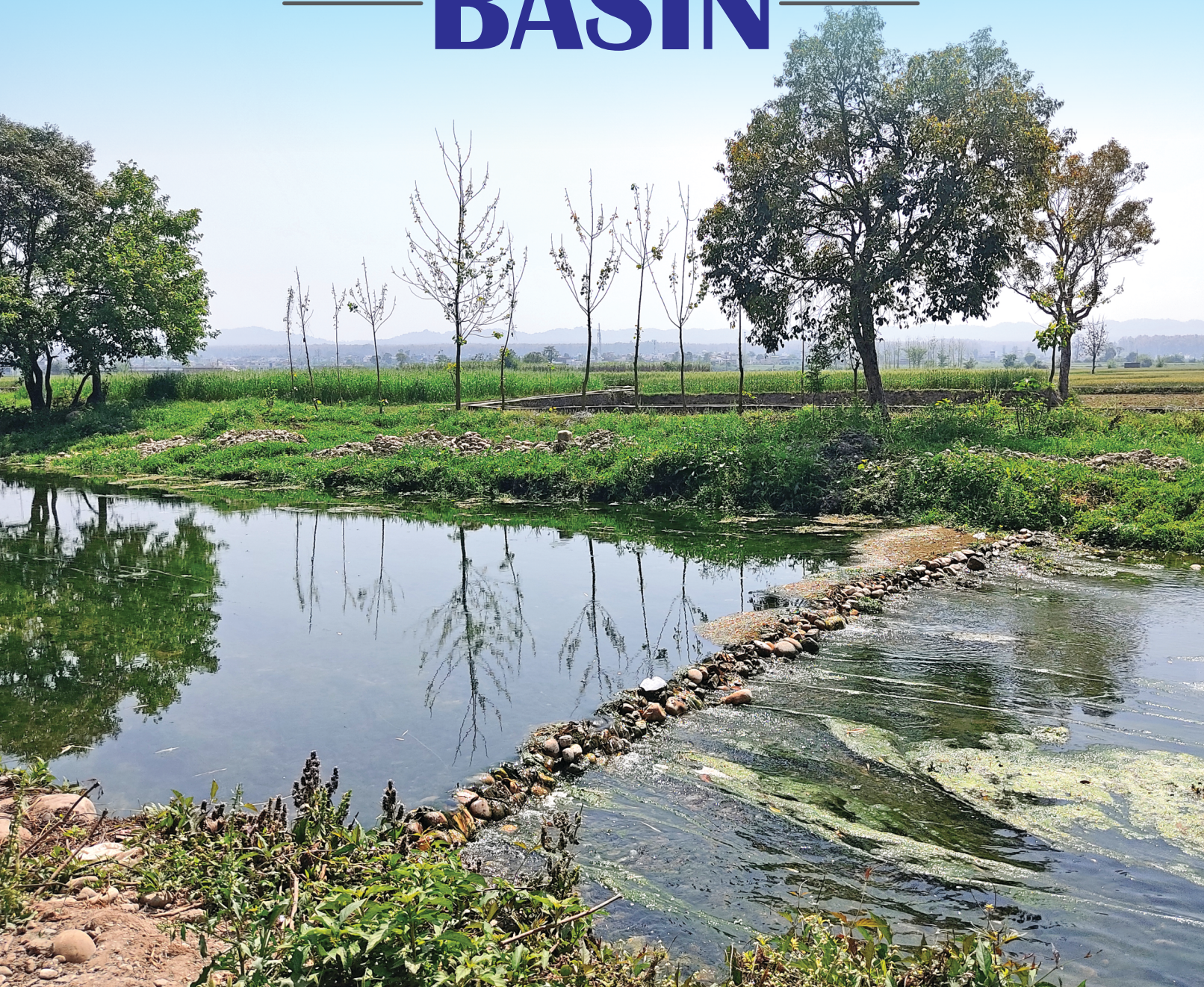


BIODIVERSITY PROFILING AND ASSESSMENT OF KEY ECOSYSTEM SERVICES OF ASAN RIVER —BASIN—



BIODIVERSITY PROFILING AND ASSESSMENT OF KEY ECOSYSTEM SERVICES OF ASAN RIVER —BASIN—

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Photo credit
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SUMMARY

Combination of river rejuvenation and forestation brings positive changes in the health of an ecosystem. Woody plants contribute in reducing impact of green house gases and climate change. A study in Doon valley of Uttarakhand has highlighted efforts of government and non-government organizations in river rejuvenation and forest protection. Due to combined decadal efforts of Himalayan Environmental Studies and Conservation Organization (HESCO) and Uttarakhand Forest Department, a long neglected rivulet was restored in Shuklapur area of Dehradun which now provides refuge to 120 species of birds during winter and spring seasons and harbours 143 species of plants. During present study, H8, H2 and H14 were found to be the most diverse and species rich sampling plots and overall 516.38 individuals/ha stand tree density was calculated in 29 sampling plots in HESCO and adjacent forest. Now, this tropical sal dominated forest has visitors like leopard and barking deer also. In addition to thriving biodiversity, the HESCO and adjacent forest has potential of 90 Mg/ ha carbon sequestration by woody plants. Of which, Shorea robusta contributes largest proportion in sequestration and biomass. During efforts of HESCO rivulet rejuvenation, the water volume capacity was increased almost eight folds during ten years of restoration program between 2009 and 2019. The aquatic habitat of HESCO harbours 48 species of birds and 90 in forest habitat. Rejuvenation brought wellbeing for local residents in terms of fulfilling water requirement in irrigation and daily use. Further, seasonal studies on various aspects are required to determine detailed biodiversity profile of HESCO and adjacent forest.

INTRODUCTION

1

Woody plants contribute in recharging ground water and also provide refuge to some of the threatened species in urban spaces (Ives et al., 2016). Global forest ecosystems are known to store more carbon than the entire atmosphere (FAO 2006). They also contribute in carbon sequestration to deal with climate crisis and reduce concentration of CO₂ in atmosphere (Bar-On et al., 2018). Several rapidly increasing urban spaces (cities & towns) are left with a very few green patches. To reduce adverse affects of green house gases, Indian government accentuated on green urban development in its national policy and encouraged green spaces (NITI Ayog 2021). On International level, "Reduction of Emissions from Deforestation and Forest Degradation" (REDD & REDD+) programs were initiated with participation of local communities and other stakeholders (UNFCCC 2008).

In cities and towns, most of such urban green spaces are restricted to parks, government offices, and university/college campuses. Assessing their potential to stock carbon and biomass generation enhances their importance as an ecosystem service provider and contributes in policy making (Reichstein and Carvalhais, 2019; Herold et al., 2019). Some Indian campuses have assessed their carbon sequestration potential which highlights their contribution in maintaining ecological balance amid densely populated cities and towns (Pragasan et al. 2013; Gavali and Shaikh 2016; Narayana et al. 2020; Sharma et al. 2021; Anjali et al. 2023). Biomass estimation has been used as surrogate to assess probable emission due to degradation of forests (Houghton et al., 2009). Live above ground biomass (AGB) estimation method has been used in assessing carbon storage (IPCC 2003).

World's large proportion of threatened biodiversity thrives in tropical forests (Myers & Mittermeier, 2000). Global tropical forests contribute about 331 pg of AGB from 2251.7 million hectares (Santoro et al. 2021). About 11 million ha. sal (*Shorea robusta*) forest has been distributed in India, Nepal and Bangladesh (Gautam and Devoe 2006). In India, tropical moist forests cover around 1,35,492 sq. km area in

shivalik, north-eastern states, western ghats and parts of west Orissa, Chattisgarh and Jharkhand (FSI 2019). With total 38,000 sq. km forest area, Uttarakhand contributes 5.21% in India's total forest carbon stock. Of which, ~16 % is constituted of moist sal forests (FSI 2019). In urban places of Uttarakhand, *Quercus leucotrichophora* is the most dominated species followed by *Mangifera indica* and *Cedrus deodara* (FSI 2009). Out of these three species, *Mangifera indica* is mostly distributed in tropical region. In Doon valley, various studies have highlighted AGB and carbon stock potential of *S. robusta* and other woody plants (Kaul et al. 1979; Singh et al. 2013; Shahid & Joshi, 2015, 2017; Purohit et al. 2018; Kaushal & Baishya, 2021).

