EXPLORATION OF IMPORTANT ENVIRONMENTAL DETERMINANTS OF FLOWERING PHENOLOGY IN THE WESTERN HIMALAYAN FORESTS OF DHIRKOT, AZAD JAMMU AND KASHMIR, PAKISTAN

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Abstract. The flowering phenology of plants is influenced by the unique set of environmental variations, and therefore, elucidation of important driving factors is important. The study area of Dhirkot (western Himalaya, Pakistan) is explored to record the interactions among the flowering phenology of the vascular plants and current climate along the temporal gradient from March-2015 to February-2018. A total of 38 randomly selected representative sites were visited to record the timing of flowering response and compared with mean monthly climatic data. Multivariate classification and ordination tools were used to analyze the data. The results revealed that majority (185 spp; 68%) of plant species passes through thier flowering phase in the month of July. Canonical correspondence analysis (CCA) results depicted that about 63.7% of the phenological variations were explained by the monthly explanatory climatic variables, and mean minimum temperature, precipitation, wind speed and soil moisture were significantly (p-adj. <0.05) important. Pseudo-canonical correlation of the first three CCA axes was found higher than 0.8 which depicted that the selected variables were important determinants. This study concluded that predicted future temperature increase might alter the phenological responses, and prove to be devastating for valuable plant species of this unique and very delicate western Himalayan ecosystem.
Keywords: *floral diversity, life forms, climatic variations, flowering events, multivariate analysis*

Introduction

The word phenology is derived from the Greek word *phainomai*, which means "to appear". It is the study of the timing of life events of plants (Vashistha et al., 2009). Phenological events attract special attention when the normal pattern deviates, e.g. out of season flowering. Phenological studies are important to understand the interaction of species and community function, just like many other temporal and spatial aspects (Fenner, 1998). Flowering phenological studies observe the duration and timing of flowering, and temporal and spatial variations in the number of flowers in response to different environmental gradients (Rathcke and Lacey, 1985). The term phenology is used in ecology more generally to designate the period of any seasonal or cyclic phenomena, including the dates of last appearance (Menzel et al., 2006; Mier, 2007).

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Changes in phenological events are closely related to climatic variations (Bertin, 2008) and such changes can alter the functioning of ecosystem (Parmesan, 2006; Calinger et al., 2013) and ecological interactions such as those amongst plants and pollinators (Forrest, 2015; Kharouba and Vellend, 2015) or plants and migratory birds (Both et al., 2006). Selection pressure is considered as long-term cause of timing of a life history event, which is the cause of plants idiosyncratic phenology. These pressures vary from biotic types such as seasonal presence of pollinators, dispersers and predators to abiotic constraints such as seasonally unfavorable temperatures and unpredictable rainfall (Fenner, 1998; Badeck et al., 2004; Neil and Wu, 2006).

Phenology is an extremely delicate indicator (Peñuelas et al., 2004; Williams and Abberton, 2004), and thermoperiodic and photoperiodic responses affect flowering time variations from species to species (Holway and Ward, 1965; Khan et al., 2018). Phenological and phenomenological differences of plants are due to the interaction between environment and genotype (Raunkiaer, 1934; Mooney and Billings, 1960; Khan et al., 2019a,b). The ability of some plant species to grow in either early or late growth seasons indicate their ability to survive in harsh environment say least water availability, and low or high temperature (Vashistha et al., 2009; Patel et al., 2010). Any species not responding to climate change might have a risk of shorter growing season as compared to active competitors (Cleland et al., 2012). It has been shown that species not responding to temperature variations have declined significantly in abundance over the past 150 years (Willis et al., 2008), while species adaptive in their phenology with increase of warming have better chance of survival (Cleland et al., 2012). This clearly indicates that temperature variations influence species' capacity of survival (Wang et al., 2018).

