.) J.B. Gillett & Ali	Herb	Papilionaceae	2.34
163	*Tetrapogon tenellus* (Koen. ex Roxb.) Chiov.	Grass	Poaceae	4.91
164	*Tragus roxburghii* Panigrahi	Grass	Poaceae	0.21
165	*Tribulus terrestris* L.	Prostrate herb	Zygophyllaceae	0.48
166	*Trichodesma sedgwickianum* Banerjee	Herb	Boraginaceae	1.83
167	*Tridax procumbense* L.	Procumbent herb	Astraceae	0.84
168	*Triumfetta rhomboidea* Jacq.	Woody Herb	Tiliaceae	2.02
169	*Urginea indica* (Roxb.) Kunth	Perennial herb	Asparagaceae	3.90
170	*Vernonia cinerarea* (L.) Less.	Herb	Asteraceae	1.28
171	*Vigna mungo* (L.) Hepper	Climbing herb	Fabaceae	0.89
172	*Vigna trilobata* (L.)Verd.	Twiner herb	Papilionaceae	1.41
173	*Waltheria indica* L.	Subshrub	Sterculiaceae	0.33
174	*Zornea gibbosa* Span	Herb	Fabaceae	3.96

Annexure 2. Topographical position and most and least dominant species in Siwana hills forest areas of Barmer, Rajasthan, India

SNo.	Topographical position		Dominant species		Least dominant species	
	Aspect	Elevation	2017	2018	2017	2018
1	E	<230	*O. thomaeum*	*O. thomaeum*	*E. granulata*	*A. viridis*
2	E	230-300	*T. purpurea*	*A. adscensionis*	*P. erioptera*	*P. erioptera*
3	E	300-400	*T. purpurea*	*A. adscensionis*	*T. terrestris*	*C. pumila*
4	E	400-500	*A. adscensionis*	*A. adscensionis*	*T. strigosa*	*T. strigosa*
5	E	500-600	*A. adscensionis*	*A. mutica*	*B. erecta*	*A. echioides*
6	E	600-700	*O. thomaeum*	*B. pusilla*	*P. lapacea*	*T . strigosa*
7	E	700-800	*A. mutica*	*A. mutica*	*T. uniflora*	*A. aspera*
8	E	800-900	*A. mutica*	*A. mutica*	*B. maderaspatensis*	*S. africanus*
9	N	<230	*D. verticillata*	*P. paniculata*	*A. aspera*	*C. halicacabum*
10	N	230-300	*A. adscensionis*	*A. adscensionis*	*V. trilobata*	*C. halicacabum*
11	N	300-400	*A. adscensionis*	*A. adscensionis*	*C. pumila*	*P. erioptera*
12	N	400-500	*E. bifaria*	*A. adscensionis*	*Corchorus aestuans*	*J. simplex*
13	N	500-600	*E. bifaria*	*A. adscensionis*	*S. hewrensis*	*T. sedgwickianum*
14	N	600-700	*U. indica*	*Z. gibbosa*	*U. indica*	*T. uniflora*
15	N	700-800	*H. contortus*	*A. mutica*	*T. strigosa*	*M. uniflorum*
16	N	800-900	*A. mutica*	*A. mutica*	*B. erecta*	*D. patulus*
17	NE	<230	*O. thomaeum*	*O. thomaeum*	*S. cordifolia*	*A. aspera*
18	NE	230-300	*L. trinervis*	*L. trinervis*	*A. aspera*	*P. erioptera*
19	NE	300-400	*L. trinervis*	*L. trinervis*	*I. eriocarpa*	*E. indica*
20	NE	400-500	*A. mutica*	*A. mutica*	*C. maderaspatanus*	*T. strigosa*