Besides carbon sequestration, forest diversity is an essential element to strategies for conservation and management of natural resources especially in fragmented habitats (Bawa & Seidler 1996; Hill & Curran 2003; Ganivet & Bloomberg, 2019). Forests play a significant role in restoring degraded watersheds and they also improve soil and water quality of ground and surface (Kumari et al. 2019).

1.1. Rejuvenation of HESCO Rivulet: a case study

Rejuvenation of rivers and streams is considered as one of the major parts of restoration ecology (Feld et al. 2011). However, India is still facing several challenges to achieve such objectives. Apart from having few archetypical models, most of the rivers are yet polluted and depleting in their volume and physiochemical properties due to various anthropogenic factors. In the last ten years, HESCO has rejuvenated a rivulet in Dehradun (India) using natural and engineering tools in 46 hectares area which now provides different ecological benefits to the local inhabitants and provides refuge to 76 species of avi-fauna (Sharma 2021) and mammals like leopard, wild boar and barking deer. A joint effort of HESCO and Uttarakhand Forest Department, adopted water harvesting method in watershed area by constructing gabion structures, percolation ponds, water holes and recharge

pits/trenches in multiple places in adjacent sal dominated forest. A significant increase (~8 folds) was recorded in water discharge capacity of rivulet from 2009 to 2019. In 2009, the average water discharge in rivulet was 89.86 Lit/sec which increased about 724.99 Lit/sec in 2019 (HESCO 2019). HESCO had also conducted multiple plantation drives in and around their campus to improve ground water recharge capacity of the forest (HESCO 2014).

Realizing importance of such unique campus and adjacent forest in rapidly changing landscape, capacity of carbon stocking and sequestration must be elucidate to determine the ecosystem service. Hence, present study was commenced to assess status, diversity and carbon sequestration potential of woody plants in HESCO and adjacent forest during the month of May and June, 2022.



STUDY AREA

2

HESCO is a non-profit organisation that works in the HESCO village region. It is located in Shuklapur village of Dehradun (Uttarakhand), situated in the Himalayan foothills of Asharodi range at elevation of 648 meters asl which is 13km away from Dehradun city centre. This area falls under Baronwala Reserved Forest of Karwapani Beat in Dehradun Forest Division. The climate is humid subtropical during summers when temperatures rise up to 44 °C (111 °F) and during winters it varies between 1 - 20 °C. During monsoon season, Doon valley receives the highest annual rainfall, of which July and August are being the wettest with average annual rainfall of 2073.3 mm.

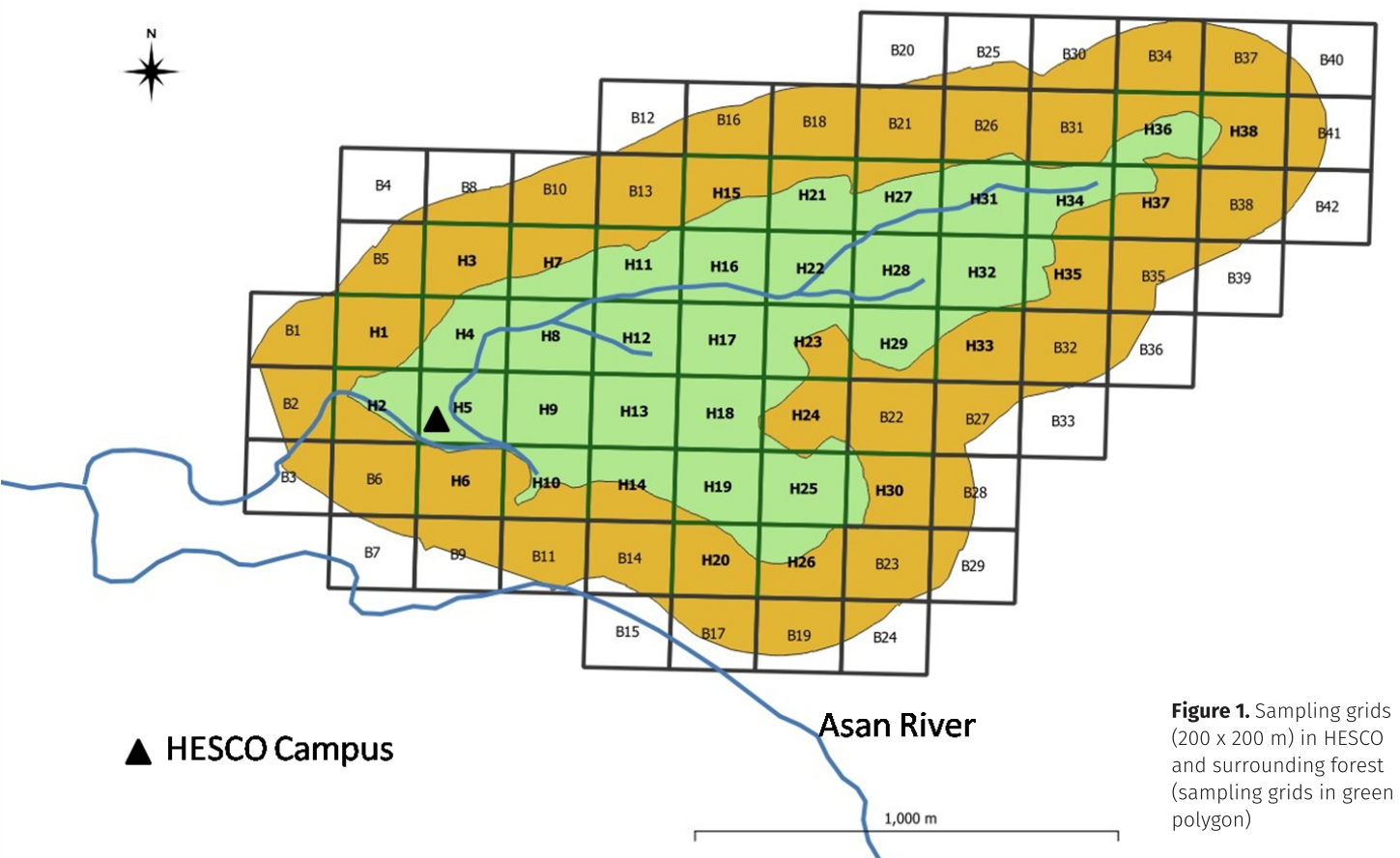


Figure 1. Sampling grids (200 x 200 m) in HESCO and surrounding forest (sampling grids in green polygon)

The average soil moisture is 9.29% and the soil nature shows slightly acidic and the average drainage of catchment areas is 724.99 Lt/sec in 2019 (HESCO 2019). The tropical semi deciduous forest (Champion and Seth 1968) patch is dominated by sal (*Shorea robusta*), rohini (*Mallotus philippensis*) and dandal (*Xylosma longifolia*). Shrubs like star jasmine (*Jasminum multiflorum*), curry tree (*Murraya koenigii*), hill glory bower (*Clerodendrum infortunatum*), *Desmodium* sp and *Flemingia* sp were commonly found. Lianas like hiptage (*Hiptage benghalensis*), *Gouania tiliefolia*, cockspur thron (*Maclura cochinchinensis*), common ivy (*Hedera helix*) were also common. A variety of tree species has been planted in the campus, including kachnar (*Bauhinia variegata*), guryal (*Rubus ellipticus*), bahera (*Terminalia bellirica*), pear (*Pyrus communis*), semal (*Bombax ceiba*), and others, which have medicinal properties and are also utilised for fodder by the local people.



METHODOLOGY 3

3.1. Data collection

3.1.1. Vegetation sampling

Sampling of tree and shrub species was made from a 20 x 20 meter quadrat in each sampling unit of 200 x 200 meter (4 hectare) in 29 grids. The observer recorded the five most dominant trees (all vegetation) 6 ft. in height was listed in the order of dominance (abundance), also same procedure was used in shrub species (>20cm and <6ft.) in order of dominance (abundance). Shrub was assessed on 5 points scale (0 to 4 i.e. absent to most abundant) for density estimation. Also five dominated weed species were recorded and canopy size or cover assessed in 0 to 1 scale.



