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RESEARCH ARTICLE

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# Evaluating the current ecological status and proposing rehabilitation interventions for the low flooded riparian reserve forest in Punjab Pakistan

Asma Mansoor (Mansoor, A.)[1*], Faiza Sharif (Sharif, F.)[1], Sharoon Hanook (Hanook, S.)[2], Laila Shahzad (Shahzad, L.)[1] and Amin-U. Khan (Khan, A.U.)[1]

[1]*Sustainable Development Study center, Government College University, Lahore, Pakistan.* [2]*Department of Statistics, Forman Christian College (A Chartered University), Lahore, Pakistan.*

## Abstract

*Aim of study:* The complex community of riparian reserve forest has become of great concern for researchers to develop more viable management strategies. The paper aimed to evaluate the current structural diversity of vegetation and its association with the physical environment of low-lying forest for proposing the rehabilitation interventions.

*Area of study:* We studied two forests, Chung-Mohlanwal and Dhana-Bheni on both riverbanks along river Ravi in the Jhok riparian reserve forest situated in the southwest of Lahore, Pakistan.

*Material and methods:* A methodological framework was developed based firstly, on direct comparison of diversity (measured by Hill numbers) and structure of existed vegetation layers (trees, shrubs, herbs, and grasses) and environmental factors (canopy structure, anthropogenic activities, microclimate, and soil characteristics) between the two forests and secondly, on environment-vegetation association using Canonical Correspondence Analysis (CCA) ordination method.

*Main results:* Dhana-Bheni forest was more diverse (Shannon Diversity index $^1D < 11$) and intact due to plantation of uneven-aged tree stands of varied stand basal area and stem density. Microclimate under this forest could not support the dominant understory positively unlike the monoculture forest. On the contrary, Chung-Mohlanwal forest was under the influence of uncontrolled grazing activities, fuelwood extraction, and invasive species. Multivariate analysis CCA elucidated that most variance was shown by soil characteristics (38.5 %) for understory vegetation in both forests.

*Research highlights:* Overstory stand structure, species composition, distance to nearby communities, and soil characteristics should be considered for developing forest planting and management strategies.

**Keywords:** Vegetation Structure; Hill Numbers; Grazing; Environment; Management.

**Abbreviation used:** CCA (Canonical Correspondence Analysis); $^1D$ (Shannon Diversity); Ca + Mg (Calcium + Magnesium); Na (Sodium); ECe (Electrical Conductivity); DBH (Diameter at Breast Height); IUCN (International Union for Conservation of Nature); SBA (Stand Basal area); BA (Basal Area); $^0D$ (Richness); $^2D$ (Simpson Index); IVI (Importance Value Index); LU (Livestock Unit); GPS (Global Positioning System); OC (Organic Carbon); OM (Organic matter); SAR (Sodium Adsorption Ratio); N (Nitrogen); P (Phosphorous); K (Potassium); DCA (Detrended Correspondence Analysis); S (Shrub); H (Herb); G (Grass).

**Authors' contributions:** : AM collected the data, analyzed, interpreted, and contributed in writing the manuscript, FS conceived and designed the research, SH applied statistical analysis, LS helped in writing the introduction and drafting. AUK reviewed the manuscript. All authors read and approved the final manuscript.

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**Supplementary material:** Tables S1, S2, and Figure S1 accompany the paper on FS website.

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**Correspondence** should be addressed to Asma Mansoor: asmamansoor02@gmail.com

# Introduction

Riparian ecosystem is a unique eco-tone and the most valuable ecological system which sustains the hydrological cycle and tends to harbor more biodiversity than terrestrial landscapes (Baran *et al.*, 2020; Liu *et al.*, 2017). Riparian forests maintain the ecosystem functions including nutrients level, reduction of soil erosion and water pollution, recharging of water table, timber production, increased filtration rate and thermic regulation of water body, provide habitat and food to wildlife as well as source of recreational and aesthetic beauty for community (Roberts *et al.*, 2017). These functions make the riparian forests of utmost importance for both terrestrial and aquatic biodiversity. The species distribution on riparian habitat is determined by floodplain morphology, regional climate, hydrology, and geomorphology as well as by plant tolerance and response to disturbance regime (Ren *et al.*, 2017; Leishangthem & Singh, 2018).

Currently, urban riparian forests face pressing challenges by various human activities and climate change with severe impacts on plant diversity and the environment (Kroll *et al.*, 2020; Kleindl *et al.*, 2015). Considering the exceptional ecological relevance, special legal protection is assigned to the disturbed water corridors to mitigate the high flooding and sedimentation in many parts of the world. The main rationale for protecting riparian reserves is to enhance the habitat quality and percentage of vegetation cover which are the strongest predictors of wildlife diversity mainly for bird species richness (Vesipa *et al.*, 2017). Thus, monitoring has become a necessary tool to assess the impacts of anthropogenic activities on the ecological functioning and the effectiveness of management strategies. Cover of shrub, herb, and grass, called ground vegetation, on riparian heterogeneous habitat, is used for long-term studies as bio-indicator of environmental variations and overstory floristic dynamics (Gonzalez *et al.*, 2017). It is relatively more convenient to assess understory responses to environmental heterogeneity like macroclimate, microclimate, and physiography conditions which are difficult to measure directly (Magdaleno & Martinez, 2014). Moreover, tree diversity along with structure information (species composition, canopy closure, tree height, and diameter) is fundamental to create microclimatic conditions (Fatehi *et al.*, 2015). Stands thinning strategies are helpful to increase the forest regeneration rates (Pretzsch & Schutze, 2018). Well-defined species-environment interactions are indispensable to recognize vegetation patterns and considered an important approach in management practices of the forest landscapes (Imai *et al.*, 2014).

A review of literature shows that the status of riparian forests is not well analyzed, and is most likely, one of the least-understood ecological features of rivers. All continents were studied in terms of a community of riparian vegetation except Asia, where mostly riparian vegetation is studied with a relationship to groundwater (Dufour *et al.*, 2018). Likewise, Pakistan a developing country does not have a system for regularly and consistently assessing, monitoring, and sharing data on forest cover. Although, Pakistan's total forests area is estimated at 4.47 million ha or 5.1 % of the total geographical area of the country with the prevailing deforestation in natural forests at the rate of 0.75 % per year (World Bank, 2018).

Riparian forests are among the endangered ecosystems. They cover 4.8 % of the total forest area in Pakistan, and only 0.71 % of it exists in the province of Punjab. Almost 645 thousand ha of total forest area is under legally reserved forest in Pakistan (Mitchell *et al.*, 2018). According to the latest forest assessment report of South Asian countries, unsustainable management and exploitation of available forest resources are decreasing the economy and are impediment in tackling climate change (World Bank, 2018). Another major issue is the continuous silence between scientists and policy-makers, which has resulted in non-scientific policies and disagreements in both parties. For that reason, identifying the best method to fulfill the knowledge gaps between scientists and legal authority is an essential task in designing effective forest management (de Sosa *et al.*, 2018).