According to an estimate, a rise of about 0.74°C is detected in global surface temperature over the past century by International Panel on Climate Change (IPCC, 2007), and resulting glaciers melt, decrease of snow cover, rise in sea level and change in patterns of temperature, wind and rainfall. These fluctuations have likely profound biological effects affecting many taxa in the different geographical regions of the world (Parmesan and Yohe, 2003; Menzel et al., 2006; Parmesan, 2006). For instance, many spring plants now show early leafing and flowering time across the world (Chambers et al., 2013; Schwartz et al., 2013; Ge et al., 2015), while changes in autumn phenological phases are often less obvious, but might have far reaching effects (Menzel et al., 2006; Gill et al., 2015). These studies have shown that the plant phenology phases are important biological indicators of the climate change, and influence all including terrestrial ecosystems (Rosenzweig, 2007).

The Himalayan mountain range is described as ‘‘Water Tower of Asia’’, and its melting glaciers recharge the eight largest rivers in Asia. When compared to the rest of the world, the Himalayan region is facing a relatively more pronounced rise of temperature (Khan et al., 2018) and has been declared the most vulnerable region in the world (Shrestha et al., 2012). These climatic changes are one of the main causes for loss and changes in biodiversity, species composition, shifting of geographical ranges of species, high glacier melting, increase in number of glacial lakes, and associated socioeconomic changes (Chaudhary et al., 2011). The Kashmir Himalaya is well known all over the world for its pleasing beauty. It has been referred to as a ‘Terrestrial Paradise’ (Vigne, 1842). One of the dominant features contributing to the global distinction of Kashmir is the rich biodiversity that embellishes its entrancing landscapes (Lawrence, 1895). Various studies (Shaheen et al., 2011; Nazir et al., 2012; Faiz et al., 2014; Khan et al., 2015, 2016, 2018, 2019a,b) have reported the distribution pattern of plant species and

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communities, life forms, leaf size spectra and flowering phenology of the western Himalayan forests in different parts of Azad Jammu and Kashmir (AJ&K), Pakistan. However, the western Himalayan forests of Dhirkot, AJ&K, Pakistan have remained unexplored, especially related to plant species traits, including life forms, leaf size spectra, and flowering phenology and its determinants. Therefore, documentation of existing interaction among the prevailing climate and flowering phenology of Dhirkot area would help in saving the biodiversity, and explore the following un-answered questions:

1. What about the plant species richness, and composition of major floristic groups, and pattern of biological and leaf size spectra distribution?
2. When majority of vascular plant species enter in flowering phase?
3. How the vascular plant species flowering response is correlated with the current climate?
4. What are the number of statistically significant temporal groups linked to flowering phenological response of the vascular plant species?
5. Which climatic variables are the most influential determinants of the plant species flowering phenological response?

Materials and Methods

Study area

The study area of Dhirkot is a Tehsil of District Bagh, AJ&K, Pakistan, in the western Himalayas, and located 132 km from the capital city of Islamabad. It lies between 73.50-73.69 East longitude and 33.90-34.13 North latitude, covering an area of 231 km^2. The elevation ranges from 603 to 2639 m above sea level (masl). Dhirkot borders district Muzaffarabad in the north, district Poonch in the south, tehsil Harighel of district Bagh in the east, and the river Jhelum in the west (*Fig. 1*). The entire area is a mountainous terrain with generally sloping orientation from North-East to South-West, and covered with thick, green coniferous forests.