For biomass estimation, diameter at breast height (DBH) of each tree species was measured in 29 quadrates at the height of 1.37 m (Feldpausch et al. 2011) and converted Girth >5 cm GBH trees were used for biomass estimation.

3.2. Data Analysis

3.2.1. Plant Diversity

To measure tree diversity in HESCO and surrounding forest, different diversity indices were used including Shannon - Wiener diversity index, Margalef's richness index, Pielou's evenness index, and McNaughton's community dominance index.

Measurement of diversity

The type of diversity used here is α - diversity which is the diversity of species within a community or habitat. The diversity index was calculated by using the Shannon - Wiener diversity index (Shannon & Weaver, 1949).

$$\text{Diversity index} = H = - \sum P_i \ln P_i$$

Where, $P_i = S / N$ S = number of individuals of one species
 N = total number of all individuals in the sample
 $\ln$ = logarithm to base e

Measurement of species richness

Species richness: Species richness (S) refers to the number of species living in a particular area (Moore 2013). Margalef's index was used as a simple measure of species richness (Margalef, 1958).



Margalef's index = $(S - 1) / \ln N$

Where, S = total number of species N = total number of individuals in the sample ln = natural logarithm

Measurement of evenness

Evenness of species: Species evenness measures the number of species in a community along with their relative abundance (Moore 2013). For calculating the evenness of species, the Pielou's Evenness Index (e) was used (Pielou, 1966).

$e = H / \ln S$

Where, H = Shannon - Wiener diversity index, S = total number of species in the sample



Measurement of Dominance

Dominance of species: Species that are abundant in comparison to other species in a community and have a proportional impact on environmental conditions, community diversity, and/or ecosystem function. Dominant species can be widespread (common) or restricted in their range (limited) (Avolio et.al. 2019). For calculating the dominance of species, McNaughton's Community dominance index was used (McNaughton 1968).

Community Dominance Index (CDI) = $(y_1+y_2)/y$

Where, y_1 = abundance of the most abundant species, y_2 = abundance of second most abundant species, y = total abundance for all the species.

All indices were calculated in R software using package 'vegan' with dependencies 'permute' and 'lattice' (R Core Team 2021; Oksanen et. al. 2019).

3.2.2. Assessment of Carbon sequestration potential

Since Dehradun receives average 2,073.3 mm annual rainfall and it is dominated by tropical moist sal forest, thus for estimation of Above Ground Biomass (AGB (DBH > 5 cm)), standard allometric equation for moist forest was used (Brown et al. 1989). The DBH (cm) of individual tree species was measured in each quadrat and further used in calculation of AGB and carbon stock. Following equations were used to estimate carbon sequestration potential of HESCO and adjacent forest.

- i. Above Ground Biomass (AGB) (Eq. 1)
= $38.4908 - 11.7883 \times \text{DBH} + 1.1926 \times \text{DBH}^2$
- ii. Below Ground Biomass (BGB) (Eq. 2)
= $\text{AGB} \times 0.15$
- iii. Total Biomass = $\text{AGB} + \text{BGB}$ (Eq. 3)
- iv. Carbon Stock = $0.5 \times \text{Total Biomass}$ (Eq. 4)
- v. Carbon Sequestration = $(\text{Carbon Stock} \times 44) / 12$ (Eq. 5)

3.2.3. Status of Avifauna in HESCO and surrounding areas

A reconnaissance survey was carried out during months of May-June, 2022 by team of Wildlife Institute of India (WII) in and around HESCO campus and recorded all bird species during morning to afternoon hours. The checklist of avifauna was prepared with help of reference book "Birds of the Indian Subcontinent" (Grimmett et al. 2012). Checklist was supplemented by data of Sharma (2021).

4

RESULTS

4.1. Status of Plant species in HESCO and adjacent forest

A total 143 species of plants were recorded during present survey including 54 trees, 31 shrubs, 40 herbs, 12 climbers and 6 weed species in HESCO and adjacent forest (Appendix 1). Overall, 599 individuals of different woody plant species were counted in 29 sampling units with stand density of 516.38 individuals/ha. In which, *S. robusta* was the most dominated tree species with stand density of 329.31 individuals/ha (63.77% relative density) followed by *Tectona grandis* with 21.55 individuals/ha (4.17%) *Pyrus pashia* (18.10 individuals/ha, 3.51%) and *M. philippensis* (16.38 individuals/ha, 3.17%). For 16 species, only one individual was recorded within entire sampling area with density of 0.86 individual/ha and with 0.17% relative density (Table 1). Human disturbance remained moderate between 1-2 out of the scale of 4 mainly owing to livestock, lopping and free-ranging dogs.

Table 1. Stand density of different plant species in HESCO and adjacent forest

Tree Species	Density (Individuals/ ha)	Relative Density (%)
<i>Aegle marmelose</i>	0.86	0.17
<i>Albizia sp</i>	0.86	0.17
<i>Albizia lebak</i>	4.31	0.83
<i>Albizia procera</i>	2.59	0.5
<i>Azadirachta indica</i>	6.03	1.17
<i>Bauhinia purpurea</i>	3.45	0.67
<i>Bauhinia variegata</i>	2.59	0.5
<i>Broussonetia papyrifera</i>	1.72	0.33
<i>Butea monosperma</i>	3.45	0.67
<i>Callistemon viminalis</i>	0.86	0.17
<i>Celtis tetrandra</i>	5.17	1
<i>Citrus aurantum</i>	1.72	0.33
<i>Citrus reticulata</i>	0.86	0.17
<i>Celtis australis</i>	1.72	0.33

Tree Species	Density (Individuals/ ha)	Relative Density (%)
<i>Citrus limon</i>	0.86	0.17
<i>Citrus maxima</i>	0.86	0.17
<i>Citrus sinensis</i>	1.72	0.33
<i>Cordia dichotoma</i>	1.72	0.33
<i>Dalbergia sissoo</i>	2.59	0.5
<i>Ehretia laevis</i>	2.59	0.5
<i>Ficus benghalensis</i>	1.72	0.33
<i>Ficus benjamina</i>	1.72	0.33
<i>Ficus hispida</i>	2.59	0.5
<i>Ficus racemosa</i>	4.31	0.83
<i>Ficus religiosa</i>	1.72	0.33
<i>Ficus rumphii</i>	0.86	0.17
<i>Ficus viren</i>	0.86	0.17
<i>Kydia calycina</i>	4.31	0.83
<i>Lannea coromondlica</i>	1.72	0.33
<i>Leuceana leucephala</i>	1.72	0.33
<i>Litchi chinensis</i>	0.86	0.17
<i>Litsea monoptela</i>	2.59	0.5
<i>Mallotus philippinensis</i>	16.38	3.17
<i>Mangifera indica</i>	1.72	0.33
<i>Melia azederach</i>	2.59	0.5
<i>Morus alba</i>	11.21	2.17
<i>Ougeinia oojeinense</i>	0.86	0.17
<i>Peltophorum africanum</i>	3.45	0.67
<i>Phyllanthus emblica</i>	1.72	0.33
<i>Pongamia pinnata</i>	0.86	0.17
<i>Populous sp</i>	1.72	0.33
<i>Psidium guajava</i>	5.17	1
<i>Pyrus pashia</i>	18.10	3.51
<i>Quercus leucotrichophora</i>	0.86	0.17
<i>Shorea robusta</i>	329.31	63.77
<i>Syzygium cumini</i>	9.48	1.84
<i>Tectona grandis</i>	21.55	4.17
<i>Terminalia arjuna</i>	1.72	0.33
<i>Terminalia bellerica</i>	0.86	0.17
<i>Terminalia chebula</i>	0.86	0.17
<i>Toona ciliata</i>	3.45	0.67
<i>Xanthoxylum sp</i>	0.86	0.17
<i>Xylosma longifolia</i>	11.21	2.17
<i>Ziziphus mauritiana</i>	0.86	0.17
Total	516.38	100

