

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

Deepak Mishra and Genda Singh*

Division of Forest Ecology and Climate Change, Arid Forest Research Institute, New Pali Road, Jodhpur -342005, Rajasthan, India

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 m² (clustered at sixty-four position 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' 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 *Arisida 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 km² 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. MATERIAL AND METHODS

2.1 Study site

The study was conducted in Haldeshwar 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%).

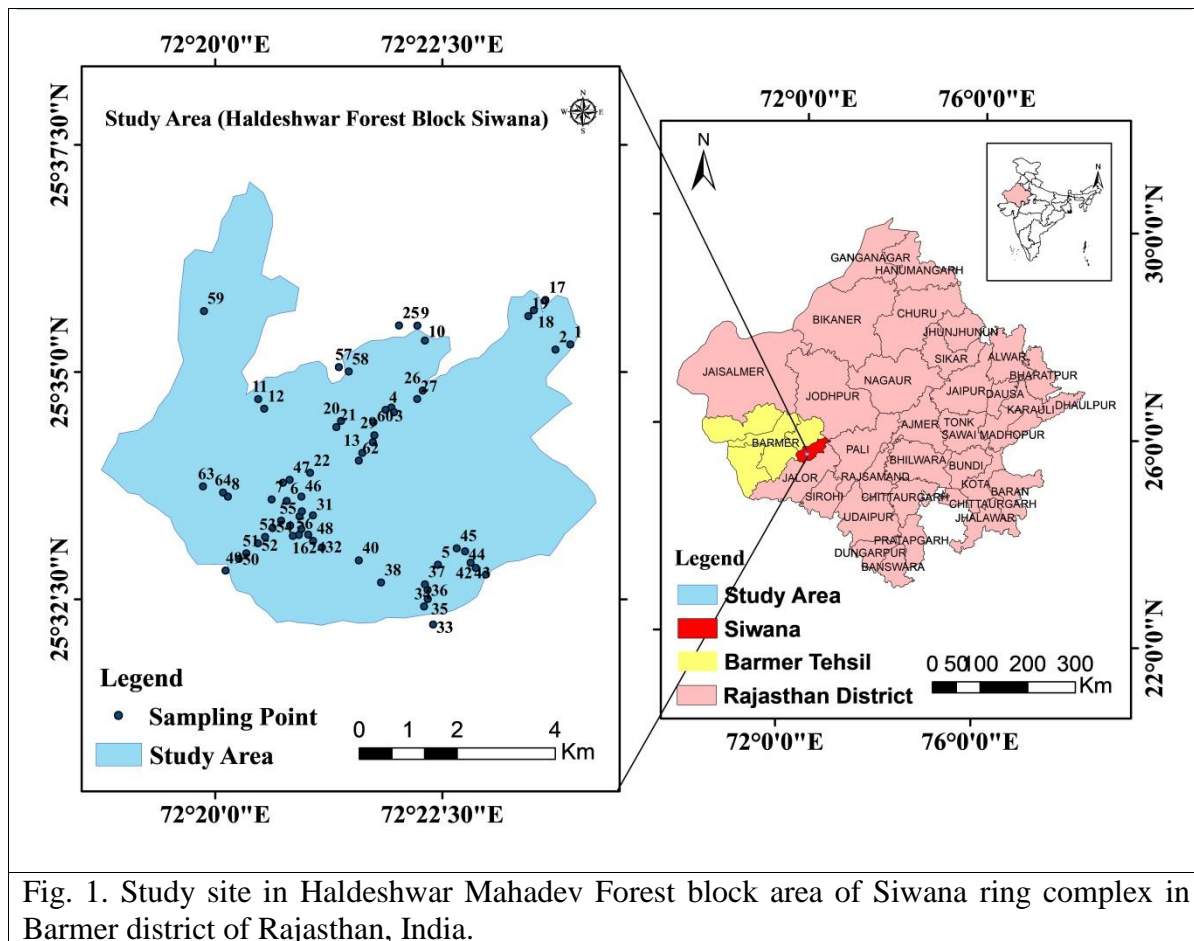


Fig. 1. Study site in Haldeshwar Mahadev Forest block area of Siwana ring complex in Barmer district of Rajasthan, India.

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 sapling plots (cluster sampling) of 1 m × 1 m size were laid out as replicates. In which 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-m² 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 $H = \sum nihi/N$. 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].

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 (49 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 pusilla*, *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 <230 m elevation. This indicates the availability of more xeric species in S and SW aspects in foothills (<230 m 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 \times aspect for all, year \times elevation for population

density, R and H' , and years \times aspect \times 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 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 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 increase 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_v 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_v 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_v. The slope aspect indirectly affected R and H_v 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.

AUTHOR CONTRIBUTIONS

Both authors contributed to field data collection, laboratory analysis, data interpretation, manuscript writing and approval.

ACKNOWLEDGMENT

Authors are thankful to Director, Arid Forest Research Institute, Jodhpur for providing necessary facilities to carry out this research work. Necessary helps and supports of staffs and officials of Forest Department of Siwana Range, Barmer (Government of Rajasthan) is gratefully acknowledged.

COMPETING INTEREST

There are no competing interests

FUNDING

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

REFERENCES

1. Coblenz DD, Riitters KH. Topographic controls on the regional-scale biodiversity of the south-western USA. *J. Biogeogr.* 2004;31:1125-1138.
2. Yang YC, Da LJ, You WH. Vegetation structure in relation to micro-landform in Tiantong National Forest Park, Zhejiang, China. *Acta Ecol. Sin.* 2005;25:2830-2840.
3. Fang JY, Shen ZH, Cui HT. Ecological characteristics of mountains and research issues of mountain ecology. *Chinese Biodiversity*, 2004;12:10-19.
4. Southwood TRE, Lineacre FRS. *Ecological methods*. (3rd ed.) p. 594.2015.
5. Gupta RD, Arora S. Characteristics of the soils of Ladakh region of Jammu and Kashmir. *J Soil Water Conserv.* 2017;16(3):260-266.
6. Gong X, Brueck H, Giese KM, Zhang L, Sattelmacher B, Lin S. Slope aspect has effects on productivity and species composition of hilly grassland in the Xilin river basin, Inner Mongolia, China. *J Arid Environ*, 2008;72:483-493.
7. Maren IE, Karki S, Prajapati C, Yadav RK, Shrestha BB. Facing north or south: Does slope aspect impact forest stand characteristics and soil properties in a semiarid trans-Himalayan valley?, *J. Arid Environ.* 2015;121:112-123.
8. Chang-Ming Z, Wei-Lie C, Zi-Qiang T, et al. Altitudinal pattern of plant species diversity in Shennongjia Mountains, Central China. *J. Integrative Plant Biology*, 2005; 47(12):1431-1449.
9. Funnell D, Parish R. *Mountain environment and communities*. London, U.K: Routledge; 2001.
10. Hakwins BA, Field R, Cornell HV. et al. Energy, water, and broad-scale geographic patterns of species richness. *Ecology*, 2003; 84:3105-3117.
11. Criddle RS, Church JN, Smith BN, et al. Fundamental causes of the global patterns of species range and richness. *Russian J. Plant Physiology*. 2003;50:192-199.
12. Singh G, Mishra D, Singh K, Shukla S, Choudhary GR. Geographical settings and tree diversity influenced soil carbon storage in different forest types in Rajasthan, India. *Catena*. 2022;209:105856.
13. Haina Z, Peixi S, Shanxia L, Zijuan Z., Tingting X, Qingfang Z. Indicative effect of the anatomical structure of plant photosynthetic organ on WUE in desert region. *ActaEcologicaSinica*, 2013; 33:4909-4918.
14. Chen SP, Wang WT, Xu WT, Wang Y.. Plant diversity enhances productivity and soil carbon storage. *Proceedings of the National Academy of Sciences*, 2018; 115:4027-4032.
15. Palaniappan, SP, Chandrasekaran A, Kang DS, Singh K, Rajput RP, Kauraw DL, Velayutham M, Lal R, "Sustainable management of natural resources for security and environmental quality: case studies from India – A Review. In: E. Lichtfouse (ed.), *Climate*