Therefore, there is a need to highlight timely the ecological status by adopting a more multidimensional integrated approach at various vegetation levels for more effective management. It is an urgency to understand the riparian reserve communities, anthropogenic pressure, and management conflicts over resources in the developing countries. By keeping above points in consideration, this study is designed 1) to evaluate the structural diversity of vegetation quantitatively of two sub-forests 2) to identify the association of overstory structure, microclimate, soil, and anthropogenic factors with the understory vegetation 3) to propose the rehabilitation interventions for low flooded riparian reserve forest.

# Materials and Methods

## *Study Site*

Jhok reserve forest is a largest riparian forest and situated downstream River Ravi about 11 to 40 kilometers southwest of Lahore, which lie between 31°- 15' to 31°- 30' North and 74°- 4' to 75°-15' East in Pakistan. This site is mostly flat and its terrain elevation above sea level is 201 m. The total area of forest is 1243 ha and is parted into two distinguished forests erected on both riverbanks; Chung-Mohlanwal (745 ha) and Dhana-Bheni (498 ha) forests surrounded by agriculture lands and villages (Fig 1). Both riparian forests Chung-Mohlanwal and Dhana-Bheni are managed by different entities: provincial Forest department and private partnership, respectively. The Jhok Reserve forest is flooded annually during monsoon season by river Ravi and some patches are undulating. It is partially interspersed with small drains and floodwater channels. Inundations, the main source of irrigation to these forests have declined considerably. During the past, the water supply was quite sufficiently available for afforestation. Historically, the last 30 years data showed that average flood peak discharge is 2082.44 $m^{3/}s$. River Ravi with its meandering habitats has been causing con-

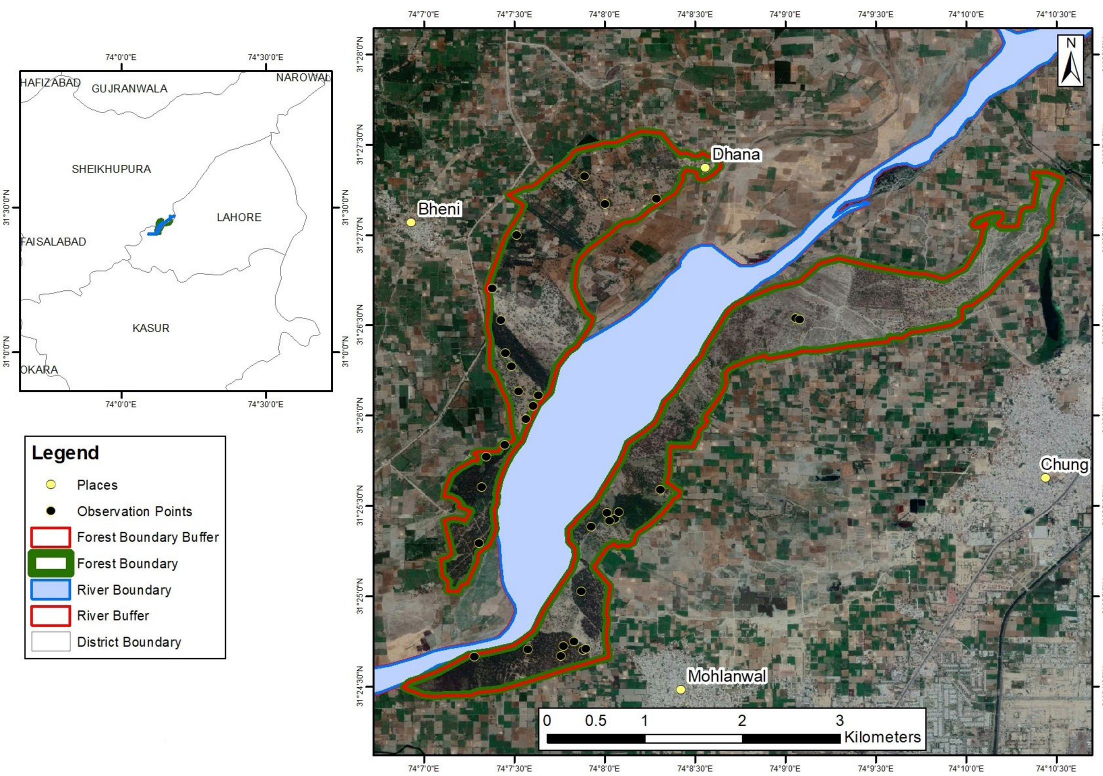


**Figure 1.** Location map of Jhok Reserve Forest.

siderable damage. Every year the area is damaged due to water erosion as 261 ha of the total area was washed away by the river. Mean peak rainfall (180 mm) can be seen in August and lower (27 mm) in February during the last 30 years. Mean relative humidity is high *i.e.* 84 % in December. The average minimum and maximum monthly temperatures are in January (7.31 ± 0.19 oC) and June (39.35 ± 0.17 oC) respectively (Fig. S1 [suppl.]). The population size of main adjacent villages; Chung, Mohlanwal, Dhana, and Bheni is 65000, 25000, 6000, and 10000 inhabitants, respectively and people used to extract the fuel wool. Hundreds of livestock animals graze this forest for fodder purposes (Mansoor, 2015; GOP, 2013).

## *Study Design*

A methodology framework based on two approaches was used to evaluate the ecological status and proposing rehabilitation interventions for the Jhok Reserve forest. The first approach was the direct comparison of both the forests made by measuring selective variables. Field surveys gave the inventory and species count that help in the identification of vegetation layers of both Chung-Mohlanwal and Dhana Bheni forests. The second approach was; to apply CCA for an environment-vegetation association for identification of disturbance factors and positive attributes. Some rehabilitation interventions are given to eradicate and wipe out the unfavorable factors (Fig 2).

## *Vegetation Sampling*

This study employed a random sampling technique based on monoculture and mixed stands of overstory found in both forests. To study overstory structure, diversity, and composition, 17 samples of frame quadrants having a dimension of 40 m x 40 m (0.16 ha) were taken from each forest (total 34 samples). Each sample quadrat was subjected to total count of each tree species, height (m), and DBH (cm) (diameter at breast height at 1.34 m). Within each sample plots, 1 subplot of 10 m x 10 m (0.01 ha) size was used for the data collection of shrubs, herbs, and grasses (Sutherland, 1996). Likewise, a total of 34 sub plotting for understory was laid out in both forests. In each subplot, total numbers of each understory species, their abundance and visual estimation of percent cover were observed as well as recorded. Most species were identified on the spot but some samples of unidentified species were collected and preserved on herbarium sheets. The name and origin of plants were identified by consulting the Lahore District Flora (Kashyap, 1936; Nasir, 1981). After knowing the habitat type of each plant species, their International Union for Conservation of Nature (IUCN) status was also identified (IUCN, 2018). Secondary data regarding Jhok reserve