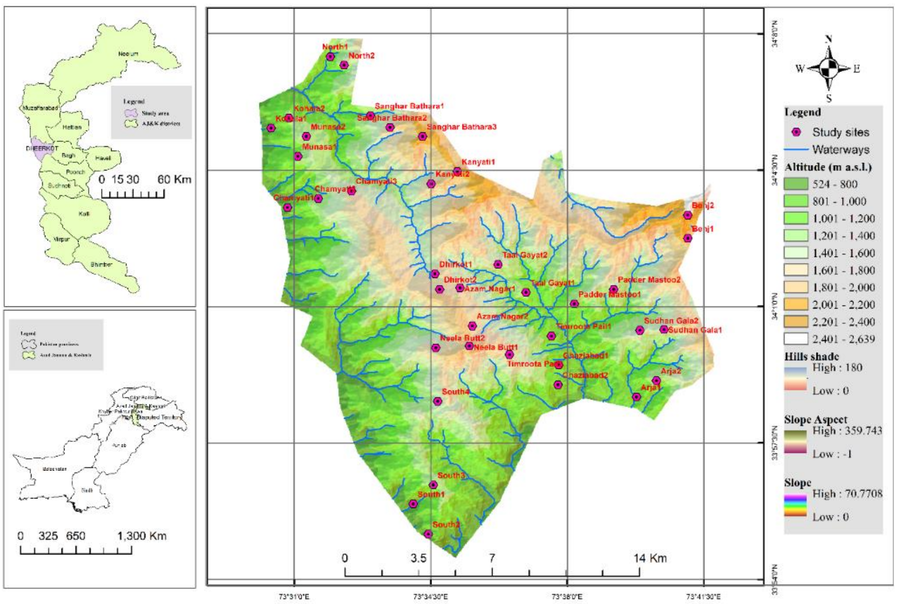

Figure 1. *Map of the study area displaying study locations and topographic variations*

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The forest vegetation of the study area is comprised of western Himalayan mixed temperate forests with dominance of *Pinus wallichiana* (Blue Pine) and *Cedrus deodara* (Deodar). The humid subtropical zone harbors *Pinus roxburghii* (Chir Pine) as abundant species (*Fig. 2*). A total of 15 bird and 20 mammal species are commonly encountered, including globally threatened species like leopard (Khan, 2002). The human population of the area is 36270 based on the population census results of 2017 (Anonymous, 2017). The majority of local communities has inadequate income resources and depends on agro-based activities for their livelihoods. The most important crops include maize, wheat and vegetables, with a major share of tomatoes and potatoes. As the study area is mountainous, terrace cultivation techniques are adopted, and the yield is significantly linked to rainfall patterns in the area.

Figure 2. *Diverse landscape of two elevation zones representing sampled microhabitats (a: subtropical broad leaved evergreen forest zone; b: subtropical evergreen coniferous forest zone; c-d: Himalayan moist temperate forest zone*

Floristic and phenological data collection

A total of 38 randomly selected sites (*Fig. 1*) of the study area are visited on monthly basis (Dates: 11^{th}-20^{th}) from March 2015 to February 2018 (36 months) for collection of plant specimens, and to record the temporal variations in flowering response. The applied observation frequency is appropriate, and the same was also used by Khan et al. (2018). At each site, 3 plots of varying sizes (herbs: 2×1 m; shrubs: 10×5 m; tree: 20×10 m) were laid, and the presence/absence of each plant species (criterion; if more than 50% individuals of any recorded species are found passing through their flowering phase in

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the considered plot/month subsequently counted as present otherwise absent.) were recorded. All the collected plant specimens were pressed, dried and mounted on the standard sized herbarium sheets, followed by identification using *Flora of Pakistan* (http://www.efloras.org/) and other floristic literature (Nasir and Ali, 1970-1989; Ali and Nasir, 1989-1991; Ali and Qaiser, 1993-1995, 2000-2014). After identification, the binomials of each plant species and their family names were copied from the plant list (TPL) ver. 1.1 (http://www.theplantlist.org/) (TPL 2013) to avoid the use of illegitimate and synonymous binomials (Khan et al., 2015, 2016, 2018). The determined voucher specimens were deposited in the herbarium of Department of Botany, Pir Mehr Ali Shah Arid Agriculture University Rawalpindi, Pakistan for future reference and record. Additional information, including local names, Raunkiaer’s biological spectra or life forms (Batalha and Martins, 2002; Khan et al., 2019b) and leaf size spectra (Cain and Castro, 1959) were also recorded for each plant species. Additionally, native or introduced status of each species is recorded along with thier abundance (frequency of occurrence among the studied sites) status and invassive-noninvassive capabilities.