- Change, Intercropping, Pest Control and Beneficial Microorganisms”, *Sustainable Agriculture Reviews*, pp. 339-372. 2009.
16. Hashemi SA. Evaluating Plant species diversity and physiographical factors in natural broad leaf forest. *American J. Environmental Sci*: 2010; 6:20-25.
 17. Kharkwal G, Mehrotra P, Rawat YS, Pangtey YPS. Comparative study of herb layer diversity in pine forest stands at different altitudes of central Himalaya, *ApplEcol Environ Res*. 2004;2(2):15-24.
 18. Wenk EH, Dawson TE. Interspecific differences in seed germination, establishment, and early growth in relation to preferred soil type in an alpine community. *Arctic, Antarctic and Alpine Res*. 2007;30(1):165-176.
 19. Palpurina S, Wagner V, Wehrden H, Hajek M, Horsak M, Brinkert, A. et al. 2016. The relationship between plant species richness and soil pH vanishes with increasing aridity across Eurasian dry grasslands. *Glob. Ecol. Biogeogr*. 2016;26(4):425-434.
 20. Khadka D, Lamichhane S, Thapa B. Assessment of relationship between soil pH and macronutrients, Western Nepal. *J. Chemical, Biological and Physical Sci*. 2016;6(2):303-311.
 21. Zhang S, Chen D, Sun D, Wang X, Smith JL, Du G. Impacts of altitude and position on the rates of soil nitrogen mineralization and nitrification in alpine meadows on the eastern Qinghai–Tibetan Plateau, China. *Biol. and Fertil.of Soils*. 2012;48(4):393-400.
 22. Singh G, Singh B, Tomar UK and Sharma, S. A Manual for dryland afforestation and management, Scientific Publisher, Jodhpur. ISBN: 9788172339784.2017.
 23. Bakliwal PC, Wadhawan SK. Geological evolution of Thar Desert in India-issues and prospects. *Proc. Indian Nat Sci Acad*. 2003; 69A(2):151-165.
 24. Bhandari MM. Flora of the Indian Desert. Scientific publishers. Jodhpur. 1990.
 25. Sharma KK, Pandey AK. Phytosociological study of vegetation of some selected arid region of the Thar desert of Rajasthan, India. *Curr. World Environ*. 2010;5(1):51-58.
 26. Shetty BV, Singh V. Flora of Rajasthan. Botanical Survey of India. Vol I-III. 1993.
 27. Mahendran V, Jagadeeswar Rao P, Bera AK. Vulnerability of different geomorphic units to Deserts I parts of western Rajastha-A study based on remote sensing and GIS. *J Remote Sensing and GIS*. 2017;6(3):204. DOI: 10.4172/2469-4134.1000204.
 28. Qanbari V, Jamali AA. The relationship between elevation, soil properties and vegetation cover in the Shorb-O1-Ain watershed of Yazd. *J. of Biodivers.and Environ. Sci*. 2015;6(5):49-56.
 29. Misra R. Ecology Work Book. Oxford and IBH Publishing Company, Calcutta. 1968.
 30. Magurran AE. Ecological diversity and its measurement. Princeton University Press, New Jersey. p.179. 1988.
 31. Pielou EC. The Measurement of diversity in different types of biological collections. *J. Theoretical Biology*, 1966;13:131-144.
 32. Shannon CE, Weaver W. The mathematical theory of communication. Univ. Illinois Press, Urbana. p 117. 1963.
 33. Simpson EH. Measurement of diversity. *Nature*. 1949;163:683-688.
 34. Philips EA. Methods of vegetation study. Henry Holt and Co. Inc; New York. p.318.1959.
 35. Singh G, Mishra D, Singh K, Parmar R. Effects of rainwater harvesting on plant growth, soil water dynamics and herbaceous biomass during rehabilitation of degraded hills in Rajasthan, India. *For. Ecol. Manag*. 2013;310:612–622.
 36. Jackson ML. Soil chemical analysis. Prentice Hall of India (Pvt.) Ltd., New Delhi. 1973.

37. Walkley A, Black IA. "An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method," *Soil Sci.* 1934;37(1):29–38.
38. Bhardwaj DR, Tahiry H, Sharma P, Pala NA, Kumar D, Kumar, A. Bharti. Influence of aspect and elevational gradient on vegetation pattern, tree characteristics and ecosystem carbon density in Northwestern Himalayas. *Land.* 2021;10:1109.
39. Pandita, S, Kumar, V, Dutt HC. Environmental variables vis-à-vis distribution of herbaceous tracheophytes on northern sub-slopes in Western Himalayan ecotone. *Ecol.Process.* 2019;8:45.
40. Moharana P, Jena R, Kumar N, Singh S. Assessment of soil organic and inorganic carbon stock at different soil depths after conversion of desert into arable land in the hot arid regions of India. *Carbon Manag.* 2021;12(2):153-165.
41. Singh G. Studies on carbon sequestration in different forest types of Rajasthan. Project completion report, submitted to Indian Council of Forestry Research and Education, Dehradun, Uttarakhand. 2014.
42. Singh G, Choadhary GR, Ram B, Limba NK. Effects of rainwater harvesting on herbage diversity and productivity in degraded Aravalli hills in western India. *J. Forestry Res.* 2011;22(3):329–340.
43. Fischer C, Leimer S, Christiane Roscher C, Ravenek J, de Kroon H, et al. Plant species richness and functional groups have different effects on soil water content in a decade-long grassland experiment. *J Ecol.* 2019;107(1):127–141.
44. Zeng XH, Zhang WJ, Yi-Gang S, Shen HT. Slope aspect and slope position have effects on plant diversity and spatial distribution in the hilly region of Mount Taihang, North China. *J. Food, Agriculture Environ.* 2014;12:391-397.
45. Louhaichi M, Toshpulot R, Moyo HP, Belgacem AO. Effect of slope aspect on vegetation characteristics in mountain rangelands of Tajikistan: considerations for future ecological management and restoration. *African J. Range & Forage Sci.* 2021;1–9.
46. Choudhary K, Nama KS. Phyto-diversity of Mukundara hills national park of Kota district, Rajasthan, India. *Advances in Appl. Sci. Res.* 2014;5(1):18-23.
47. Jin XM, Zhang YK, Schaepman ME, Clevers JGPW, Su Z. Impact of elevation and aspect on the spatial distribution of vegetation in the qilian mountain area with remote sensing data. Conference Paper-The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. 2008;37.10.5167/uzh-77426. https://www.isprs.org/proceedings/xxxvii/congress/7_pdf/8_icwg-vii-iv/05.pdf
48. Panthi MP, Chaudhary RP, Vetaas OR. Plant species richness and composition in a trans-Himalayan inner valley of Manang district, central Nepal. *Himalayan J. Sci.* 2007;4(6):57-64.
49. Ucles O, Villagrancia L, Canton Y, Lazaro R, Domingo F. Non-rainfall water inputs are controlled by aspect in a semiarid ecosystem. *J. of Arid Environ.* 2015;113:43–50.
50. Xue R, Yang Q, Miao F, Wang X, Shen Y. Slope aspect influences plant biomass, soil properties and microbial composition in alpine meadow on the Qinghai-Tibetan Plateau. *J. of Soil Sci. and Plant Nutrition.* 2018;18(1):1-12.
51. Singh S. Understanding the role of slope aspect in shaping the vegetation attributes and soil properties in montane ecosystems. *Trop.Ecol.* 2018;59(3):417–430.
52. Mata-Gonzalez R, Pieper RD, Cardenas MM. Vegetation patterns as affected by aspect and elevation in small desert mountains. *The southwestern naturalist.* 2002;47(3):440-448.