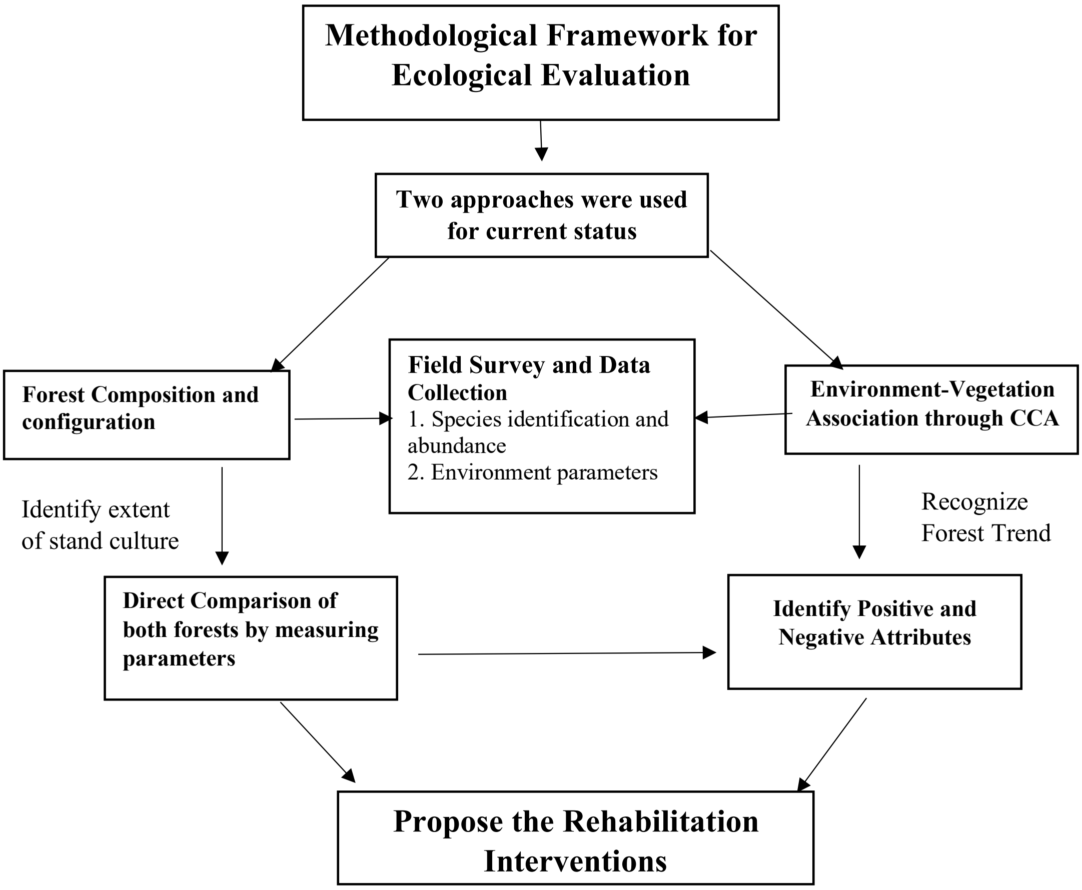


**Figure 2.** A methodological framework for study of Jhok Reserve forest.

forest, livestock, meteorological information, and population size of villagers were obtained from their relevant government departments.

### *Floristic diversity, Structure, and Importance value*

To calculate the vegetation diversity, Hill numbers of order *q* or the effective numbers of species or true diversities were used as unified framework based on abundance data of species (Chao *et al.*, 2012). Hill numbers are statistically rigorous alternative to other traditional diversity indices and are increasingly used to describe the taxonomic, phylogenetic, or functional diversity of a community. Empirical estimates of Hill numbers (${}^{q}D$) includes species richness ($q$ = 0) is the number of species in all quadrats of each forest, Shannon diversity ($q$ =1, the exponential of Shannon's entropy index) is the species weightage in proportion to their frequency, and the Simpson diversity ($q$ = 2, multicaptive inverse of Simpson's concentration index) discounts the all but only very abundant species, and can be interpreted as the effective number of dominant species in the studied forests.  Stand Basal area (SBA) is an efficient way to link the stand area of different forests (Wong & Blackett, 1994). Stand density was calculated to know stand spacing in Riparian Jhok Reserve Forest (Mohammadi *et al.*, 2010) (Table 1). Diameter Classes (cm) was developed with the following ranges as 1 (1-10), 2 (10-20), 3(20- 30), 4(30-40), 5(40-50), 6(60-70), 7(70-80), 8(80-90). Importance Value Index of species (IVI) was calculated to identify the most dominant species in both forests (Ellenberg & Mueller-Dombois, 1974).

### *Anthropogenic and Micro-climate conditions*

To assess the anthropogenic activities, number of grazing animals was counted in 10 sites (5 Mohlanwal, 5 Dhana) of 25 ha plots to measure grazing intensity as described by Cowling *et al.*, (1997). Grazing intensity gives how much area is required for one animal unit. Livestock density gives one-hectare land can support how many animal units (ha/LU). Longitude and latitude points were noted using Global Positioning System (GPS) detector to measure the distance between quadrat and the nearest village in aiming to determine the impact of human disturbance. Moreover, the boundary around forests was marked using ArcGIS to propose the buffer zone. Micro-climate conditions were assessed in each quadrat by taking three readings under different crown cover of the overstory. Ambient air temperature, light

**Table 1.** Mathematical equations (Plant species diversity indexes, tree stand characteristics and grazing indexes) used in the study

| Parameter | Mathematical equation | Description |
|---|---|---|
| Hill numbers $^qD$ | | |
| Richness ($^0D$) = | $\left(\sum_{i=1}^{s} p_i^0\right)^{1/1-0}$ | *S* is the number of species in the assemblage, and the *pi* denotes the relative abundance of the *i*th species = 1, 2. . . S. |
| Shannon ($^1D$) = Diversity | $\left(\sum_{i=1}^{s} p_i \log p_i\right)$ | |
| Simpson ($^2D$) = Diversity | $\left(\sum_{i=1}^{s} p_i^2\right)^{1/1-2}$ | |
| Impostance = Value Index (IVI) | $Rf + \quad RD + \quad RA$ | RF= Relative frequency, RD= Relative Density, RA= Relative Abundance. The IVI value near to 300 is considered as the most dominant species. |
| Stand Basal = Area (SBA) | $\frac{\sum_{i=1}^{n} \mathrm{BAi}}{\mathrm{A}}$ | BAi is the basal area of the ith tree and A is the area of the stand within the quadrat |
| Density = | $\frac{\mathrm{N}}{\mathrm{A}}$ | N is number of trees A is area in hectare |
| Grazing = Intensity | $\frac{\mathrm{A}}{\mathrm{LU}}$ | LU = Livestock Unit, it varies and depends on the size of the animal unit. Its Grazing intensity is highest near 0 value. |
| Livestock = Density | $\frac{\mathrm{LU}}{\mathrm{A}}$ | |

intensity, and humidity were recorded by using IR Thermometer (TES-1376), Lux meter (TEMNA 72-6693 Taiwan), and humidity meter (TSI-TH-CALC), respectively. A total of 34 soil samples were gathered using auger from the surface layer (0 - 10 cm) in each quadrat for laboratory testing. Every sample was bagged and labeled and brought to the laboratory. All collected samples were dried and sieved using a 2 mm sieve. Soil saturated extracts was prepared and analyzed the physical and chemical properties such as soil texture, electrical conductivity (EC), pH, Organic Matter (OM), Organic Carbon (OC), Calcium plus Magnesium (Ca + Mg), Sodium (Na), Nitrogen (N), Phosphorous (P), Potassium (K), Sodium Absorption Ratio (SAR) as described by Ryan *et al.*, (2001).