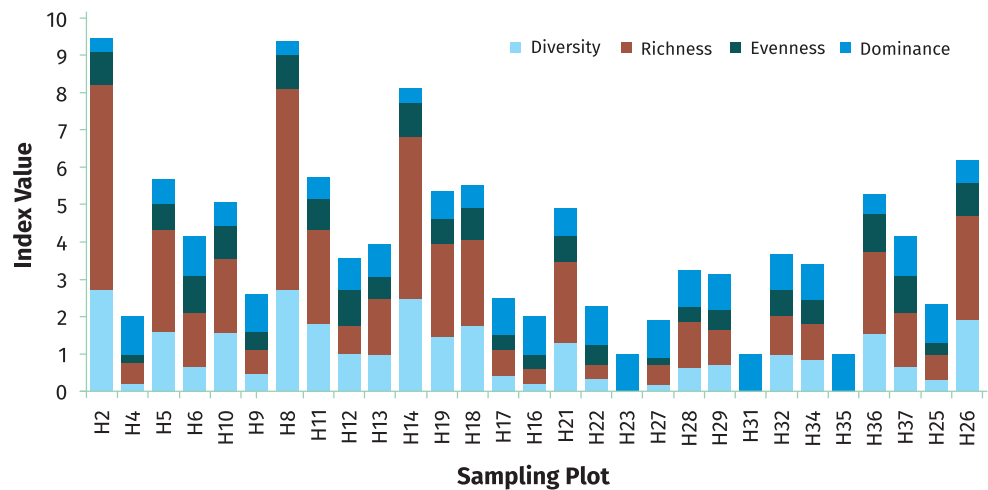


4.2. Plant diversity

Highest diversity (Shannon-Wiener Index) was found in sampling plot H8 ($H' = 2.80$) followed by H2 (2.73) and H14 (2.51) and lowest for H19, H23, H29, H31, and H35 since these plots were dominated by only single species (*Shorea robusta*) (Fig. 2). Similarly, highest richness (Margalef's Index) was found in same plots, H8 ($R = 5.62$), H2 (5.50) and H14 (4.35) and H19, 23, 29, 31, and 35 had only one species in respective plots. Highest evenness was found in plots H6 and H37 ($J' = 1$) followed by H36 (0.97), H12 (0.95) and H14 (0.93). Plots (H19, H23, H29, H31, and H35) with single dominated species (*Shorea robusta*) had highest CDI values and contrastingly most diverse plots showed least dominance value H8 (0.31), H14 (0.32) and H2 (0.34).



Figure 2. Diversity, Richness, Evenness and Dominance of different plots in HESCO and adjacent forest



4.3. Carbon sequestration potential

Among 37 woody plant species, the largest DBH was recorded for *S. robusta* varying between 90.73-105.06 cm contributing 56.44% in relative biomass (AGB) among all tree species followed by *Pyrus pashia* (10.12%), *Ficus racemosa* (8.58%), *Mallotus philippensis* (4.90%), and *F. benjamina* (3.07%). The highest carbon stock were found in *S. robusta* (14 Mg/ha) followed by *Pyrus pashia* (2.51 Mg/ha), *Ficus racemosa* (2.13 Mg/ha) and *M. philippensis*

(1.21 Mg/ha) (Table 2). Since the study area was a sal dominated forest, thus *S. robusta* was widely distributed and dominated in sampling plots. Out of total 90.93 Mg/ha carbon sequestration potential, *S. robusta* had highest carbon sequestration potential (51.32 Mg/ha) followed by *Pyrus pashia* (9.20 Mg/ha), *F. racemosa* (7.81 Mg/ha), and *M. philippensis* (4.45 Mg/ha). *Citrus sinensis* and *Quercus leucotrichophora* plantation had lowest for carbon sequestration potential (0.02 Mg/ha) (Fig. 3).

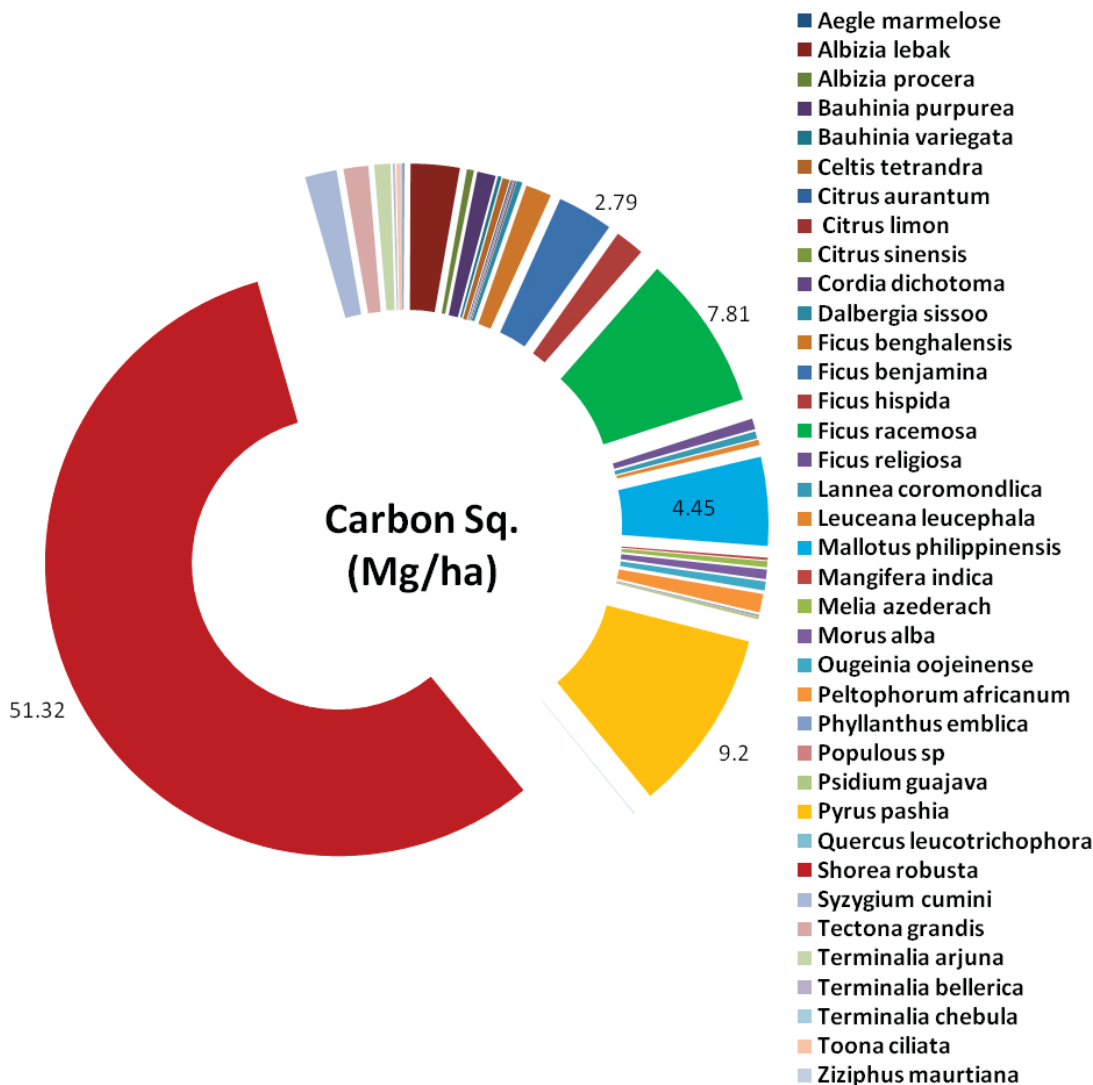


Figure 3. Carbon Sequestration Potential of different plant species in HESCO and adjacent forest

Table 2. Above Ground Biomass (AGB), Below Ground Biomass (BGB), Total Biomass, Carbon Stock and Carbon Sequestration of different tree species in HESCO and adjacent forest