53. Singh K. Effect of Land use types on floral diversity and carbon sequestration in Jodhpur district of Rajasthan. Ph.D. Thesis submitted to Forest Research Institute (Deemed) University, Dehradun: 182 Pp.2016.
54. Tamene GM, Adiss HK, Alemu MY. Effect of slope aspect and land use types on selected soil physicochemical properties in North Western Ethiopian Highlands. *Appl. and Environ. Soil Sci.* Article ID 8463259:8 p.2020.
55. Zhao H, Wang QR, Fan W, Song GH. The relationship between secondary forest and environmental factors in the southern Taihang Mountains. *Sci. Rep.* 2017;7:16431.
56. Zhu M, Feng Q, Zhang M, Liu W, Qin Y, Deo RC, Zhang C. Effects of topography on soil organic carbon stocks in grasslands of a semiarid alpine region, north-western China. *J. of soils and sediments.* 2018;19:1640-1650.
57. Begum F, Bajracharyab RM, Sitaulac BK, Sharmab S. Seasonal dynamics, slope aspect and land use effects on soil mesofauna density in the mid-hills of Nepal. *Int. J. Biodiversity Sci., Ecosystem Services and Manag.* 2013;9(4):290–297.
58. Pei J, Yang W, Cai Y, Yi Y, Li X. Relationship between Vegetation and Environment in an Arid-Hot Valley in Southwestern China. *Sustainability.*2018;10:4774.
59. Cirimwami L, Doumenge C, Kahindo JM, Amani C. The effect of elevation on species richness in tropical forests depends on the considered lifeform: results from an East African mountain forest. *Trop.Ecol.* 2019;60:473-484.
60. Lozano-Garcia B, Parras-Alcantara L, Brevik EC. Impact of topographic aspect and vegetation (native and reforested areas) on soil organic carbon and nitrogen budgets in Mediterranean natural areas. *Sci. Total Environ.* 2016;544:963–970.
61. Lee MA, Burger G, Green ER, Kooij PW. Relationships between resource availability and elevation vary between metrics creating gradients of nutritional complexity. *Oecologia.* 2021;195:213–223.
62. Habib T, Malik ZH, Hussain MA, Khan MQ. Plant species diversity along the altitudinal gradient at Garhi Dopatta Hills, Muzaffarabad. *J. Medicinal Plants Research,* 2011; 5(20):5194-5196.
63. McCain CM, Grytnes JA. Elevational gradients in species richness. In: *Encyclopedia of Life Sciences (ELS).* John Wiley & Sons, Ltd: Chichester. 2010. DOI: 10.1002/9780470015902.a0022548.
64. Nepali BR, Skartveit J, Baniya CB. Impacts of slope aspects on altitudinal species richness and species composition of Narapani-Masina landscape, Arghakhanchi, West Nepal. *J. Asia-Pac. Biodivers.* 2021;14:415-424.
65. Yang J, ElKassaby YA, Guan W. The effect of slope aspect on vegetation attributes in a mountainous dry valley, Southwest China. *Sci.Rep.* 2020;10:16465.
66. Graff P, Aguiar MR, Chaneton EJ. Shifts in positive and negative plant interactions along a grazing intensity gradient.*Ecology.* 2007;88:188-199.