### *Data Analysis*

The Hill numbers was calculated to assess the structural diversity of vegetation through ‘iNext Online’ (Chao *et al.*, 2016). An independent sample t-test was applied to find out the potential difference of ecological parameters between both forests using software SPSS (SPSS, 16). The Multivariate CCA ordination was applied to determine the relationship between vegetation and environment because the eigenvalue of first axis of detrended correspondence analysis (DCA) was greater than 3 for vegetation gradient. The significance of vegetation and environment correlation was detected by the Monte Carlo test (499 permutations). The ordination analyses were run using an R package ‘Vegan’ and ‘BiodiversityR’ in R version 3.2.1 (R Studio Team, 2015).

## Results

### *Plant Species Inventory*

The field inventory yielded 13,408 individuals of 73 plant species in 34 sampled plots, belonging to 27 families and 73 genera. Out of 73 plant species 14 trees, 7 shrubs, 33 herbs, and 19 grasses were found. Among these, 9 plants were recognized as invasive species. According to IUCN status of all plants, 17 species were least concerned, 2 were data deficient and the remaining have no assigned status.

### *First Approach: Comparative Analysis between study sites*

#### *Structural Diversity Analysis*

In 34 sampled plots, a total of 1695 individuals of 14 trees species belonging to 8 families were found over a survey area of 5.6 ha. The *q* order ($q$ = 0, $q$ = 1, $q$ = 2) of Hill numbers ($^qD$) demonstrated the higher Richness ($^0D$ = 14) and Shannon diversity ($^1D$ = 6.77) for tree species in Dhana-Bheni forest. The value of inverse Simpson ($^2D$ = 4.47) ensured the existence of very abundant species and the shape of diversity curve conveyed the result of unevenness of the tree species in this forest region. The diversity value of vegetation species drops as the q order grows from 0 to n. The results declared that Chung-Mohlanwal had lesser diversity of more evenly distributed tree species, shown by the curve shape of diversity profile (Fig 3a).

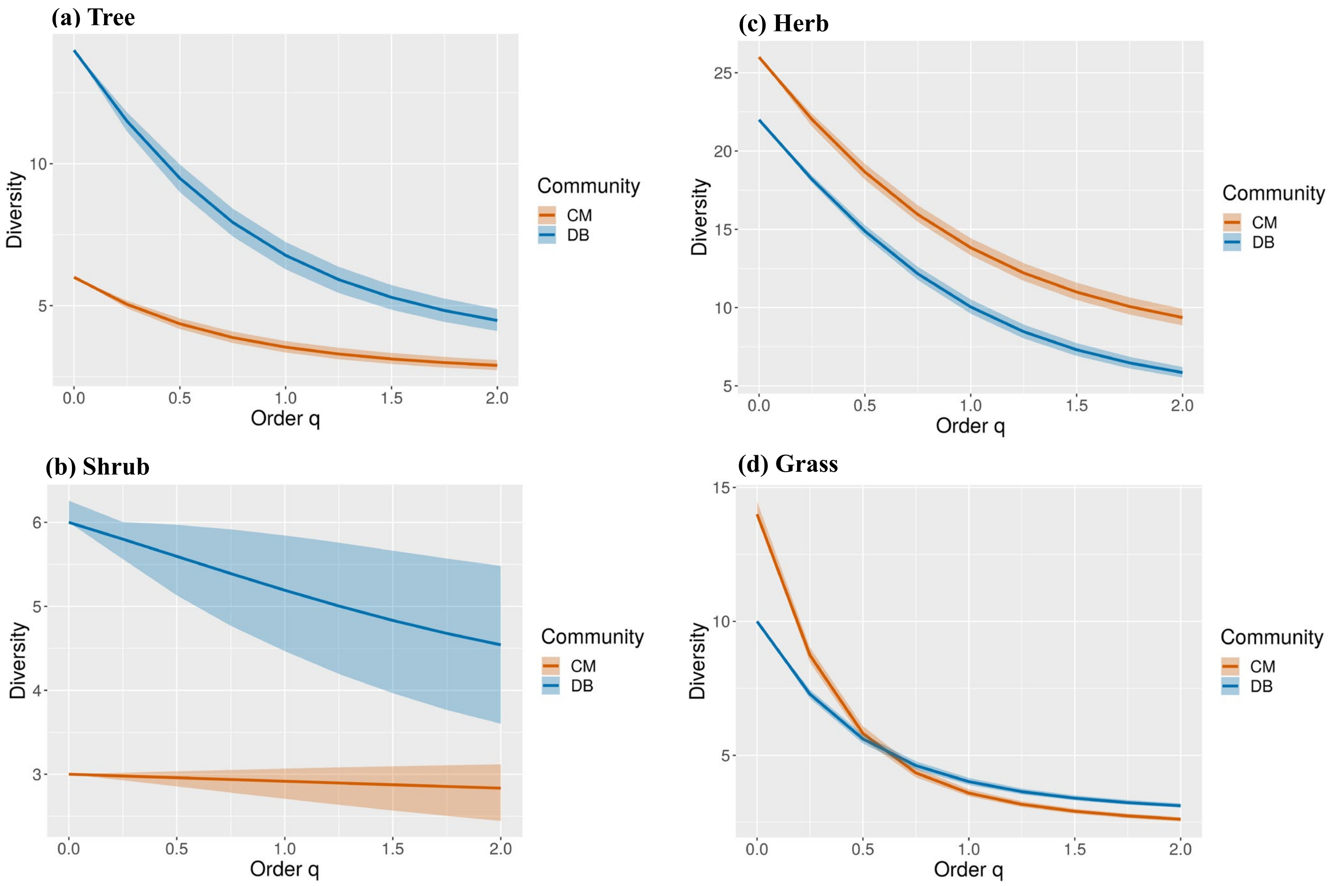


**Figure 3.** Hill Numbers comparison of all vegetation layers between forests.

Out of 73 species, total 59 understory species known to 22 families were recorded in the study area of 0.31 ha. Both forests; Chung-Mohlanwal and Dhana-Bheni showed highest values of Hill numbers (*q* from 0 to 2) for the herbaceous riparian species among the all understory vegetation layers (Fig 3b). Furthermore, the curve shape showed the unevenness of herb species in both forest communities. But comparatively, Chung-Mohlanwal showed higher diversity ($^0D$ = 26, $^1D$ = 13.8, $^2D$ = 9.36) for herb layer than the Dhana-Bheni forest. The diversity of shrub species in Dhana-Bheni forest showed similar values from $^0D$ to $^2D$ (6, 5.19, & 4.54). In Chung-Mohlanwal, shrub layer was under the influence of mismanagement as depicted by *q* orders (Fig 3c). In terms of perennial grass species, there was subtle differences detected between the both forests in *q* orders ($^1D$ and $^2D$) of Hill Numbers (Fig 3d).