Tree Species	AGB (Mg/ha)	BGB	Total Biomass (Mg/ha)	Carbon Stock (Mg/ha)	Relative Biomass (%) (Mg/ha)
<i>Aegle marmelose</i>	0.03	0.00	0.03	0.02	0.06
<i>Albizia lebak</i>	1.16	0.17	1.34	0.67	2.70
<i>Albizia procera</i>	0.16	0.02	0.19	0.09	0.38
<i>Bauhinia purpurea</i>	0.44	0.07	0.51	0.25	1.03
<i>Bauhinia variegata</i>	0.09	0.01	0.10	0.05	0.20
<i>Celtis tetrandra</i>	0.17	0.03	0.20	0.10	0.40
<i>Citrus aurantium</i>	0.04	0.01	0.05	0.02	0.10
<i>Citrus limon</i>	0.02	0.00	0.02	0.01	0.04
<i>Citrus sinensis</i>	0.01	0.00	0.01	0.01	0.02
<i>Cordia dichotoma</i>	0.04	0.01	0.05	0.02	0.10
<i>Dalbergia sissoo</i>	0.13	0.02	0.15	0.08	0.30
<i>Ficus benghalensis</i>	0.62	0.09	0.71	0.36	1.43
<i>Ficus benamina</i>	1.32	0.20	1.52	0.76	3.06
<i>Ficus hispida</i>	0.70	0.10	0.80	0.40	1.61
<i>Ficus racemosa</i>	3.70	0.56	4.26	2.13	8.59
<i>Ficus religiosa</i>	0.25	0.04	0.29	0.15	0.58
<i>Lannea coromondlica</i>	0.17	0.03	0.20	0.10	0.40
<i>Leuceana leucephala</i>	0.13	0.02	0.15	0.08	0.30
<i>Mallotus philippinensis</i>	2.11	0.32	2.43	1.21	4.90
<i>Mangifera indica</i>	0.06	0.01	0.07	0.03	0.14
<i>Melia azederach</i>	0.14	0.02	0.16	0.08	0.32
<i>Morus alba</i>	0.23	0.03	0.26	0.13	0.52
<i>Ougeinia oojeinense</i>	0.21	0.03	0.25	0.12	0.50
<i>Peltophorum africanum</i>	0.44	0.07	0.51	0.25	1.03
<i>Phyllanthus emblica</i>	0.03	0.00	0.03	0.02	0.06
<i>Populous sp</i>	0.02	0.00	0.02	0.01	0.04
<i>Psidium guajava</i>	0.06	0.01	0.07	0.03	0.14
<i>Pyrus pashia</i>	4.37	0.65	5.02	2.51	10.12
<i>Quercus leucotrichophora</i>	0.01	0.00	0.01	0.01	0.02
<i>Shorea robusta</i>	24.34	3.65	27.99	14.00	56.43
<i>Syzygium cumini</i>	0.75	0.11	0.87	0.43	1.75
<i>Tectona grandis</i>	0.59	0.09	0.67	0.34	1.35
<i>Terminalia arjuna</i>	0.39	0.06	0.44	0.22	0.89
<i>Terminalia bellerica</i>	0.04	0.01	0.05	0.02	0.10
<i>Terminalia chebula</i>	0.02	0.00	0.02	0.01	0.04
<i>Toona ciliata</i>	0.09	0.01	0.10	0.05	0.20
<i>Ziziphus maurtiana</i>	0.05	0.01	0.05	0.03	0.10
Total	43.13	6.46	49.6	24.8	100

4.4 Water discharge change

The joint efforts of HESCO and Uttarakhand forest department worked wonder by improving water harvesting capacity of the forested area which increased the water discharge in the rivulet. Based on previous studies by HESCO, a significant change in the water discharge capacity of rivulet was observed between two lean periods (June, 2009 and June, 2019). In 2009-2010, the average water discharge capacity of stream was about 89.96 - 96.34 (Lit/sec) during June and January respectively, which almost increased eight folds in 2019, 64911 (Lit/sec) $\pm$ SE 91.71 (Fig 4).

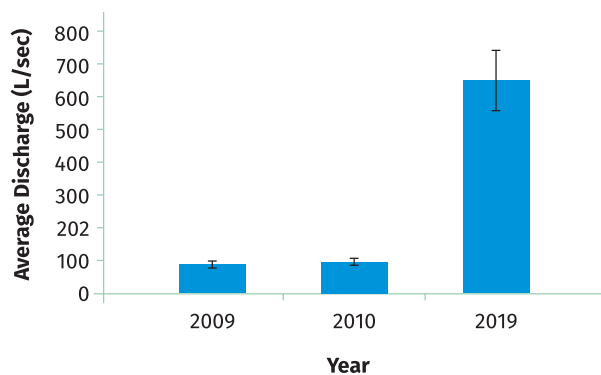


Figure 4. Change in Water discharge capacity change in HESCO River (2009-2019) (Source: HESCO)



During intensive monitoring from October-2018 to June-2019 by HESCO, a decrease of 224.06 Lit/sec was observed in average water flow capacity of rivulet. During onset of autumn in October, 2018, the average water flow capacity was 873.5 Lit/sec which reduced about 649.44 Lit/sec during lean season of June, 2019. (Fig. 5).

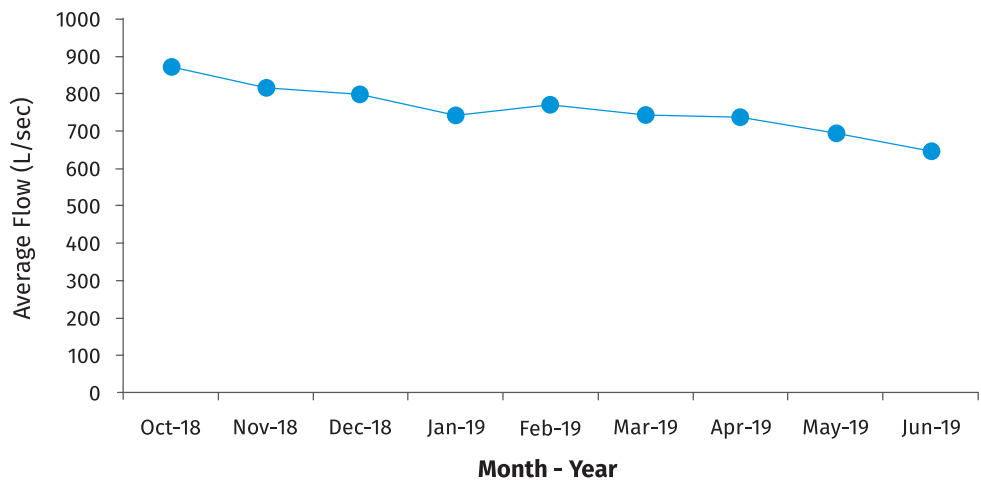


Figure 5. Monthly water flow between October, 2018 and June, 2019 in HESCO Rivulet (Source: HESCO)

4.5 Avi-fauna in HESCO and adjacent forest

Based on present rapid assessment and a previous short study by Sharma (2021) in and around HESCO campus between the months of February and June, a total 120 species belonging to 45 families were recorded in HESCO and adjacent areas in different types of habitats including forest, river and agriculture (Appendix 2). Muscicapidae (11) was the most dominated family followed by Accipitridae (7) and Picidae (6) including 2 Endangered, 1 Vulnerable and 2 Near-Threatened species were recorded.

The detailed checklist of birds has been provided in Appendix-2. Among 120 species, maximum species were found in forest habitat followed by river and agriculture (Fig. 6). Of which, eight species were recorded in all three types of habitats whereas 51 species were only common in forest habitat and 20 in riverine.

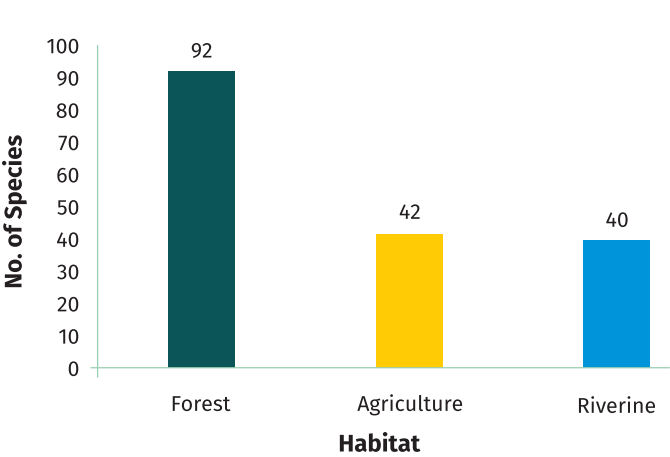


Figure 6. Habitat wise avi-faunal species distribution in and around HESCO campus



DISCUSSION

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Present study highlighted the importance of carbon sequestration capacity in urban green spaces. The potential of carbon sequestration in HESCO and adjacent forest indicates need of green areas in the anthropocene. Usually, carbon stock and tree basal area can be influenced by tree size and growth (Borah et al., 2015). Additionally, species richness and diversity also may affect the carbon stock potential (Solomon et al., 2017; Zuo et al., 2017). Because mixed forest can sequester rapid CO₂ attributed to range in photosynthetic rate of different species (Montagnini and Porras 1998).