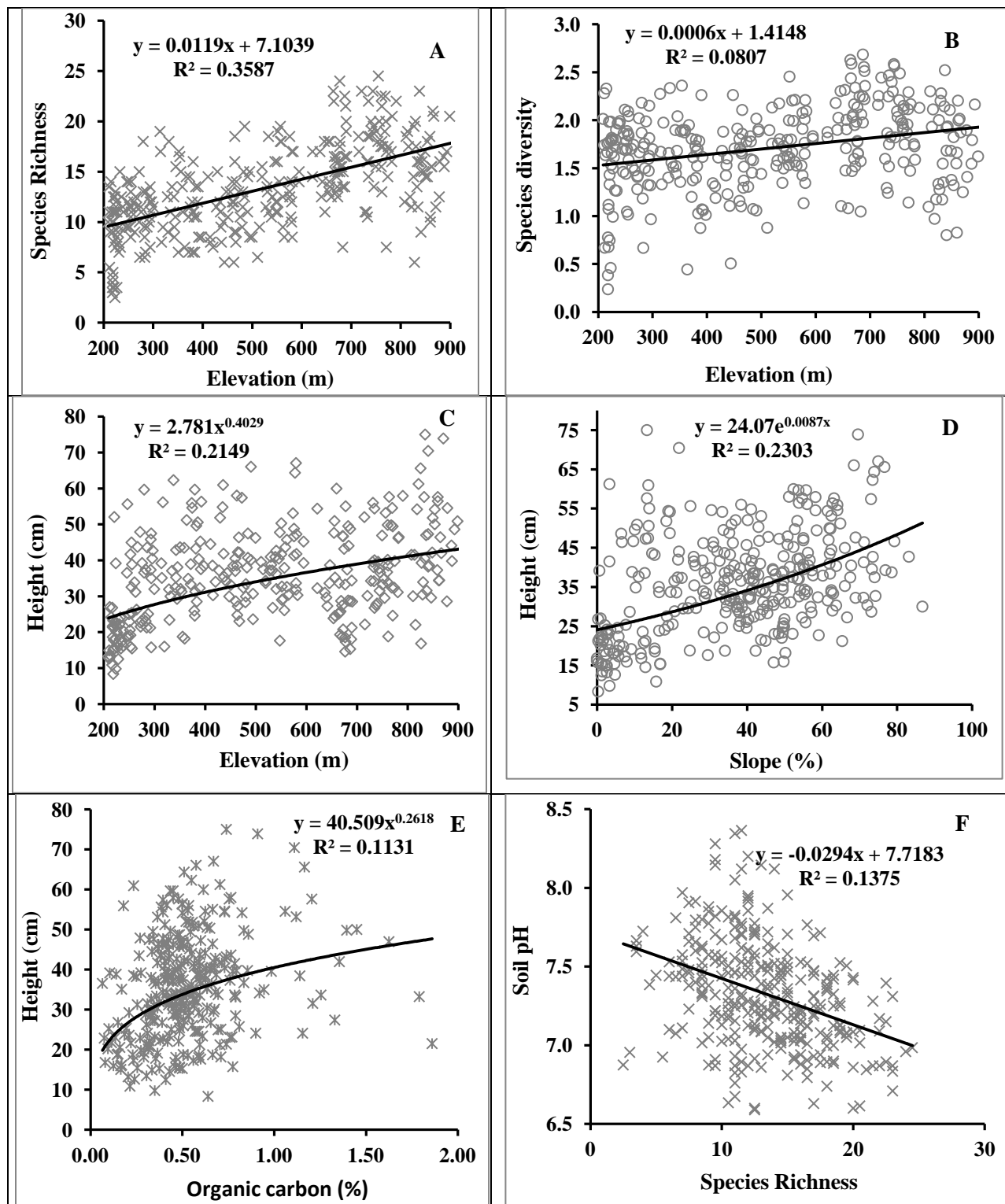


Fig. 2. Relationships among different topographical features, diversity indices and soil parameters. (a) Species richness, (b) Species diversity and (c) plant height with elevation, (d) slope (%) vs. plant height, (e) soil organic carbon vs. height and (f) species richness vs. soil pH.

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 | | | | | | |
|-----------------------------------|--------------------------|--------------------------|------------------------------------|--------|--------|-----------|----------------------------------|-----------|---------|
| | 2017 | 2018 | Tests of Within-Subjects Effects | | | | Tests of Between-Subject Effects | | |
| | | | 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 (%) | -0.214** | 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 (%) | -0.188** | 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) | | | | | | | | Mean |
|--------------------------|----------------------------|---------------------------|----------------------------|---------------------------|---------------------------|--------------------------|----------------------------|---------------------------|-------------|
| | N (0°) | NE (45°) | E (90°) | SE (135°) | S (180°) | SW (225°) | W (270°) | NW (315°) | |
| 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±0.04 ^a | 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) | | | | | | | | Mean |
|--------------------------|---------------------------|---------------------------|--------------------------|--------------------------|---------------------------|--------------------------|--------------------------|---------------------------|-------------|
| | <230 | 230-300 | 300-400 | 400-500 | 500-600 | 600-700 | 700-800 | 800-900 | |
| 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.

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 | <i>Abelmoschus moschatus</i> (L.) Medic | Herb | Malvaceae | 0.41 |
| 2 | <i>Acalypha ciliata</i> Forssk. | Herb | Euphorbiaceae | 0.86 |
| 3 | <i>Acanthospermum hispidum</i> DC. | Herb | Asteraceae | 1.76 |
| 4 | <i>Achyranthes aspera</i> L. | Herb | Amaranthaceae | 2.20 |
| 5 | <i>Acrachne racemosa</i> (B.Heyne ex Roem. & Schult.) Ohwi. | Grass | Poaceae | 1.13 |
| 6 | <i>Actiniopteris radiata</i> (J. König ex Sw.) Link. | Small fern | Pteridaceae | 5.32 |
| 7 | <i>Adiantum lunulatum</i> Burm. f. | Small fern | Pteridaceae | 3.11 |
| 8 | <i>Alternanthera paronychioides</i> St. Hil., Voy. | Decumbent herb | Amaranthaceae | 0.17 |
| 9 | <i>Alysicarpus monilifer</i> (L.) DC. | Herb | Fabaceae | 0.51 |
| 10 | <i>Alysicarpus rugosus</i> (Willd.) DC. | Prostrate herb | Fabaceae | 0.34 |
| 11 | <i>Amaranthus viridis</i> L. | Herb | Amaranthaceae | 0.32 |
| 12 | <i>Andrographis echinoides</i> (L.) Nees. | Herb | Acanthaceae | 1.26 |
| 13 | <i>Anisochilus carnosus</i> (L.f.) Wall. | Herb | Lamiaceae | 0.57 |
| 14 | <i>Anisomeles indica</i> (L.) Kuntze | Herb | Lamiaceae | 0.42 |
| 15 | <i>Apluda mutica</i> L. | Grass | Poaceae | 22.86 |
| 16 | <i>Aristida adscensionis</i> Linn. | Grass | Poaceae | 22.06 |
| 17 | <i>Aristida funiculata</i> Trin. & Rupr. | Grass | Poaceae | 0.55 |
| 18 | <i>Aristida mutabilis</i> Trin. & Rupr. | Grass | Poaceae | 0.60 |
| 19 | <i>Artemisia scoparia</i> Waldst. & Kit. | Herb | Asteraceae | 0.16 |
| 20 | <i>Arthraxon lanceolatus</i> (Roxb.) Hochst. | Grass | Poaceae | 1.77 |
| 21 | <i>Arthraxon lancifolius</i> (Trin.) Hochst. | Grass | Poaceae | 1.25 |
| 22 | <i>Bidens pilosa</i> L. | Herb | Asteraceae | 1.60 |
| 23 | <i>Blainvillea acmella</i> (L.) Philipson | Herb | Asteraceae | 2.91 |
| 24 | <i>Blepharis maderaspatensis</i> (L.) B.Heyne ex Roth | Procumbent herb | Acanthaceae | 1.03 |
| 25 | <i>Blumea mollis</i> (D. Don) Merr. | Herb | Asteraceae | 0.32 |
| 26 | <i>Blumea virens</i> DC. | Herb | Asteraceae | 0.39 |
| 27 | <i>Boerhavia diffusa</i> L. | Prostrate herb | Nyctaginaceae | 1.67 |
| 28 | <i>Boerhavia erecta</i> L. | Herb | Nyctaginaceae | 2.81 |
| 29 | <i>Borreria pusilla</i> (Wall.) DC. | Herb | Rubiaceae | 5.46 |
| 30 | <i>Brachiaria ramosa</i> (L.) Stapf. | Grass | Poaceae | 5.58 |
| 31 | <i>Cardiospermum halicacabum</i> L. | Climbing vine | Sapindaceae | 1.19 |
| 32 | <i>Catharanthus pusillus</i> (Murr.) G. Don . | Herb | Apocynaceae | 0.18 |
| 33 | <i>Celosia argentea</i> L. | Glabrous herb | Amaranthaceae | 1.11 |
| 34 | <i>Cenchrus biflorus</i> Roxb. | Grass | Poaceae | 0.24 |
| 35 | <i>Cenchrus ciliaris</i> L. | Grass | Poaceae | 5.55 |
| 36 | <i>Cenchrus pennisetiformis</i> Hochst. & Steud. | Grass | Poaceae | 1.00 |
| 37 | <i>Cenchrus prieurii</i> (Kunth) Maire | Grass | Poaceae | 0.75 |
| 38 | <i>Ceropegia bulbosa</i> Roxb. var. <i>lushii</i> (Grah.) Hook.f. | Twining herb | Apocynaceae | 0.48 |
| 39 | <i>Chamaecrista absus</i> (L.) H.S. Irwin & | Herb | Caesalpinaceae | 0.80 |
| 40 | <i>Chamaecrista pumila</i> (Lamk.) K. Larsen, | Herb | Caesalpinaceae | 1.74 |
| 41 | <i>Chloris barbata</i> Sw. | Grass | Poaceae | 0.53 |
| 42 | <i>Chloris dolichostachya</i> Lagasca, | Grass | Poaceae | 0.91 |
| 43 | <i>Citrullus colocynthis</i> (L.) Schrad | Trailing vine | Cucurbitaceae | 0.33 |
| 44 | <i>Cleome gracilis</i> Edgew. | Herb | Capparaceae | 0.54 |
| 45 | <i>Cleome viscosa</i> L. | Herb | Capparaceae | 1.43 |
| 46 | <i>Clitoria annua</i> J. Graham . | Herb | Fabaceae | 0.57 |
| 47 | <i>Coccinia grandis</i> (L.) Voigt | Climber | Cucurbitaceae | 0.16 |
| 48 | <i>Commelina benghalensis</i> L. | Herb | Commelinaceae | 0.77 |