Monthly flowering response (timing and duration) of each plant species is calculated by using the formula conveyed by Khan et al. (2015), and presented in *Eq.1*.

$$SFR\ (\%) = \frac{Species\ found\ in\ flowering\ in\ a\ month\ at\ all\ studied\ sites}{Total\ species\ found\ in\ flowering\ in\ all\ months\ and\ sites} \times 100 \quad \text{(Eq.1)}$$

Where SFR is the monthly species flowering response of the studied plants. Subsequently, monthly responses were averaged to calculate the seasonal flowering response of each plant species say winter (November-February), spring (March-April), summer (May-mid July), monsoon (mid July-mid September), and autumn (mid September-October).

Family richness (FR) was calculated by using the formula (*Eq.2*) as conveyed by Khan et al. (2018).

$$FR\ (\%) = \frac{Species\ belong\ to\ a\ plant\ family}{Total\ species\ recorded\ in\ all\ months\ and\ sites} \times 100 \quad \text{(Eq.2)}$$

Climate data collection

The climate of the area varies considerably on temporal scales. The month of January was recorded as the coldest month in the study area, and minimum temperature varied between -0.35-2 °C during 2015-2018, whereas the month of June was the hottest and maximum temperature varied from 31.32-34.04 °C. The minimum precipitation received in the month of December (varied between 2.79-55.87 mm) and the July was recorded as the wettest receiving maximum (381.29-625.72 mm) (*Supplementary Data Table 2*). The remote sensing based monthly climate data of precipitation, maximum and minimum temperature, specific humidity, soil moisture, wind speed, and short & longwave radiation (36 months) of the study area (Dhirkot) was acquired from the United States National Centers for Environmental Prediction (US-NCEP) Climate Forecast System Reanalysis (CFSR) by using climate engine (https://app.climateengine.org/). The data source was CFSv2 19200 m (1/5-deg) daily reanalysis dataset, National Oceanic and Atmospheric Administration (NOAA) (*Supplementary Data Table 2*). The majority of study area receives precipitation in the form of snowfall from December to mid-March (Khan et al., 2018).

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Statistical analyses

The events of sporogenesis in pteridophytes, strobili development in gymnosperms and flowering in angiosperms were treated as flowering response during each of 36 months at 38 ranodomly selected sites. This response data was entered in Microsoft excel spreadsheets (species vs. month/seasons) as binary data matrix. The total number of plant species found in flowering in each month at all the study sites was calculated and correlated with remote sensing based climatic data by using R statistical package (R Core Team, 2015) to develop pairwise correlation, distribution and scatterplots (Khan et al., 2015, 2018). Hierarchical clustering (Distance: Correlation, Linkage: Ward) was developed using the package "*pvclust*" in the R statistical package. As the species flowering respose data is of binary (presence/absence) nature, detrended correspondence analysis (DCA), a unimodal unconstrained model, was selected to seek the gradient length in the binary compositional response data whereas CCA (a constrained unimodal ordination model) was performed to explore; how much variations in the response data were explained by the studied predictors, and what is their order of importance. Multicollinearity in the climatic variables was detected by observing the variance inflation factor values (VIFs) of each climatic variable, and a threshold value of <5 was selected to remove the highly collinear explanatory variables. If the overall CCA model results found significant (p-value < 0.002), subsequently all the explanatory variables were further tested for their significance and order of importance by using permutation test via both simple (marginal) and conditional (net) term effects testing. All the p-values were corrected by using false discovery rate method. The ordination was performed by using Canoco software (Ter Braak and Smilauer, 2012).

Results

Floristic categorization

A total of 287 vascular plant species belonging to 219 genera and 77 plant families were recorded in the study area. The results of species categorization into major taxonomic groups depicted that there were 8 species (2.79%) of pteridophytes, and distributed in 5 genera (2.28%) and 3 families (3.9%). A total of four species (1.39%) of gymnosperms were recorded, and belong to 3 genera (1.37%) and 2 families (2.6%). The majority of plant species (275 species; 95.8%) belong to angiosperms, and found distributed in 211 genera (96.34%) and 72 plant families (93.5%). Within the latter group, 59 plant species (20.56%) belong to monocotyledons, and distributed in 46 genera (21%) and 6 plant families (7.8%) whereas, 216 species (75.26%) belong to dicotyledons, and distributed in 165 genera (75.34%) and 66 plant families (85.7%) (*Table 1*).