In previous studies, capacity of carbon stock and sequestration potential in tropical sal dominated forests of Doon valley varied between 57.5 - 291 Mg/ ha (Singh 2010) which fairly coincide with present study. About ~15 % large trees (>60 cm DBH) had contributed in total carbon storage while rest by small trees (>5 cm - <60 cm, DBH) in present study. Further, proportion of small trees indicates the future capacity of carbon sequestration of HESCO and adjacent forest. The allometric equation used in present study was applicable for plants having > 5 cm DBH hence saplings were discarded from biomass analysis. Apart from ground based biomass calculations, GIS based spatial modelling studies have also contributed in extrapolation of landscape level carbon stock potential (Singh et al. 2013; Shahid & Joshi 2017; Purohit et al. 2018).

In 2016, Government of India initiated Namami Gange programme to rejuvenate the Ganga and its tributaries under National Mission for Clean Ganga (NMCG). Sinha et al. (2013) has highlighted rejuvenation efforts of 'Tarun Bharat Sangh' in different parts of India. Another recent small rejuvenation example is from Delhi where INTACH revived of Hauz Khas Lake (SANDRP 2021). More replicates are required considering HESCO rivulet rejuvenation as archetype of restoration of aquatic habitats. Decadal changes in the water volume brought wellbeing for local residents of Shuklapur in terms of irrigation demand and water mills which highlights the importance of water resources for human sustenance.

Besides, floral diversity is an essential component for sustenance of different taxa, for instance, avi-fauna density gets affected by plant species richness and patch size in green urban spaces of Doon valley (Kaushik et al. 2021). Long term plot monitoring helps in conservation and management of forests and climate crisis (Condit 1995, Negi et al. 2019). Creation and management of green urban spaces have many challenges including lack of space and tree richness (Kaushik et al. 2021).

A recent study by Shaklani et al. (2019) recorded 126 species of avifauna from different sites of Doon valley. However, WII campus harbours around 351 species of birds including resident and migratory species and Forest Research Institute (FRI) has a total 361 species in its vast campus so far (www.ebird.org). Given habitat heterogeneity and scope of more studies and regular monitoring in HESCO and adjacent forest, it will surely add more species in its account. Simultaneously, density estimates will provide more weightage to its biodiversity profile. Further soil carbon stock and occurrence of different micro and macro-fauna could add more weightage to importance of urban green spaces like HESCO.

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APPENDICES

Appendix 1. Checklist of Plant species in HESCO and adjacent forest

S. No.	Species name	Type	Family
1	<i>Achranthes aspera</i>	Herbs	Amaranthaceae
2	<i>Acmella ciliata</i>	Herbs	Asteraceae
3	<i>Aegle marmelose</i>	Tree	Rutaceae
4	<i>Aerva</i> sp.	Herbs	Amaranthaceae
5	<i>Ageratum conyzoides</i>	Weed	Asteraceae
6	<i>Albizi</i> sp.	Tree	Fabaceae
7	<i>Albizia lebak</i>	Tree	Fabaceae
8	<i>Albizia procera</i>	Tree	Fabaceae
9	<i>Alternanthera</i> sp.	Herbs	Amaranthaceae
10	<i>Amaranthaceae Unidentified</i>	Herbs	Amaranthaceae
11	<i>Ampelocissus</i> sp.	Climber	Vitaceae
12	<i>Ardisia</i> sp.	Shrubs	Primulaceae
13	<i>Artemisia</i> sp.	Herbs	Asteraceae
14	<i>Artemisia vulgaris</i>	Herbs	Asteraceae
15	<i>Asparagus racemosus</i>	Shrubs	Asparagaceae
16	<i>Asteraceae Unidentified</i>	Herbs	Asteraceae
17	<i>Azadirachta indica</i>	Tree	Meliaceae
18	<i>Azanza lampas</i>	Shrubs	Malvaceae
19	<i>Bamboo</i> sp.	Herbs	Poaceae
20	<i>Barleria</i> sp.	Herbs	Acanthaceae
21	<i>Bauhinia purpurea</i>	Tree	Fabaceae
22	<i>Bauhinia variegata</i>	Tree	Fabaceae
23	<i>Bidens pilosa</i>	Weed	Asteraceae
24	<i>Broussonetia papyrifera</i>	Tree	Moraceae
25	<i>Broussonetia</i> sp.	Shrubs	Moraceae
26	<i>Brugmansia suaveolens</i>	Shrubs	Solanaceae
27	<i>Butea monosperma</i>	Tree	Fabaceae
28	<i>Callicarpa macrophylla</i>	Shrubs	Lamiaceae
29	<i>Callistemon viminalis</i>	Tree	Myrtaceae
30	<i>Calotropis procera</i>	Shrubs	Apocynaceae

S. No.	Species name	Type	Family
31	<i>Carissa opaca</i>	Shrubs	Apocynaceae
32	<i>Carissa spianrum</i>	Shrubs	Apocynaceae
33	<i>Catanurugam spinosa</i>	Shrubs	Rubiaceae
34	<i>Celtis australis</i>	Tree	Cannabaceae
35	<i>Celtis tetrandra</i>	Tree	Cannabaceae
36	<i>Cissampelos pareira</i>	Climber	Menispermaceae
37	<i>Citrus aurantum</i>	Tree	Rutaceae
38	<i>Citrus limon</i>	Tree	Rutaceae
39	<i>Citrus maxima</i>	Tree	Rutaceae
40	<i>Citrus reticulata</i>	Tree	Rutaceae
41	<i>Citrus sinensis</i>	Tree	Rutaceae
42	<i>Clematis</i> sp.	Climber	Ranunculaceae
43	<i>Clerodendrum inforentum</i>	Shrubs	Lamiaceae
44	<i>Colocasia</i> sp.	Herbs	Araceae
45	<i>Commenlina</i> sp.	Herbs	Commelinaceae
46	<i>Cordia dichotoma</i>	Tree	Boraginaceae
47	<i>Cryptolepis buchanni</i>	Climber	Asclepiadaceae
48	<i>Curcuma longa</i>	Herbs	Zingiberaceae
49	<i>Cynodon dactylon</i>	Herbs	Poaceae
50	<i>Dalbergia sissoo</i>	Tree	Fabaceae
51	<i>Desmodium</i> sp.	Herbs	Fabaceae
52	<i>Dicliptra</i> sp.	Herbs	Acanthaceae
53	<i>Dioscorea</i> sp.	Climber	Dioscoreaceae
54	<i>Ehretia laevis</i>	Tree	Boraginaceae
55	<i>Eranthemum</i>	Herbs	Acanthaceae
56	<i>Eupatrum</i> sp.	Weed	Asteraceae
57	<i>Fabaceae herb</i>	Herbs	Fabaceae
58	<i>Ficus benghalensis</i>	Tree	Moraceae
59	<i>Ficus benamina</i>	Tree	Moraceae
60	<i>Ficus hispida</i>	Tree	Moraceae
61	<i>Ficus racemosa</i>	Tree	Moraceae
62	<i>Ficus religiosa</i>	Tree	Moraceae
63	<i>Ficus rumphii</i>	Tree	Moraceae
64	<i>Ficus scandens</i>	Climber	Moraceae
65	<i>Ficus viren</i>	Tree	Moraceae
66	<i>Fragaria vesca</i>	Herbs	Rosaceae
67	<i>Frageria</i> sp.	Herbs	Rosaceae
68	<i>Glycomis pentaphylla</i>	Shrubs	Rutaceae
69	<i>Hibiscus</i> sp.	Shrubs	Malvaceae
70	<i>Hiptrage benghalensis</i>	Climber	Malpighiaceae
71	<i>Ipomoea carica</i>	Climber	Convolvulaceae
72	<i>Ipomoea carnea</i>	Weed	Convolvulaceae
73	<i>Ipomoea indica</i>	Herbs	Convolvulaceae
74	<i>Jasminum multiforum</i>	Shrubs	Oleaceae
75	<i>Jatropha</i>	Shrubs	Euphorbiaceae