| | | | | |
|----|---|----------------------|----------------|------|
| 49 | <i>Commelina erecta</i> L. | Decumbent herb | Commelinaceae | 2.93 |
| 50 | <i>Commelina forskaoii</i> Vahl. | Prostrate herb | Commelinaceae | 0.20 |
| 51 | <i>Commicarpus boissieri</i> (Heimerl.) Cufod. | Decumbent undershrub | Nyctaginaceae | 1.06 |
| 52 | <i>Corallocarpus epigaeus</i> (Rottl.) C.B.Clark | Climbing Herb | Cucurbitaceae | 0.16 |
| 53 | <i>Corbichonia decumbens</i> (Forssk.) Exell | Procumbent herb | Molluginaceae | 0.90 |
| 54 | <i>Corchorus aestuans</i> L. | Herb | Tiliaceae | 0.85 |
| 55 | <i>Corchorus depressus</i> (L.) Stocks | Prostrate herb | Tiliaceae | 0.34 |
| 56 | <i>Corchorus tridens</i> L. | Herb | Tiliaceae | 0.68 |
| 57 | <i>Crinum pratense</i> Herb. | Herb | Amaryllidaceae | 1.89 |
| 58 | <i>Crotalaria mysorensis</i> Roth | Tall herb | Fabaceae | 0.65 |
| 59 | <i>Cucumis maderaspatanus</i> L. | Climbing Herb | Cucurbitaceae | 1.99 |
| 60 | <i>Cyanotis fasciculata</i> (B.Heyne ex Roth) Schult. & Schult.f. | Glabrous Herb | Commelinaceae | 0.88 |
| 61 | <i>Cymbopogon jwarancusa</i> (Jones) Schult. | Grass | Poaceae | 1.41 |
| 62 | <i>Cymbopogon martinii</i> (Roxb.) Watson | Grass | Poaceae | 4.64 |
| 63 | <i>Cynodon dactylon</i> (L.) Pers. | Grass | Poaceae | 0.71 |
| 64 | <i>Cyperus arenarius</i> Retz. | Perennial herb | Cyperaceae | 1.14 |
| 65 | <i>Cyperus difformis</i> L. | Glabrous herb | Cyperaceae | 0.17 |
| 66 | <i>Cyperus rotundus</i> L. | Perennial herb | Cyperaceae | 1.16 |
| 67 | <i>Dactyloctenium aegyptium</i> (L.) Willd. | Grass | Poaceae | 1.58 |
| 68 | <i>Dactyloctenium scindicum</i> Boiss. | Grass | Poaceae | 2.36 |
| 69 | <i>Desmodium triflorum</i> (L.) DC. | Prostrate herb | Papilionaceae | 0.98 |
| 70 | <i>Dichanthium annulatum</i> (Forsk.) Stapf. | Grass | Poaceae | 7.02 |
| 71 | <i>Dichanthium foveolatum</i> (Delile) Roberty | Grass | Poaceae | 1.30 |
| 72 | <i>Dichanthium huegelii</i> (Hack.) S.K.Jain & Deshp. | Grass | Poaceae | 0.66 |
| 73 | <i>Dicliptera verticillata</i> (Forssk.) C. Christensen | Herb | Acanthaceae | 1.07 |
| 74 | <i>Dicoma tomentosa</i> Cass. | Herb | Asteraceae | 0.56 |
| 75 | <i>Digitaria pennata</i> (Hochst.) T.Cooke | Grass | Poaceae | 4.81 |
| 76 | <i>Digitaria sanguinalis</i> (L.) Scop. | Grass | Poaceae | 0.37 |
| 77 | <i>Digitaria bicornis</i> (Lam.) Roem. & Schult. | Grass | Poaceae | 2.55 |
| 78 | <i>Dipteracanthus patulus</i> (Jacq.) Nees | Pubescent herb | Acanthaceae | 4.01 |
| 79 | <i>Eclipta alba</i> (L.) Hassk. | Herb | Asteraceae | 0.18 |
| 80 | <i>Elyonurus royleanus</i> Nees ex A.Rich | Grass | Poaceae | 1.56 |
| 81 | <i>Enneapogon persicus</i> Boiss. | Grass | Poaceae | 1.05 |
| 82 | <i>Eragrostiella bifaria</i> (Vahl) Bor | Grass | Poaceae | 3.42 |
| 83 | <i>Eragrostis cilianensis</i> (All.) Janch. | Grass | Poaceae | 0.54 |
| 84 | <i>Eragrostis ciliaris</i> (Linn.) R.Br. | Grass | Poaceae | 0.95 |
| 85 | <i>Eragrostis minor</i> Host. | Grass | Poaceae | 1.98 |
| 86 | <i>Eragrostis tenella</i> (Linn.) P Beauv. | Grass | Poaceae | 0.93 |
| 87 | <i>Eragrostis tremula</i> (Lam.) Hochst. ex Steud. | Grass | Poaceae | 0.55 |
| 88 | <i>Euphorbia granulata</i> Forssk. | Prostrate herb | Euphorbiaceae | 0.32 |
| 89 | <i>Euphorbia hirta</i> L. | Herb | Euphorbiaceae | 0.88 |
| 90 | <i>Euphorbia indica</i> Lam. | Herb | Euphorbiaceae | 0.50 |
| 91 | <i>Evolvulus alsinoides</i> var. <i>alsinoides</i> (L.) L. | Herb | Convolvulaceae | 3.04 |
| 92 | <i>Evolvulus alsinoides</i> var. <i>linifolius</i> (L.) Kuntze | Herb | Convolvulaceae | 0.38 |
| 93 | <i>Galactia tenuiflora</i> (Willd.) Wight & Arn. | Climbing herb | Fabaceae | 0.53 |
| 94 | <i>Glinus lotoides</i> L. | Prostrate herb | Molluginaceae | 0.16 |
| 95 | <i>Glossocardia bosvallea</i> (L.f) DC | Herb | Asteraceae | 1.08 |
| 96 | <i>Heliotropium marifolium</i> Retz. | Herb | Boraginaceae | 1.08 |
| 97 | <i>Heteropogon contortus</i> (L.) P. Beauv. Ex Roem. & Schult | Grass | Poaceae | 7.58 |
| 98 | <i>Hibiscus micranthus</i> L.f. | Subshrubs | Malvaceae | 1.40 |
| 99 | <i>Hibiscus palmatus</i> Forsk. | Herb | Malvaceae | 0.16 |