Table 1. *Floral composition of the major plant taxa in the study area*

Taxa	Families (percent)	Genera (percent)	Species (percent)
Pteridophytes	03 (3.9%)	05 (2.28%)	08 (2.79%)
Gymnosperms	02 (2.6%)	03 (1.37%)	04 (1.39%)
Monocots	06 (7.8%)	46 (21%)	59 (20.56%)
Dicots	66 (85.7%)	165 (75.34%)	216 (75.26%)
Total	77	219	287

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The study area was dominated by herbs (212 species; 73.86%), followed by shrubs (33 species; 11.49%), trees (32 species; 11.15%), and climbers group (10 species; 3.48%) (*Supplementary Data Table 1*). The family richness (FR) results showed that Poaceae was the leading family with 41 species (14.28%), followed by Compositae (34 species, 11.84%), Lamiaceae (22 species, 7.66%), Leguminosae (14 species, 4.87%), Cyperaceae (11 species, 3.83%), Rosaceae (10 species, 3.48%), Amaranthaceae and Polygonaceae (8 species each, 2.79%), and Solanaceae (7 species, 2.44%), whereas the remaining plant families were represented by ≤ 6 species (*Supplementary Data Table 1*).

The results of biological (life form) classification of recorded plant species showed the dominance of therophytes with 106 species (36.93%), followed by hemicryptophytes (67 species, 23.34%), phanerophytes (65 species, 22.99%), geophytes (22 species, 7.66%), chamaephytes (16 species, 5.57%), and lianas (10 species, 3.48%). The phanerophytes were further distributed into nanophanerophytes (29 species, 10.10%), mesophanerophytes (21 species, 7.32%), microphanerophytes (10 species, 3.48%), and megaphanerophytes (6 species, 2.09%) (*Fig. 3*). The leaf size spectrum of the recorded vascular flora was dominated by microphylls (137 species, 47.74%), followed by mesophylls (69 species, 24%), nanophylls (56 species, 19.51%), leptophylls (19 species, 6.62%), and macrophylls (6 species, 2.09%) (*Fig. 4*).

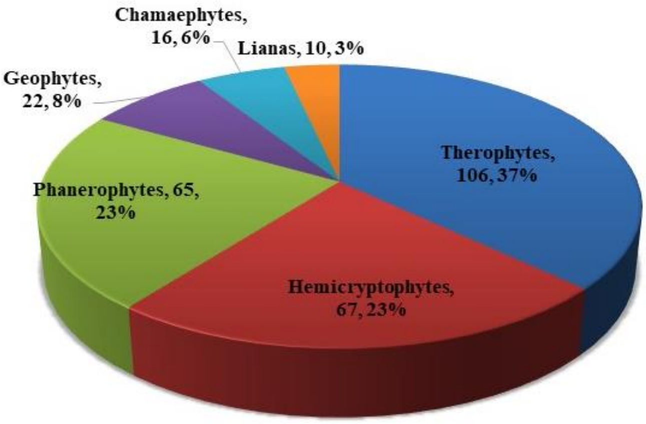

Figure 3. *Graph depicting the distribution of recorded vascular plant species into different life form classes*

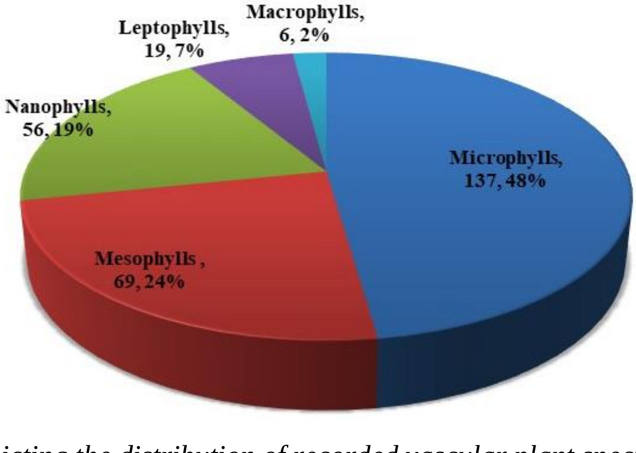

Figure 4. *Graph depicting the distribution of recorded vascular plant species into different leaf size classes*

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A total of 234 plant species (81.5%) were native of the area, and 53 (18.5%) are introduced ones. Similarly, on the basis of frequency of occurrence of the recorded plant species among the studied sites, 110 (38.3%) were very common, 101 (35.2%) were common, 55 (19.2%) were rare, and 21 (7.3%) were very rare. A total 48 plant species (16.7%) were recorded as highly invassive in the study area (*Supplementary Data Table 1*).