S. No.	Species name	Type	Family
76	<i>Justicia adhatoda</i>	Shrubs	Acanthaceae
77	<i>Kydia calycina</i>	Tree	Malvaceae
78	<i>Lamiaceae herb</i>	Herbs	Lamiaceae
79	<i>Lannea coromondlica</i>	Tree	Anacardiaceae
80	<i>Lantana camara</i>	Weed	Verbenaceae
81	<i>Lepigatish sp.</i>	Shrubs	Acanthaceae
82	<i>Leuceana leucephala</i>	Tree	Fabaceae
83	<i>Litchi chinensis</i>	Tree	Sapindaceae
84	<i>Litsea monopecta</i>	Tree	Lauraceae
85	<i>Maclura cochinchinensis</i>	Climber	Moraceae
86	<i>Mallotus philippinensis</i>	Tree	Euphorbiaceae
87	<i>Mangifera indica</i>	Tree	Anacardiaceae
88	<i>Melia azederach</i>	Tree	Meliaceae
89	<i>Morus alba</i>	Tree	Moraceae
90	<i>Murraya koenigii</i>	Shrubs	Rutaceae
91	<i>Murraya paniculata</i>	Shrubs	Rutaceae
92	<i>Musa paradisiaca</i>	Herbs	Musaceae
93	<i>Nelsonia sp.</i>	Herbs	Acanthaceae
94	<i>Oplismenus sp.</i>	Herbs	Poaceae
95	<i>Oplismenus burmannii</i>	Herbs	Poaceae
96	<i>Ougeinia obovatifolia</i>	Tree	Fabaceae
97	<i>Oxalis articulata</i>	Herbs	Oxalidaceae
98	<i>Oxalis corniculata</i>	Herbs	Oxalidaceae
99	<i>Oxalis corymbosa</i>	Herbs	Oxalidaceae
100	<i>Parthenium hysterophorus</i>	Weed	Asteraceae
101	<i>Passiflora foetida</i>	Climber	Passifloraceae
102	<i>Peltophorum africanum</i>	Tree	Fabaceae
103	<i>Phyllanthus emblica</i>	Tree	Phyllanthaceae
104	<i>Plumbago sp</i>	Herbs	Plumbaginaceae
105	<i>Poaceae Unidentified</i>	Herbs	Poaceae
106	<i>Polygonum sp</i>	Herbs	Polygonaceae
107	<i>Pongamia pinnata</i>	Tree	Fabaceae
108	<i>Populus sp</i>	Tree	Salicaceae
109	<i>Psidium guajava</i>	Tree	Myrtaceae
110	<i>Pyrus pashia</i>	Tree	Rosaceae
111	<i>Quercus leucotrichophora</i>	Tree	Fagaceae
112	<i>Rawlsonia serpentina</i>	Herbs	Apocynaceae
113	<i>Rhamnus variegata</i>	Shrubs	Rhamnaceae
114	<i>Ricinus communis</i>	Shrubs	Euphorbiaceae
115	<i>Rivina humilis</i>	Herbs	Petiveriaceae
116	<i>Rosa domestica</i>	Shrubs	Rosaceae
117	<i>Rubus niveus</i>	Shrubs	Rosaceae
118	<i>Rubus sp</i>	Shrubs	Rosaceae
119	<i>Sambucus canadensis</i>	Shrubs	Adoxaceae
120	<i>Senna sp</i>	Herbs	Fabaceae
121	<i>Shorea robusta</i>	Tree	Dipterocarpaceae

S. No.	Species name	Type	Family
122	<i>Sida</i> sp	Herbs	Malvaceae
123	<i>Solanum nigrum</i>	Herbs	Solanaceae
124	<i>Solanum pseudocapsicum</i>	Herbs	Solanaceae
125	<i>Solanum torvum</i>	Shrubs	Solanaceae
126	<i>Solanum viarum</i>	Shrubs	Solanaceae
127	<i>spatholobus roxburghii</i>	Climber	Fabaceae
128	<i>Syzygium cumini</i>	Tree	Myrtaceae
129	<i>Tabernaemontana divaricata</i>	Shrubs	Apocynaceae
130	<i>Tectona grandis</i>	Tree	Lamiaceae
131	<i>Terminalia arjuna</i>	Tree	Combretaceae
132	<i>Terminalia bellerica</i>	Tree	Combretaceae
133	<i>Terminalia chebula</i>	Tree	Combretaceae
134	<i>Thunbergia</i>	Climber	Acanthaceae
135	<i>Toona ciliata</i>	Tree	Meliaceae
136	<i>Tradescantis</i> sp	Herbs	Commelinaceae
137	<i>Tradescantis</i> sp	Herbs	Asteraceae
138	<i>Urena lobata</i>	Shrubs	Malvaceae
139	<i>Vitex negundi</i>	Shrubs	Lamiaceae
140	<i>Xanthoxylum</i>	Tree	Rutaceae
141	<i>Xylosma longifolia</i>	Tree	Salicaceae
142	<i>Ziziphus mauritiana</i>	Tree	Rhamnaceae
143	<i>Ziziphus</i> sp	Shrubs	Rhamnaceae

Appendix 2. Checklist of Avifaunal species in HESCO and its surrounding habitats

Species	Scientific Name	Family	IUCN Status
Alexandrine Parakeet	<i>Psittacula eupatria</i>	Psittaculidae	NT
Ashy Prinia	<i>Prinia socialis</i>	Cisticolidae	LC
Asian Barred Owlet	<i>Glaucidium cuculoides</i>	Strigidae	LC
Asian Pied Starling	<i>Gracupica contra</i>	Sturnidae	LC
Asian Plain Martin	<i>Riparia chinensis</i>	Hirundinidae	LC
Barn Swallow	<i>Hirundo rustica</i>	Hirundinidae	LC
Bar-tailed Treecreeper	<i>Certhia himalayana</i>	Certhiidae	LC
Baya Weaver	<i>Ploceus philippinus</i>	Ploceidae	LC
Besra	<i>Accipiter virgatus</i>	Accipitridae	LC
Black Bulbul	<i>Hypsipetes leucocephalus</i>	Pycnonotidae	LC
Black Drongo	<i>Dicrurus macrocercus</i>	Dicruridae	LC
Black Kite	<i>Milvus migrans</i>	Accipitridae	LC
Black-chinned Babbler	<i>Cyanoderma pyrrhops</i>	Timaliidae	LC
Black-crowned Night Heron	<i>Nycticorax nycticorax</i>	Ardeidae	LC
Black-hooded Oriole	<i>Oriolus xanthornus</i>	Oriolidae	LC
Black-lored Tit	<i>Machlolophus xanthogenys</i>	Paridae	LC
Black-throated Sunbird	<i>Aethopyga saturata</i>	Nectariniidae	LC
Black-winged Stilt	<i>Himantopus himantopus</i>	Recurvirostridae	LC
Blue Whistling Thrush	<i>Myophonus caeruleus</i>	Muscicapidae	LC
Blue-throated Barbet	<i>Psilopogon asiaticus</i>	Ramphastidae	LC
Blue-throated Flycatcher	<i>Cyornis rubeculoides</i>	Muscicapidae	LC