### *Importance Value Index*

In this comprehensive study, most important species *Eucalyptus camaldulensis* showed the highest IVI Value (145.34 %) in contrast, Chung-Mohlanwal planted with this species more distinctly than Dhana-Bheni (120.26 %). Other dominant species were *Dalbergia sissoo* (98.15 %), *Acacia nilotica* (27.64 %) in Chung-Mohlanwal and *Salix tetrasperma* (53.39 %), *D. sissoo* (31.87 %) in Dhana-Bheni (Fig. 4a). The yielding of IVI reported 31 species as the most important out of 59 understory species in both Chung-Mohlanwal and Dhana-Bheni forests (Table S1 [suppl]. & Table S2 [suppl].). Herb species *Oxalis corniculata* (39.74 %) and *Parthenium hysterophorus* (invasive) (37.51 %) showed the highest importance values in Chung-Mohlanwal. In Dhana, highest IVI was shown by *O. corniculata* (63.72 %) and *Sisymbrium irio* (37.40 %). This forest didn't show any threat and signs of invasive herb species (Fig. 4b). The most dominant shrub was *Calotropis Procera* as indicated by IVI (118 %) in Chung-Mohlanwal forest whereas *Abutilon x hybridum* hort. ex Voss had highest IVI (88.76 %) in Dhana-Bheni forest and followed by *Ricinus communis*, *Abutilon bidentatum*, Ipomea. carnea, *Lantana camara* (invasive), and *Withania somnifera* (Fig. 4c). Out of 19 grass species, *Cynodon dactylon* was given top rank by highest value (110 %) among all grasses in the Chung-Mohalnwal forest. *Desmostachya bipinnata* was considerably most dominant (97.17 %) grass in the Dhana-Bhen forest and covered the most ground area with its leafy structure that's why no too much bare ground was seen (Fig .4d).

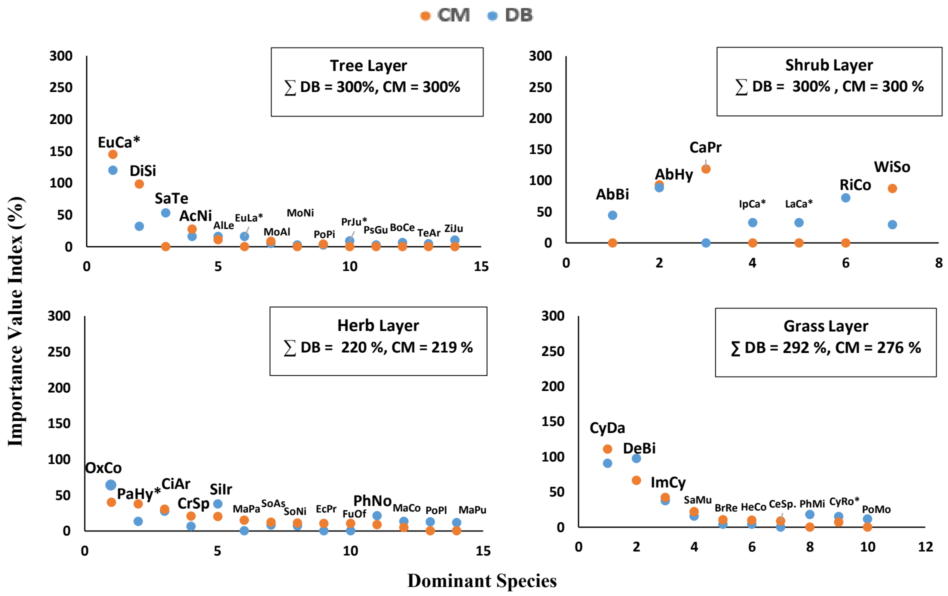


**Figure 4.** Importance value index (IVI) comparison of all vegetation layers between both forests. Only species of high IVI was summed up (∑) and shown on the graph. Most dominant species were represented by large and bold letters. *Invasive species. Full species names and abbreviations are shown in the supplementary file Table S2.

*Vegetation structure, Anthropogenic and Micro-climate variables*

The results of Independent sample t-Test showed the statistical variation in overstory structure parameters, anthropogenic activities, microclimatic, and soil chemical characteristics between both Dhana-Bheni and Chung-Mohlanwal forests (Table 2).

Dhana forest showed statistically higher SBA (mean value of 26 $m^2$) and non-significantly higher stand density (357 trees per ha) with the stems ranged from 262 to 506 trees per ha. Chung-Mohlanwal forest had lower SBA mean of 15.6 $m^2$ and mean tree density (256.8 trees per ha). Positive trend was seen between diameter classes and height but bell-shaped curve was obtained reflecting the decline in number of tree individuals after DBH class III (20-30 cm) (Fig. 5). Dhana-Bheni sustained more multi-layered stems of heights 6.15 to 31.8 m distributed in all diameter classes (I-VIII) of mixed tree stands while Chung-Mohlanwal was showing stems of heights 6 to 20 m with the diameter ≤ 50cm (I-V). Majority of trees being found within the DBH class III (20-30 cm) with the average height (12.05 m) in both forests. Less number of trees having DBH class VI and VII (50-60 and 60-70 cm respectively) were observed.

In relation with anthropogenic activities, grazing intensity and livestock density were significantly higher in Chung-Mohlanwal as compared to Dhana-Bheni forest. Average distance from both forests to nearest villages was less than 2 km. According to mean values, light intensity and temperature were significantly higher ($p < 0.05$) beyond the optimal level in Dhana-Bheni due to its multi-layer canopy of mixed tree species. But these two parameters were moderate under stands of Chung-Mohlanwal, and showed an inverse relationship with relative humidity.

The content of pH, K, and SAR was significantly higher in Chung-Mohlanwal than Dhana forest. Soil of Dhana-Bheni forest had an excess of Ca+ Mg, Na, and water content (Table 2). The soil of both Dhana-Bheni and Chung-Mohlanwal forests was alkaline, but it was found to be slightly saline at some places, particularly under the monoculture stands. The concentration of OM, OC, N and P was low in both forests. The potassium was adequate in the soil of Mohlanwal forest, but it was marginal in Dhana forest.