Flowering phenology

The results of flowering response of the recorded plant species showed that majority of plant species (185 species, 64.46%) were in flowering phase during the month of July, followed by August (182 species, 63.41%), June (167 species, 58.19%), and September (145 species, 50.52%). The least response was observed in the month of December (14 species, 4.88%) and January (13 species, 4.53%) (*Fig. 5*). The flowering phenology response results indicated that most of the plant species go through their initial reproductive phase (flowering) from March to October.

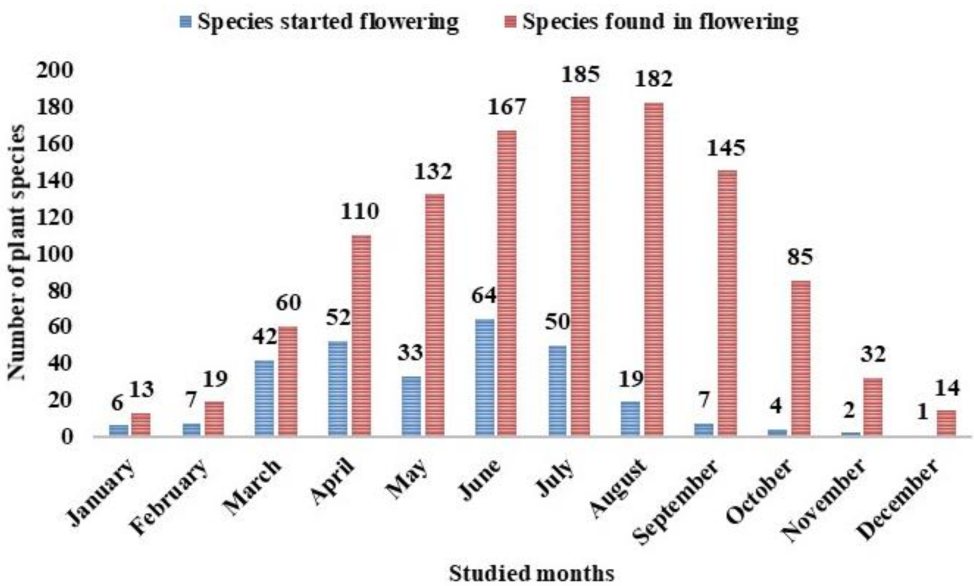

Figure 5. *Graph depicting the variations in flowering phenology of the recorded vascular plant species during studied months (each monthly value represent the cumulative number of 36 studied months/3 years: March-2015 to February-2018)*

As far as the results of initiation of flowering event during the studied months are concerned, majority of plant species were entered in flowering phase in the month of June (64 species, 22.3%), followed by April (52 species, 18.12%), July (50 species, 17.42%), and March (42 species, 14.63%), whereas, least species were found entering in their flowering phase in the month of December (1 species, 0.35%), followed by November (2 species, 0.7%), October (4 species, 1.39%), and January (6 species, 2.09%) (*Fig. 5*).

The results of Pearson's correlation and its significance depicted that the total plant species found in flowering phase in different months (SFR%) was strongly correlated ($r > 0.8$) with the mean monthly values of five different climatic variables. These includes mean minimum temperature ($r = 0.93$), shortwave radiation ($r = 0.93$), longwave radiation ($r = 0.92$), mean maximum temperature ($r = 0.89$), and mean specific humidity ($r = 0.88$).

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Similarly, precipitation was found moderately positively correlated (r = 0.49). A strong negative correlation was observed with wind speed (r = -0.69), whereas no correlation of flowering abundance was observed with the soil moisture of the study area (*Fig. 6*).