Species	Scientific Name	Family	IUCN Status
Brahminy Starling	<i>Sturnia pagodarum</i>	Sturnidae	LC
Brown Crake	<i>Zapornia akool</i>	Rallidae	LC
Brown Rock Chat	<i>Oenanthe fusca</i>	Muscicapidae	LC
Brown-headed Barbet	<i>Psilopogon zeylanicus</i>	Ramphastidae	LC
Cattle Egret	<i>Bubulcus ibis</i>	Ardeidae	LC
Chestnut-headed Bee-eater	<i>Merops leschenaulti</i>	Meropidae	LC
Chestnut-shouldered Petronia	<i>Gymnoris xanthocollis</i>	Passeridae	LC
Chestnut-tailed Starling	<i>Sturnia malabarica</i>	Sturnidae	LC
Cinereous Tit	<i>Parus cinereus</i>	Paridae	LC
Common Greenshank	<i>Tringa nebularia</i>	Scolopacidae	LC
Common Kingfisher	<i>Alcedo atthis</i>	Alcedinidae	LC
Common Moorhen	<i>Gallinula chloropus</i>	Rallidae	LC
Common Myna	<i>Acridotheres tristis</i>	Sturnidae	LC
Common Sandpiper	<i>Actitis hypoleucos</i>	Scolopacidae	LC
Coppersmith Barbet	<i>Psilopogon haemacephalus</i>	Ramphastidae	LC
Crested Serpent Eagle	<i>Spilornis cheela</i>	Accipitridae	LC
Crimson Sunbird	<i>Aethopyga siparaja</i>	Nectariniidae	LC
Egyptian Vulture	<i>Neophron percnopterus</i>	Accipitridae	EN
Emerald Dove	<i>Chalcophaps indica</i>	Columbidae	LC
Eurasian Collared Dove	<i>Streptopelia decaocto</i>	Columbidae	LC
Great Tit	<i>Parus major</i>	Passeridae	LC
Greater Coucal	<i>Centropus sinensis</i>	Cuculidae	LC
Greater Golden-backed Woodpecker	<i>Chrysocolaptes lucidus</i>	Picidae	LC
Green Bee-eater	<i>Merops orientalis</i>	Meropidae	LC
Grey Treepie	<i>Dendrocitta formosae</i>	Corvidae	LC
Grey-breasted Prinia	<i>Prinia hodgsonii</i>	Cisticolidae	LC
Grey-headed Woodpecker	<i>Picus canus</i>	Picidae	LC
Grey-headed Parakeet	<i>Psittacula finschii</i>	Psittaculidae	NT
Grey-hooded Leaf Warbler	<i>Seicercus xanthoschistos</i>	Phylloscopidae	LC
Grey-winged Blackbird	<i>Turdus boulboul</i>	Turdidae	LC
Hair-crested Drongo	<i>Dicrurus hottentottus</i>	Dicruridae	LC
Himalayan Bulbul	<i>Pycnonotus leucogenys</i>	Pycnonotidae	LC
Himalayan Grasshopper-warbler	<i>Locustella kashmirensis</i>	Locustellidae	LC
Himalayan Swiftlet	<i>Aerodramus brevirostris</i>	Apodidae	LC
Himalayan Flameback	<i>Dinopium shorii</i>	Picidae	LC
House Crow	<i>Corvus splendens</i>	Corvidae	LC
House Sparrow	<i>Passer domesticus</i>	Passeridae	LC
Indian Cuckoo	<i>Cuculus micropterus</i>	Cuculidae	LC
Indian Golden Oriole	<i>Oriolus kundoo</i>	Oriolidae	LC
Indian Grey Hornbill	<i>Ocyeros birostris</i>	Bucerotidae	LC
Indian Pond Heron	<i>Ardeola grayii</i>	Ardeidae	LC
Indian Spot-billed Duck	<i>Anas poecilorhyncha</i>	Anatidae	LC
Indian Spotted Eagle	<i>Clanga hastata</i>	Accipitridae	VU
Jacobin Cuckoo	<i>Clamator jacobinus</i>	Cuculidae	LC
Jungle Babbler	<i>Turdoides striata</i>	Leiothrichidae	LC
Jungle Myna	<i>Acridotheres fuscus</i>	Sturnidae	LC
Jungle Prinia	<i>Prinia sylvatica</i>	Cisticolidae	LC
Kalij Pheasant	<i>Lophura leucomelanos</i>	Phasianidae	LC
Large Grey Babbler	<i>Argya malcolmi</i>	Leiothrichidae	LC
Large-billed Crow	<i>Corvus macrorhynchos</i>	Corvidae	LC

Species	Scientific Name	Family	IUCN Status
Laughing Dove	<i>Streptopelia senegalensis</i>	Columbidae	LC
Lemon-rumped Warbler	<i>Phylloscopus chloronotus</i>	Phylloscopidae	LC
Lesser Golden-backed Woodpecker	<i>Dinopium benghalense</i>	Picidae	LC
Lesser Racket-tailed Drongo	<i>Dicrurus remifer</i>	Dicruridae	LC
Little Cormorant	<i>Microcarbo niger</i>	Phalacrocoracidae	LC
Little Egret	<i>Egretta garzetta</i>	Ardeidae	LC
Long-tailed Shrike	<i>Lanius schach</i>	Laniidae	LC
Oriental Magpie Robin	<i>Copsychus saularis</i>	Muscicapidae	LC
Oriental Turtle Dove	<i>Streptopelia orientalis</i>	Columbidae	LC
Oriental White-eye	<i>Zosterops palpebrosus</i>	Zosteropidae	LC
Pied Bushchat	<i>Saxicola caprata</i>	Muscicapidae	LC
Plain Mountain Finch	<i>Leucosticte nemoricola</i>	Fringillidae	LC
Plain Prinia	<i>Prinia inornata</i>	Cisticolidae	LC
Plumbeous Water Redstart	<i>Rhyacornis fuliginosa</i>	Muscicapidae	LC
Plum-headed Parakeet	<i>Psittacula cyanocephala</i>	Psittaculidae	LC
Puff-throated Babbler	<i>Pellorneum ruficeps</i>	Pellorneidae	LC
Purple Sunbird	<i>Cinnyris asiaticus</i>	Nectariniidae	LC
Red Avadavat	<i>Amandava amandava</i>	Estrildidae	LC
Red Junglefowl	<i>Gallus gallus</i>	Phasianidae	LC
Red-vented Bulbul	<i>Pycnonotus cafer</i>	Pycnonotidae	LC
Red-wattled Lapwing	<i>Vanellus indicus</i>	Charadriidae	LC
Red-whiskered Bulbul	<i>Pycnonotus jocosus</i>	Pycnonotidae	LC
Rock Pigeon	<i>Columba livia</i>	Columbidae	LC
Rose-ringed Parakeet	<i>Psittacula krameri</i>	Psittaculidae	LC
Rufous Treepie	<i>Dendrocitta vagabunda</i>	Corvidae	LC
Rufous-bellied Niltava	<i>Niltava sundara</i>	Muscicapidae	LC
Rufous-bellied Woodpecker	<i>Dendrocopos hyperythrus</i>	Picidae	LC
Scaly-breasted Munia	<i>Lonchura punctulata</i>	Estrildidae	LC
Shikra	<i>Accipiter badius</i>	Accipitridae	LC
Speckled Piculet	<i>Picumnus innominatus</i>	Picidae	LC
Spotted Dove	<i>Spilopelia chinensis</i>	Columbidae	LC
Spotted Forktail	<i>Enicurus maculatus</i>	Muscicapidae	LC
Spotted Owlet	<i>Athene brama</i>	Strigidae	LC
Steppe Eagle	<i>Aquila nipalensis</i>	Accipitridae	EN
Stork-billed Kingfisher	<i>Pelargopsis capensis</i>	Alcedinidae	LC
Streaked Laughingthrush	<i>Trochalopteron lineatum</i>	Leiothrichidae	LC
Tickell's Blue Flycatcher	<i>Cyornis tickelliae</i>	Muscicapidae	LC
Verditer Flycatcher	<i>Eumyias thalassinus</i>	Muscicapidae	LC
Western Koel	<i>Eudynamys scolopaceus</i>	Cuculidae	LC
White-capped Water Redstart	<i>Chaimarrornis leucocephalus</i>	Muscicapidae	LC
White Wagtail	<i>Motacilla alba</i>	Motacillidae	LC
White-breasted Waterhen	<i>Amaurornis phoenicurus</i>	Rallidae	LC
White-throated Kingfisher	<i>Halcyon smyrnensis</i>	Alcedinidae	LC
White-browed Scimitar Babbler	<i>Pomatorhinus schisticeps</i>	Timaliidae	LC
White-browed Wagtail	<i>Motacilla maderaspatensis</i>	Motacillidae	LC
White-throated Fantail	<i>Rhipidura albicollis</i>	Rhipiduridae	LC
Wire-tailed Swallow	<i>Hirundo smithii</i>	Hirundinidae	LC
Yellow-bellied Fairy-fantail	<i>Chelidorhynch hypoxanthus</i>	Stenostiridae	LC
Zitting Cisticola	<i>Cisticola juncidis</i>	Cisticolidae	LC

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