SNo.	Topographical position		Dominant species		Least dominant species	
	Aspect	Elevation	2017	2018	2017	2018
21	NE	500-600	*A. mutica*	*A. mutica*	*A. aspera*	*C. halicacabum*
22	NE	600-700	*A. mutica*	*A. mutica*	*H. marifolium*	*Euphorbia indica*
23	NE	700-800	*A. mutica*	*A. mutica*	*L. bipinnata*	*P. amarus*
24	NE	800-900	*A. mutica*	*A. mutica*	*P. amarus*	*C. mysorensis*
25	NW	<230	*O. thomaeum*	*O. thomaeum*	*C. mysorensis*	*C. pumila*
26	NW	230-300	*T. tenellus*	*A. adscensionis*	*C. halicacabum*	*C. maderaspatanus*
27	NW	300-400	*A. adscensionis*	*L. trinervis*	*D. pennata*	*H. marifolium*
28	NW	400-500	*C. ciliaris*	*D. pennata*	*J. simplex*	*T. strigosa*
29	NW	500-600	*A. adscensionis*	*D. pennata*	*B. diffusa*	*C. pumila*
30	NW	600-700	*H. contortus*	*B. pusilla*	*P. erioptera*	*A. rugosus*
31	NW	700-800	*H. contortus*	*D. foveolatum*	*L. aspera*	*D. triflorum*
32	NW	800-900	*H. contortus*	*A. mutica*	*C. aestuans*	*P. amarus*
33	S	<230	*P. turgidum*	*P. turgidum*	*A. hispidum*	*T. purpurea*
34	S	230-300	*A. adscensionis*	*A. adscensionis*	*E. tremula*	*H. controtus*
35	S	300-400	*A. adscensionis*	*A. adscensionis*	*C. pumila*	*P. erioptera*
36	S	400-500	*A. adscensionis*	*A. adscensionis*	*C. erecta*	*H. marifolium*
37	S	500-600	*A. adscensionis*	*D. annulatum*	*I. eriocarpa*	*B. pusilla*
38	S	600-700	*A. adscensionis*	*B. ramosa*	*B. pilosa*	*H. micranthus*
39	S	700-800	*C. martinii*	*A. mutica*	*C. viscosa*	*C. halicacabum*
40	S	800-900	*A. mutica*	*A. mutica*	*C. tridens*	*Sida cordata*
41	SE	<230	*O. thomaeum*	*O. thomaeum*	*D. verticillata*	*I. linnaei*
42	SE	230-300	*A. adscensionis*	*A. adscensionis*	*C. boissieri*	*P. paniculata*
43	SE	300-400	*A. adscensionis*	*A. adscensionis*	*C. maderaspatanus*	*T. sedgwickianum*
44	SE	400-500	*A. adscensionis*	*A. adscensionis*	*V. trilobata*	*T. purpurea*
45	SE	500-600	*A. adscensionis*	*A. adscensionis*	*P. erioptera*	*J. simplex*
46	SE	600-700	*D. scindicum*	*O. thomaeum*	*J. simplex*	*J. simplex*
47	SE	700-800	*A. mutica*	*A. mutica*	*V. cinerarea*	*V. cinerarea*
48	SE	800-900	*A. mutica*	*A. mutica*	*S. hewrensis*	*P. erioptera*
49	SW	<230	*C. arenarius*	*C. arenarius*	*C. tridens*	*B. diffusa*
50	SW	230-300	*A. adscensionis*	*A. adscensionis*	*E. hirta*	*D. bicornis*
51	SW	300-400	*A. mutica*	*A. mutica*	*R. minima*	*C. pumila*
52	SW	400-500	*A. mutica*	*A. mutica*	*J. simplex*	*M. uniflorum*
53	SW	500-600	*A. mutica*	*A. adscensionis*	*C. decumbens*	*R. minima*
54	SW	600-700	*A. mutica*	*A. mutica*	*S. angustifolia*	*B. diffusa*
55	SW	700-800	*A. mutica*	*A. mutica*	*B. diffusa*	*T. strigosa*
56	SW	800-900	*A. mutica*	*A. mutica*	*I. dichroa*	*B. maderaspatensis*
57	W	<230	*D. verticillata*	*C. benghalensis*	*R. minima*	*E. granulata*
58	W	230-300	*A. adscensionis*	*O. thomaeum*	*D. aegyptium*	*M. jacquemontii*
59	W	300-400	*L. trinervis*	*C. ciliaris*	*I. nill*	*E. persicus*
60	W	400-500	*A. adscensionis*	*A. adscensionis*	*T. uniflora*	*T. terrestris*
61	W	500-600	*A. adscensionis*	*A. radiata*	*T. rhomboidea*	*P. paniculata*
62	W	600-700	*A. adscensionis*	*A. adscensionis*	*C. pumila*	*R. minima*
63	W	700-800	*B. pusilla*	*B. pusilla*	*B. maderaspatensis*	*E. hirta*
64	W	800-900	*A. mutica*	*A. mutica*	*P. erioptera*	*C. aestuans*

E:East, N: North, NE: North-East, NW: North-West, S: South, SE: South-East, SW: South-West, W: West

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