| | | | | |
|-----|--|----------------------------|------------------|-------|
| 100 | <i>Indigofera cordifolia</i> Heyne ex Roth. | Herb | Fabaceae | 4.13 |
| 101 | <i>Indigofera hochstetteri</i> Baker | Spreading herb | Fabaceae | 0.26 |
| 102 | <i>Indigofera linifolia</i> (L.f.)Retz. | Prostrate herb | Fabaceae | 0.38 |
| 103 | <i>Indigofera linnaei</i> Ali | Prostrate herb | Fabaceae | 0.70 |
| 104 | <i>Ipomoea dichroa</i> Hochst. ex Choisy. | Climbing Herb. | Convolvulaceae | 1.23 |
| 105 | <i>Ipomoea eriocarpa</i> R. Br. | Twining herb | Convolvulaceae | 0.51 |
| 106 | <i>Ipomoea indica</i> (Burm. f.) Merr. | Vine herb | Convolvulaceae | 0.32 |
| 107 | <i>Ipomoea nil</i> (L.) Roth | Annual herb vine | Convolvulaceae | 0.97 |
| 108 | <i>Ipomoea pes-tigridis</i> L. | Twining herb | Convolvulaceae | 0.84 |
| 109 | <i>Ipomoea sindica</i> Stapf. | Twining herb | Convolvulaceae | 0.51 |
| 110 | <i>Justicia simplex</i> D. Don | Herb | Acanthaceae | 1.40 |
| 111 | <i>Justicia heterocarpa</i> T.Anderson | Herb | Acanthaceae | 1.07 |
| 112 | <i>Kickxia ramosissima</i> (Wall.) Janchen | Prostrate herb | Scrophulariaceae | 0.49 |
| 113 | <i>Launaea procumbens</i> L | Decumbent herb | Asteraceae | 0.74 |
| 114 | <i>Lavandula bipinnata</i> (Roth) Kuntze | Slender herb | Lamiaceae | 1.75 |
| 115 | <i>Lepidagathis cristata</i> willd. | decumbent herb | Acanthaceae | 2.44 |
| 116 | <i>Lepidagathis trinervis</i> Wall. ex. Ness | Suffruticose herb | Acanthaceae | 6.71 |
| 117 | <i>Leptothrium senegalense</i> (Kunth) Clayton | Grass | Poaceae | 0.55 |
| 118 | <i>Leucas aspera</i> (Willd.) Link | Herb | Lamiaceae | 1.23 |
| 119 | <i>Leucas urticaefolia</i> (Vahl) R. Br. | Herb | Lamiaceae | 0.59 |
| 120 | <i>Lindenbergia indica</i> (L.) Vatke | Herb | Orobanchaceae | 0.70 |
| 121 | <i>Linum mysorense</i> Heyne ex Benth. | Herb | Linaceae | 0.18 |
| 122 | <i>Macrotyloma uniflorum</i> Lam. | Twining herb | Fabaceae | 0.87 |
| 123 | <i>Melanocenchris jacquemontii</i> Jaub. & Spach | Grass | Poaceae | 4.28 |
| 124 | <i>Mollugo nudicaulis</i> Lam. | Herb | Molluginaceae | 1.01 |
| 125 | <i>Momordica dioica</i> Roxb. ex Willd. | Climbing Herb | Cucurbitaceae | 0.33 |
| 126 | <i>Nepeta bombaiensis</i> Dalzell | Herb | Lamiaceae | 1.46 |
| 127 | <i>Nothosaerva brachiata</i> (L.) Wight | Herb | Amaranthaceae | 0.22 |
| 128 | <i>Ocimum canum</i> Sims | Herb | Lamiaceae | 0.67 |
| 129 | <i>Oligochaeta ramosa</i> (Roxb.) Wagenitz. | Herb | Asteraceae | 0.16 |
| 130 | <i>Oropetium roxburghianum</i> (Steud.) S.M.Phillips | Grass | Poaceae | 1.09 |
| 131 | <i>Oropetium thomaeum</i> (L. f.) Trin. | Grass | Poaceae | 16.12 |
| 132 | <i>Panicum turgidum</i> Forsk. | Grass | Poaceae | 3.40 |
| 133 | <i>Pedaliium murex</i> Linn | Herb | Pedaliaceae | 0.19 |
| 134 | <i>Pennisetum orientale</i> L.C. Rich. | Grass | Poaceae | 0.20 |
| 135 | <i>Pentanema indicum</i> (L.) Ling | Herb | Asteraceae | 0.51 |
| 136 | <i>Peristrophe paniculata</i> (Forsk.) Brummitt | Herb | Labiatae | 2.70 |
| 137 | <i>Perotis indica</i> (L.) Kuntze. | Grass | Poaceae | 0.48 |
| 138 | <i>Phyllanthus amarus</i> Schum. & Thonn. | Herb | Euphorbiaceae | 0.50 |
| 139 | <i>Physalis minima</i> L. | Herb | Solanaceae | 0.65 |
| 140 | <i>Polygalaerioptera</i> DC. | Herb | Polygaleaceae | 1.17 |
| 141 | <i>Polygala irregularis</i> Boiss. | Herb | Polygalaceae | 0.34 |
| 142 | <i>Portulaca oleracea</i> L. | Herb | Portulacaceae | 0.16 |
| 143 | <i>Portulaca pilosa</i> L. | Herb | Portulacaceae | 0.57 |
| 144 | <i>Portulaca tuberosa</i> Roxb. | Herb | Portulacaceae | 0.20 |
| 145 | <i>Pulicaria wightiana</i> D. C. Clarke. | Herb | Asteraceae | 0.16 |
| 146 | <i>Pupalia lapacea</i> (L.) Juss | Subshrub | Amaranthaceae | 3.09 |
| 147 | <i>Rhincosia minima</i> (Camb.) Barker | Prostrate climbing herb | Fabaceae | 0.93 |
| 148 | <i>Sclerocarpus africanus</i> Jacq. | Herb | Asteraceae | 1.04 |
| 149 | <i>Sehima nervosum</i> (Rottler) Stapf. | Grass | Poaceae | 2.49 |
| 150 | <i>Senecio hewrensis</i> Hook. F. | Herb | Asteraceae | 1.78 |
| 151 | <i>Sesamum indicum</i> L. | Herb | Pedaliaceae | 0.50 |
| 152 | <i>Setaria geniculata</i> P.Beauv. | Grass | Poaceae | 0.19 |