## *Second Approach: Environment-Vegetation Association using CCA ordination*

Canonical correspondence analysis was applied between the quantitative ecological parameters and the 31 most dominant species of shrub (S), herb (H), grass (G) layers determined by IVI (Fig. 4 b-d). The CCA ordination was used because the length of the gradient (3.9) was greater than 3. The first (0.54) and second (0.43) axes had the largest Eigenvalues, which accounted for 97 % of variation in the Riparian Jhok Reserve Forest. The CCA diagram (Fig. 6) consists of three sets of points including species, sites and environmental variable which display species- environmental and sites-environmental relationships. According to weighted averages, six variables were the best predictors with species composition: EC, saturation, Na, SAR, humidity, and distance.

**Table 2.** Comparison of ecological parameters between the two studied forests. Mean, standard error, and statistical parameters (t-Test) are shown

| **Variable** | **Mean ± Standard Error** | | ***t*** | ***df*** | ***p-value*** |
|---|---|---|---|---|---|
| | **Chung-Mohlanwal** | **Dhana-Bheni** | | | |
| **Vegetation** | | | | | |
| Stand Basal Area ($m^2$) | 15.64 ± 2.24 | 26.0 ± 2.99 | -2.74 | 30 | 0.01 |
| Tree Density ($m^2$/ha) | 286.5 ± 69.83 | 357 ± 19.84 | -0.97 | 30 | 0.33 |
| Anthropogenic | | | | | |
| Grazing Intensity (ha/LU) | 0.51 ± 0.23 | 1.82 ± 0.61 | 2.11 | 30 | 0.05 |
| Livestock density (LU/ha) | 3.94 ± 1.04 | 0.89 ± 0.27 | 2.61 | 30 | 0.02 |
| Average distance to village (km) | 1.69 ± 0.25 | 1.77 ± 0.23 | -0.01 | 30 | 0.92 |
| **Micro-climate** | | | | | |
| Light Intensity (Lux) | 913.33 ± 61.53 | 1050 ± 56.83 | 2.07 | 30 | 0.04 |
| Relative Humidity (%) | 72.35 ± 0.64 | 56.3 ± 3.44 | 5.49 | 30 | 0.00 |
| Temperature (0C) | 27.16 ± 1.64 | 33.03 ± 1.16 | 2.28 | 30 | 0.00 |
| **Soil Characteristics** | | | | | |
| ECe (mS/cm) | 3.91 ± 0.64 | 2.73 ± 0.56 | 136 | 33 | 0.18 |
| pH | 8.34± 0.06 | 8.05 ± 0.07 | 2.86 | 30 | 0.00 |
| OM (%) | 0.87 ± 0.31 | 0.82 ± 0.27 | 1.38 | 30 | 0.17 |
| OC (%) | 0.50 ± 0.01 | 0.47 ± 0.01 | 1.41 | 30 | 0.16 |
| N (%)L | 0.45 ± 0.01 | 0.42 ± 0.01 | 1.46 | 30 | 0.15 |
| P (mg/kg) | 4.49 ± 2.16 | 6.45 ± 0.55 | -0.87 | 30 | 0.38 |
| K (mg/kg) | 384.08 ± 91.35 | 153.94 ± 14.67 | 2.49 | 30 | 0.01 |
| Ca +Mg (meq/l) | 2.01 ± 0.32 | 21.66 ± 5.89 | -3.36 | 30 | 0.00 |
| Na (mg/kg) | 2.71 ± 0.41 | 4.68 ± 0.65H | -2.47 | 30 | 0.01 |
| SAR | 0.13 ± 0.01 | 0.08 ± 0.01 | 2.30 | 30 | 0.02 |
| Saturation (%) | 38.06 ± 0.93 | 42.59 ± 1.04H | -3.08 | 30 | 0.00 |

Significant < 0.05, highly significant < 0.01

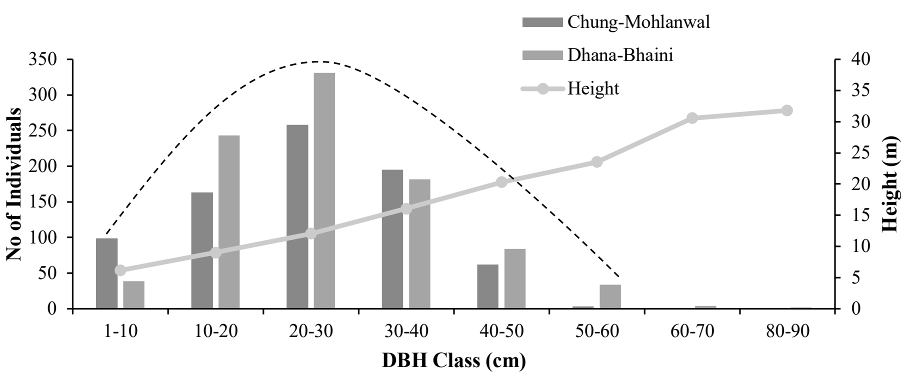


**Figure 5.** Number of trees, average height (m), and DBH class (cm) distribution of Diameter classes between Chung-Mohlanwal and Dhana-Bheni Forests.

The Monte Carlo permutation test was statistically significant ($F = 6$, $p < 0.05$) for the first axis. The species occupying central portion of triplot diagram showed the least influence of ecological parameters. The most closely related associations of species and environmental variables are given below.

The first axis was positively correlated with N, OM, OC, saturation, and EC, which were proved as good chemical indicators for the survival of herb and grass layers. EC showed highest variance (6.05 %) as compared to N, OM, and OC for the dominant grass *C. dactylon* in Chung-Mohlanwal (Fig 6, Table 3). In Dhana-Bheni, EC