| | | | | |
|-----|--|-------------------|----------------|------|
| 153 | <i>Sida cordata</i> (Brum. F.) Bross | Herb | Malvaceae | 0.87 |
| 154 | <i>Sida cordifolia</i> L. | Herb | Malvaceae | 0.49 |
| 155 | <i>Sorghum halepense</i> (L.) Pers. | Grass | Poaceae | 1.04 |
| 156 | <i>Sporobolus coromandelianus</i> (Retz.) Kunth | Grass | Poaceae | 0.67 |
| 157 | <i>Sporobolus diander</i> (Retz.) P.Beauv. | Grass | Poaceae | 2.59 |
| 158 | <i>Striga angustifolia</i> (D. Don) C.J. Saldanha | Herb | Orobanchaceae | 0.72 |
| 159 | <i>Striga gesnerioides</i> (Willd.) Vatke. | Herb | Orobanchaceae | 0.95 |
| 160 | <i>Tephrosia purpurea</i> (Linn.) Pers. | Suffruticose herb | Fabaceae | 6.44 |
| 161 | <i>Tephrosia strigosa</i> (Dalzell) Santapau & Maheshw | Herb | Fabaceae | 1.81 |
| 162 | <i>Tephrosia uniflora</i> Pers. ssp. <i>petrosa</i> (Blatt. & Hall.) J.B. Gillett & Ali | Herb | Papilionaceae | 2.34 |
| 163 | <i>Tetrapogon tenellus</i> (Koen. ex Roxb.) Chiov. | Grass | Poaceae | 4.91 |
| 164 | <i>Tragus roxburghii</i> Panigrahi | Grass | Poaceae | 0.21 |
| 165 | <i>Tribulus terrestris</i> L. | Prostrate herb | Zygophyllaceae | 0.48 |
| 166 | <i>Trichodesma sedgwickianum</i> Banerjee | Herb | Boraginaceae | 1.83 |
| 167 | <i>Tridax procumbense</i> L. | Procumbent herb | Astraceae | 0.84 |
| 168 | <i>Triumfetta rhomboidea</i> Jacq. | Woody Herb | Tiliaceae | 2.02 |
| 169 | <i>Urginea indica</i> (Roxb.) Kunth | Perennial herb | Asparagaceae | 3.90 |
| 170 | <i>Vernonia cinerarea</i> (L.) Less. | Herb | Asteraceae | 1.28 |
| 171 | <i>Vigna mungo</i> (L.) Hepper | Climbing herb | Fabaceae | 0.89 |
| 172 | <i>Vigna trilobata</i> (L.) Verd. | Twiner herb | Papilionaceae | 1.41 |
| 173 | <i>Waltheria indica</i> L. | Subshrub | Sterculiaceae | 0.33 |
| 174 | <i>Zornea gibbosa</i> 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 | <i>O. thomaeum</i> | <i>O. thomaeum</i> | <i>E. granulata</i> | <i>A. viridis</i> |
| 2 | E | 230-300 | <i>T. purpurea</i> | <i>A. adscensionis</i> | <i>P. erioptera</i> | <i>P. erioptera</i> |
| 3 | E | 300-400 | <i>T. purpurea</i> | <i>A. adscensionis</i> | <i>T. terrestris</i> | <i>C. pumila</i> |
| 4 | E | 400-500 | <i>A. adscensionis</i> | <i>A. adscensionis</i> | <i>T. strigosa</i> | <i>T. strigosa</i> |
| 5 | E | 500-600 | <i>A. adscensionis</i> | <i>A. mutica</i> | <i>B. erecta</i> | <i>A. echioides</i> |
| 6 | E | 600-700 | <i>O. thomaeum</i> | <i>B. pusilla</i> | <i>P. lapacea</i> | <i>T. strigosa</i> |
| 7 | E | 700-800 | <i>A. mutica</i> | <i>A. mutica</i> | <i>T. uniflora</i> | <i>A. aspera</i> |
| 8 | E | 800-900 | <i>A. mutica</i> | <i>A. mutica</i> | <i>B. maderaspatensis</i> | <i>S. africanus</i> |
| 9 | N | <230 | <i>D. verticillata</i> | <i>P. paniculata</i> | <i>A. aspera</i> | <i>C. halicacabum</i> |
| 10 | N | 230-300 | <i>A. adscensionis</i> | <i>A. adscensionis</i> | <i>V. trilobata</i> | <i>C. halicacabum</i> |
| 11 | N | 300-400 | <i>A. adscensionis</i> | <i>A. adscensionis</i> | <i>C. pumila</i> | <i>P. erioptera</i> |
| 12 | N | 400-500 | <i>E. bifaria</i> | <i>A. adscensionis</i> | <i>Corchorus aestuans</i> | <i>J. simplex</i> |
| 13 | N | 500-600 | <i>E. bifaria</i> | <i>A. adscensionis</i> | <i>S. hewrensis</i> | <i>T. sedgwickianum</i> |
| 14 | N | 600-700 | <i>U. indica</i> | <i>Z. gibbosa</i> | <i>U. indica</i> | <i>T. uniflora</i> |
| 15 | N | 700-800 | <i>H. contortus</i> | <i>A. mutica</i> | <i>T. strigosa</i> | <i>M. uniflorum</i> |
| 16 | N | 800-900 | <i>A. mutica</i> | <i>A. mutica</i> | <i>B. erecta</i> | <i>D. patulus</i> |
| 17 | NE | <230 | <i>O. thomaeum</i> | <i>O. thomaeum</i> | <i>S. cordifolia</i> | <i>A. aspera</i> |
| 18 | NE | 230-300 | <i>L. trinervis</i> | <i>L. trinervis</i> | <i>A. aspera</i> | <i>P. erioptera</i> |
| 19 | NE | 300-400 | <i>L. trinervis</i> | <i>L. trinervis</i> | <i>I. eriocarpa</i> | <i>E. indica</i> |
| 20 | NE | 400-500 | <i>A. mutica</i> | <i>A. mutica</i> | <i>C. maderaspatanus</i> | <i>T. strigosa</i> |
| 21 | NE | 500-600 | <i>A. mutica</i> | <i>A. mutica</i> | <i>A. aspera</i> | <i>C. halicacabum</i> |
| 22 | NE | 600-700 | <i>A. mutica</i> | <i>A. mutica</i> | <i>H. marifolium</i> | <i>Euphorbia indica</i> |
| 23 | NE | 700-800 | <i>A. mutica</i> | <i>A. mutica</i> | <i>L. bipinnata</i> | <i>P. amarus</i> |
| 24 | NE | 800-900 | <i>A. mutica</i> | <i>A. mutica</i> | <i>P. amarus</i> | <i>C. mysorensis</i> |
| 25 | NW | <230 | <i>O. thomaeum</i> | <i>O. thomaeum</i> | <i>C. mysorensis</i> | <i>C. pumila</i> |
| 26 | NW | 230-300 | <i>T. tenellus</i> | <i>A. adscensionis</i> | <i>C. halicacabum</i> | <i>C. maderaspatanus</i> |
| 27 | NW | 300-400 | <i>A. adscensionis</i> | <i>L. trinervis</i> | <i>D. pennata</i> | <i>H. marifolium</i> |
| 28 | NW | 400-500 | <i>C. ciliaris</i> | <i>D. pennata</i> | <i>J. simplex</i> | <i>T. strigosa</i> |
| 29 | NW | 500-600 | <i>A. adscensionis</i> | <i>D. pennata</i> | <i>B. diffusa</i> | <i>C. pumila</i> |
| 30 | NW | 600-700 | <i>H. contortus</i> | <i>B. pusilla</i> | <i>P. erioptera</i> | <i>A. rugosus</i> |
| 31 | NW | 700-800 | <i>H. contortus</i> | <i>D. foveolatum</i> | <i>L. aspera</i> | <i>D. triflorum</i> |
| 32 | NW | 800-900 | <i>H. contortus</i> | <i>A. mutica</i> | <i>C. aestuans</i> | <i>P. amarus</i> |
| 33 | S | <230 | <i>P. turgidum</i> | <i>P. turgidum</i> | <i>A. hispidum</i> | <i>T. purpurea</i> |
| 34 | S | 230-300 | <i>A. adscensionis</i> | <i>A. adscensionis</i> | <i>E. tremula</i> | <i>H. controtus</i> |
| 35 | S | 300-400 | <i>A. adscensionis</i> | <i>A. adscensionis</i> | <i>C. pumila</i> | <i>P. erioptera</i> |
| 36 | S | 400-500 | <i>A. adscensionis</i> | <i>A. adscensionis</i> | <i>C. erecta</i> | <i>H. marifolium</i> |
| 37 | S | 500-600 | <i>A. adscensionis</i> | <i>D. annulatum</i> | <i>I. eriocarpa</i> | <i>B. pusilla</i> |
| 38 | S | 600-700 | <i>A. adscensionis</i> | <i>B. ramosa</i> | <i>B. pilosa</i> | <i>H. micranthus</i> |
| 39 | S | 700-800 | <i>C. martinii</i> | <i>A. mutica</i> | <i>C. viscosa</i> | <i>C. halicacabum</i> |
| 40 | S | 800-900 | <i>A. mutica</i> | <i>A. mutica</i> | <i>C. tridens</i> | <i>Sida cordata</i> |
| 41 | SE | <230 | <i>O. thomaeum</i> | <i>O. thomaeum</i> | <i>D. verticillata</i> | <i>I. linnaei</i> |
| 42 | SE | 230-300 | <i>A. adscensionis</i> | <i>A. adscensionis</i> | <i>C. boissieri</i> | <i>P. paniculata</i> |
| 43 | SE | 300-400 | <i>A. adscensionis</i> | <i>A. adscensionis</i> | <i>C. maderaspatanus</i> | <i>T. sedgwickianum</i> |
| 44 | SE | 400-500 | <i>A. adscensionis</i> | <i>A. adscensionis</i> | <i>V. trilobata</i> | <i>T. purpurea</i> |
| 45 | SE | 500-600 | <i>A. adscensionis</i> | <i>A. adscensionis</i> | <i>P. erioptera</i> | <i>J. simplex</i> |
| 46 | SE | 600-700 | <i>D. scindicum</i> | <i>O. thomaeum</i> | <i>J. simplex</i> | <i>J. simplex</i> |
| 47 | SE | 700-800 | <i>A. mutica</i> | <i>A. mutica</i> | <i>V. cinerarea</i> | <i>V. cinerarea</i> |
| 48 | SE | 800-900 | <i>A. mutica</i> | <i>A. mutica</i> | <i>S. hewrensis</i> | <i>P. erioptera</i> |

| | | | | | | |
|----|----|---------|-------------------------------|--------------------------|---------------------------|---------------------------|
| 49 | SW | <230 | <i>C. arenarius</i> | <i>C. arenarius</i> | <i>C. tridens</i> | <i>B. diffusa</i> |
| 50 | SW | 230-300 | <i>A. adscensionis</i> | <i>A. adscensionis</i> | <i>E. hirta</i> | <i>D. bicornis</i> |
| 51 | SW | 300-400 | <i>A. mutica</i> | <i>A. mutica</i> | <i>R. minima</i> | <i>C. pumila</i> |
| 52 | SW | 400-500 | <i>A. mutica</i> | <i>A. mutica</i> | <i>J. simplex</i> | <i>M. uniflorum</i> |
| 53 | SW | 500-600 | <i>A. mutica</i> | <i>A. adscensionis</i> | <i>C. decumbens</i> | <i>R. minima</i> |
| 54 | SW | 600-700 | <i>A. mutica</i> | <i>A. mutica</i> | <i>S. angustifolia</i> | <i>B. diffusa</i> |
| 55 | SW | 700-800 | <i>A. mutica</i> | <i>A. mutica</i> | <i>B. diffusa</i> | <i>T. strigosa</i> |
| 56 | SW | 800-900 | <i>A. mutica</i> | <i>A. mutica</i> | <i>I. dichroa</i> | <i>B. maderaspatensis</i> |
| 57 | W | <230 | <i>D. verticillata</i> | <i>C. benghalensis</i> | <i>R. minima</i> | <i>E. granulata</i> |
| 58 | W | 230-300 | <i>A. adscensionis</i> | <i>O. thomaeum</i> | <i>D. aegyptium</i> | <i>M. jacquemontii</i> |
| 59 | W | 300-400 | <i>L. trinervis</i> | <i>C. ciliaris</i> | <i>I. nill</i> | <i>E. persicus</i> |
| 60 | W | 400-500 | <i>A. adscensionis</i> | <i>A. adscensionis</i> | <i>T. uniflora</i> | <i>T. terrestris</i> |
| 61 | W | 500-600 | <i>A. adscensionis</i> | <i>A. radiata</i> | <i>T. rhomboidea</i> | <i>P. paniculata</i> |
| 62 | W | 600-700 | <i>A. adscensionis</i> | <i>A. adscensionis</i> | <i>C. pumila</i> | <i>R. minima</i> |
| 63 | W | 700-800 | <i>B. pusilla</i> | <i>B. pusilla</i> | <i>B. maderaspatensis</i> | <i>E. hirta</i> |
| 64 | W | 800-900 | <i>A. mutica</i> | <i>A. mutica</i> | <i>P. erioptera</i> | <i>C. aestuans</i> |

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