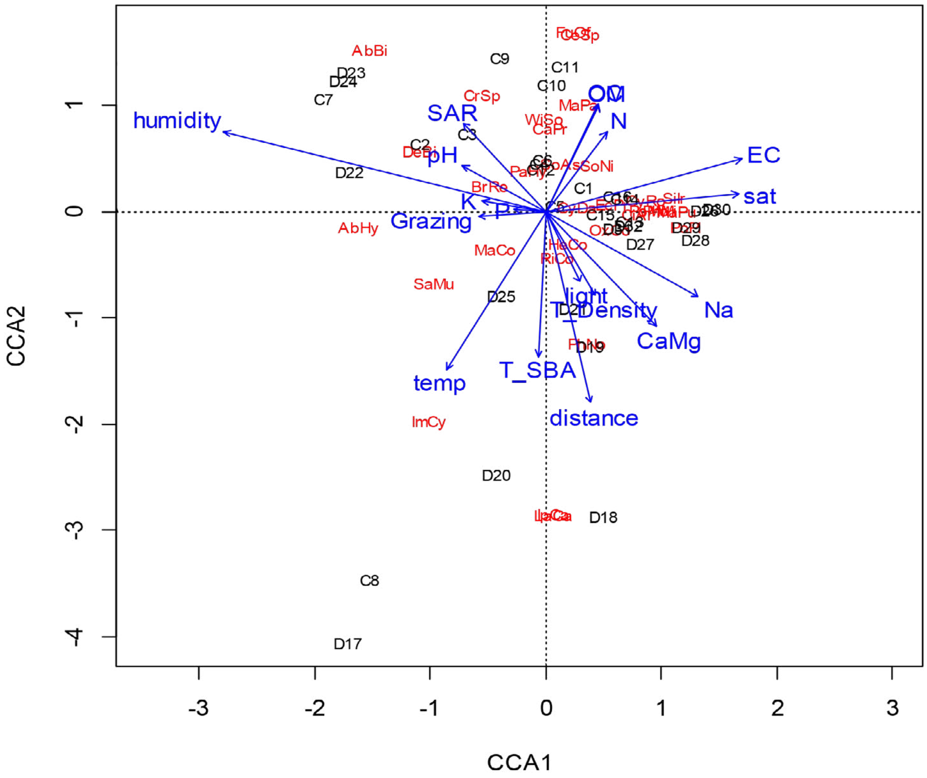


**Figure 6.** CCA attribute plot for understory vegetation abundance constrained by ecological factors (in blue color) in the riparian Jhok reserve forest. Full species names and abbreviations (in red color) are shown in the supplementary file Table S2. Capital letters $C_n$ and $D_n$ denote Chung-Mohlanwal and Dhana-Bheni forests respectively and n is the number of the sampled plot (in black color).

and soil saturation had impact on the dominant herb species and few grasses like C*yperus rotundus*, *Phalaris minor*, *Polypogon monspeliensis*. On the other hand, the first axis was negatively associated with grazing, high SBA, and temperature, which categorized the spreading of only 2 grasses *Imperata cylindrical*, and *Sacchrum munja* in Chung Mohlanwal, and one herb *Malvastrum coromandelianum* in Dhana-Bheni.

The second axis was positively associated with increasing trend of relative humidity, SAR, P, pH, and K. Relative air humidity reflected the highest variance (6.12 %), and was the important determinant of riparian vegetation productivity, and of separation of plant groups. This group of ecological parameters were significantly higher in Chung-Mohlanwal (Table 2). The associated dominant herbs were *P. hysterophorus*, and *Croton sparsiflorus*, grass *D. bipinnata*, and *Brachiaria reptans*, and shrubs *A. bidentatum*, *W. somniferara*, and *C. procera*. The spread of dominant grass *D. bipinnata* was strongly influenced by pH in both the forests. The second axis of CCA plot was negatively correlated with intensity of light, tree density, distance, Ca+Mg, and Na which were significant in structuring the dominant plant communities of Dhana-Bheni. The distance from forests to villages showed 4.36 % variance for Shurbs *I. carnea*, and *L. camara* herb *Phyla nodiflor*. As the distance decreased, plant species were induced towards the ecological vulnerability as human population exploited the forest resources. Some environmental factors such as P, K, light intensity, and tree density were not playing any significant role on scarcity and scattering of species.

# Discussion

The surveyed forests, Chung-Mohlanwal and Dhana-bheni in Jhok Reserve forest are composed of different life forms including trees, shrubs, herbs, and grasses. The customized framework distinguished the ecological status in term of vegetation structure and diversity, microclimate, soil characteristics and anthropogenic factors of both forests. Taking the disintegrating factors into consideration, some rehabilitation interventions are proposed in terms of physical and biological changes. The findings of this study may provide the baseline information to foster management strategies for both natural areas and forest plantations.

**Table 3.** Results of CCA showing the variability and F-ratio at vegetation layers

| Explanatory Variable | Explained Variability % | *F-ratio* | Vegetation Layer |
|---|---|---|---|
| **OM** | 2.95 | 1.09 | Herb |
| OC | 2.74 | 1.01 | Herb |
| N | 3.46 | 1.27 | Herb |
| ECe | 6.05 | 2.23 | Grass, Herb |
| Saturation | 3.02 | 1.11 | Grass, Herb |
| Grazing Intensity | 3.66 | 1.35 | Shrub, Herb |
| SAR | 4.81 | 1.77 | Herb |
| **Tree Density** | 3.04 | 1.12 | Shrub, Herb |
| Average distance to village | 4.36 | 1.61 | Shrub, Herb |
| Light Intensity | 3.49 | 1.29 | Shrub, Herb |
| Ca +Mg | 3.53 | 1.30 | Shrub, Herb |
| **Na** | 1.74 | 0.64 | Shrub, Herb |
| SBA | 3.29 | 1.21 | Herb |
| Relative Humidity | 6.12 | 2.25 | Grass, Shrub |
| Temperature | 3.82 | 1.41 | Grass, Herb |
| P | 1.74 | 0.64 | Grass, Shrub |
| K | 4.38 | 1.62 | Grass, Shrub |
| pH | 4.15 | 1.53 | Grass |

## *Effects of Management Practices on Tree diversity and Structure*

Analysis of stand structure is more crucial to assess the forest management than the tree species composition (Kroll *et al.*, 2020). Low plantation, and felling by management authorities are the reasons explaining the low stem density in both forests, as comparatively less stem spacing was seen in highly diverse Dhana-Bheni forest. CCA revealed that tree stem density of studied site was not playing a significant role in distribution of understory vegetation. The heterogeneous Dhana forest land, under the private ownership followed the sound strategies such as promoting mixed tree stands, and strict prohibition on fuelwood extraction by a rural community. This forest had 67 % young trees (DBH ≤ 30 cm) and the stand basal area (26 $m^2$) revealed the more continuous tree growth rate, and was an indication the steady and self-sustaining population, as compared to the other forest cover, with low richness of tree species. It is also reported by a previous study (Oliveira *et al.*, 2014) that young trees of smaller diameter eventually replace the older trees. Literature shows the same data that SBA is considered as the growth predicator (Tewari, 2007) because it depends on tree size variables (height, and diameter) (Vanhellemont *et al.*, 2018). Chung Mohlanwal administrated by the provincial Forest department, was lacking in strictly-imposed rules. An absence of some tree species (*S. tetrasperma*, *Morus spp*, *Ziziphus jujube*), and an abrupt decline in the number of trees after 30cm DBH, brought attention to the illegal extraction of fuelwood from the forest by the local villagers.

## *Overstory and micro-climatic effects on vegetation pattern*

Forest morphology and arrangement of different tree species have positive influence on the regeneration of understory species, micro-climate conditions and soil health, by increasing organic matter and soil fertility, and decreasing the vulnerability towards disturbances. Microclimate is relevant in modifying and maintaining understory species composition, ecological interactions, and riparian community structure (Rembold *et al.* 2017). In current study, CCA ordination reflected that overstory structural elements of both forests, such as mean density and SBA, exerted a strong control on riparian microclimatic variables. SBA and stand density showed positive correlation with temperature and light intensity, respectively (Fig. 6). Surprisingly, canopies of mixed forest Dhana-Bheni were unable to buffer the climate extremes and to promote optimum microclimates, which may function as microrefugia for understory species under changing climate. Forest' patches with high temperature triggered the q order diversity of shrubs, as indicated by Dhana-Bheni forest. Results were antagonistic to previous studies, where understory vegetation gained momentum beneath the mixed overstory culture through modifications of resource availability (light, water and soil nutrients), disease susceptibility, and litter layer (Halpern & Lutz, 2013). The buffering effect of Chung-Mohlanwal forest trees made the most microclimate favorable for herb species, mainly. Only relative air humidity was observed as a major limiting factor for diversity of the dominant herb and grass. Riparian forests have the humid microclimates; that is one of the reasons to conserve these zones. Other studies have shown that distribution of herbs were reinforced over the sites of high air humidity in Hubei, China (Ali *et al.*, 2019; Imai *et al.*, 2014).

### *Influence of soil and anthropogenic factors*

CCA grouped the edaphic factors which contributed to the variations in riparian vegetation. EC was one of the effective variables in the formation of herb and grass layers. Soil characteristics, particularly EC, Na, Ca+Mg, and saturation, were determined as important indicators for the biological process taking place in the grass and herb species of both forests. Soil parameters; pH, K, P, SAR, may not have favorable concentration to accelerate the growth of dominant understory species. It was reported that *Eucalyptus* tree species demand of high moisture content, and greater movement of water from deeper layers may cause salts to accumulate on the surface layer (Luke *et al.*, 2018). It has been proposed that a fluctuation in soil pH is because of the release of allelochemicals from *Eucalyptus* (Zhang *et al.*, 2014; Lamoureux *et al.*, 2018). The soil's moisture and salinity were the most important factors that restricted the survival of many plant species in East Ladakh, India (Zimbres *et al.*, 2017). Besides disturbing soil parameters, these factors support the growth of invasive species (*P. hysterophorus*) (Wang *et al.*, 2014). The observed negative association of grazing intensity with vegetation species and grouped edaphic factors of Axis 1 was also the predictor of change in unevenness and diversity. Excessive trampling by goats, cows, and buffalo, which caused topsoil scratching, was found as another reason for soil organic matter deterioration and less diverse vegetation during the assessment. The consistent grazing in Chung Mohlanwal throughout the year may also stimulate the loss of P, OC, and N from the studied area. Similar result was corroborated in another research that the continuous grazing from forests led to the loss of the adequate amount of these nutrients in the central Argentina (Cingolani *et al.*, 2014). Dhana-Bheni forest's slight anthropogenic pressure is due to low population size in Dhana and Bheni villages. Besides this, the Jhok reserve forest area is damaged due to water erosion by the river every year (GOP, 2013). All these nutrients are beneficial for plant growth as they regulate photosynthesis, protein synthesis, and transportation processes. Previous study of beech forest in Northern Iran demonstrated that richness of herb layer was very sensitive to changes in understory vegetation and site characteristic, it behaved as polymeter that combined the different environmental factors together, like macro and micro-climate, physiography, soil condition, and light intensity (Adel *et al.*, 2013). The negative correlation of distance with the vegetation of Axis 2 was the indication of fuelwood extraction by people living in nearest villages which ultimately disturbed the scattering of mostly shrub, and tree species in Chung Mohlanwal.

### *Management interventions for enhancing the ecological status*

It is proposed that only one legal authority should be responsible for all reserve forests, with the same rules and regulations, to improve and manage riparian forests sustainably. Plantation of plant species should be done after consultation with the meteorological department according to flood frequency. Regulation of good governance is crucial to maintain the vegetation status of reserve forest, and to provide alternative resources to villagers. The idea is supported by another study by Spies *et al.*, 2019.

The effectiveness of buffer zone must be ensured to avoid externalities in reserve forest. Around the forest boundary, buffer zone is proposed as a sustainable tool. It will regulate water quality by creating artificial and linear landform along River Ravi (Fig. 1). These buffers will provide corridors for wildlife and plant species to travel and migrate towards another favorable habitat (Mc Conigley *et al.*, 2017). Generally, the riverbank that is covered with vegetation will erode at a lower rate, as compared to a bare bank. Riparian vegetation will protect river banks from decay, and will restore the nutrient levels and moisture content, and will act as windbreakers and shelterbelts against windstorms. Tree species, like *Populus* spp., *A. nilotica*, *Ficus religiosa* and *D. sisso*, should be planted to hinder the bad impacts.

Rotational grazing, to minimize soil and understory degradation, should be adhered in practice. The practice of rotational grazing at regular intervals will improve the shrub and aboveground grasses vegetation (Vecchio *et al.*, 2018). Simple rotational grazing usually improves fodder yields and the quality of forest land. This will minimize the cost of fencing of the area being affected by continuous grazing.

Biological control is the deliberate management of natural competitors to avoid the harmful effect of weeds. Currently, the removal of invasive species is gaining momentum as an eco-friendly substitute for conventional methods of weed control. This method is being used in Australia, India, Pakistan and the United States (Bruno *et al.*, 2014). Different fungal species are used to control invasive species. For example, *Puccinia xanthii* has the ability to attack several parts of the plant and cease germination and transpiration. *L. camara* can be controlled by mechanical clearing and can be extracted in case of the small area under invasion. But over large affected areas, only prescribed or controlled fire can be used (Cingolani *et al.*, 2014).

## Conclusion

Consequently, the habitat quality and functioning of considered riparian forests are more ecologically vulnerable due to heterogeneity of management practices. The purpose of reserve forests remain unfulfilled due to the neglecting interaction among ecological parameters and allowing the nearest settlement of human residence. The influence of mixed culture of tree species on the understory diversity is ambiguous in this study. Microclimate induced by monoculture overstory structure has more potential to amplify the dominant understory vegetation to a larger extent in Chung-Mohlanwal forest. The understory diversity is more responsive to soil characteristics (38.5 %) and microclimate (13.43 %). Herb layer is proved as an indicator, as it is most sensitive to environmental change in riparian forests, acting as an early warning for monitoring. Shrub and grass species are badly impacted by poor organic atter, organic carbon, Na, Ca+Mg, nitrogen, phosphorous, and anthropogenic factors. These factors decrease the sustainable forest management and livelihood security of forest dependent community. The decisions taken by management authority is an important factor in the protection of riparian reserve forests and can thwart from loss of financial resources. The studies must be conducted to establish such overstory canopy that may function as microrefugia for understory vegetation. Investigation on soil characteristics and consultation with the meteorological department would be considered in forest planting and management strategies. This study will help in the identification of the knowledge gap and in redesigning the policies. More ecological integrated studies with the hydrology of rivers are needed to foster the forest cover of riparian reserve.

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