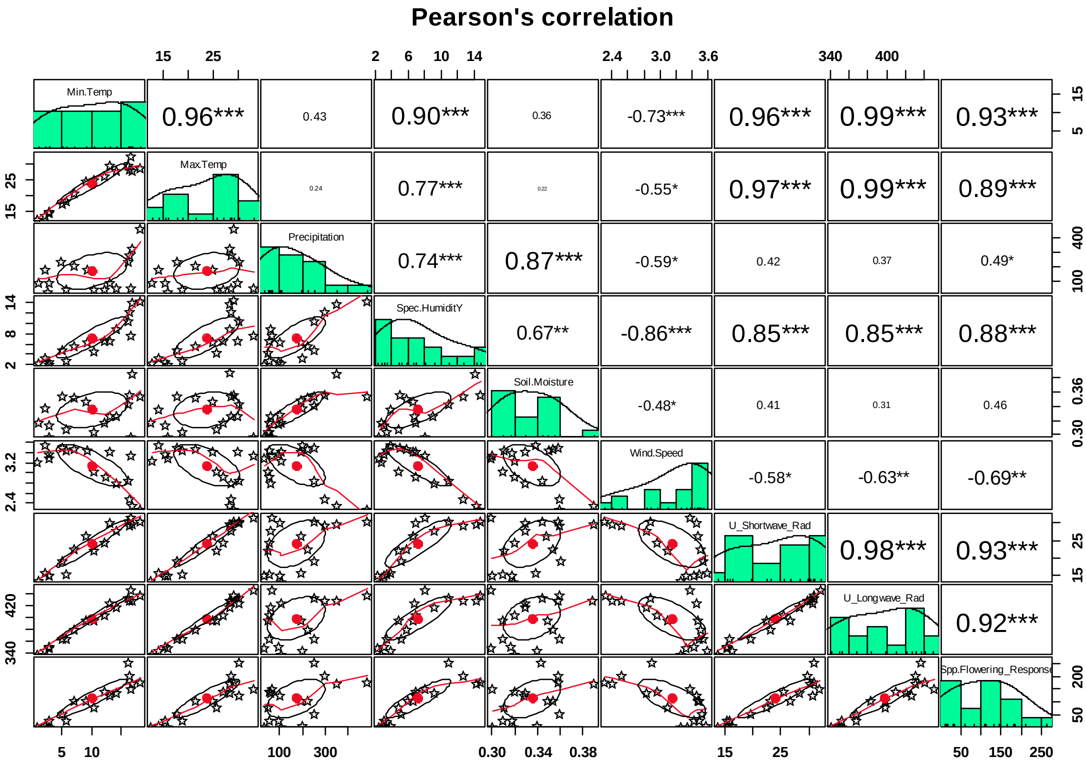

Figure 6. *Pearson correlation and its significance of climatic and SFR (n = 17; months = 12 & seasons = 5) variables. The distribution of each studied variable is shown on the diagonal, the bottom of the diagonal has bivariate scatter plots with a fitted line, and ellipses are displayed. Top of the diagonal has the correlation values coupled with significance levels as stars, representing p-values ("***" ≤ 0.001; "**" ≤ 0.01; "*" ≤ 0.05; " " > 0.05)*

Similarly, the month of June is found strongly correlated with the summer season on the basis of plant species flowering response. The months of July and August were detected as representative of monsoon season when the majority of flowering responses were observed. April was the main representative of the spring season which last from March to May. The winter season with least flowering response was primarily comprised of the months from November to February (*Fig. 7*).

Hierarchical clustering of months and seasons results were closely related to the pairwise correlation (*Fig. 7*). The dendrogram tree depicted that there were four significantly (p-value <0.05) different groups of months and seasons in the study area based on timing of plant species flowering response. The values given in green and red font colour above each cluster represent the approximately bootstrapped probability (BP %) and unbiased (AU %) p-values respectively. Likewise, the grey colored values below each cluster show the order of clustering (*Fig. 8*).

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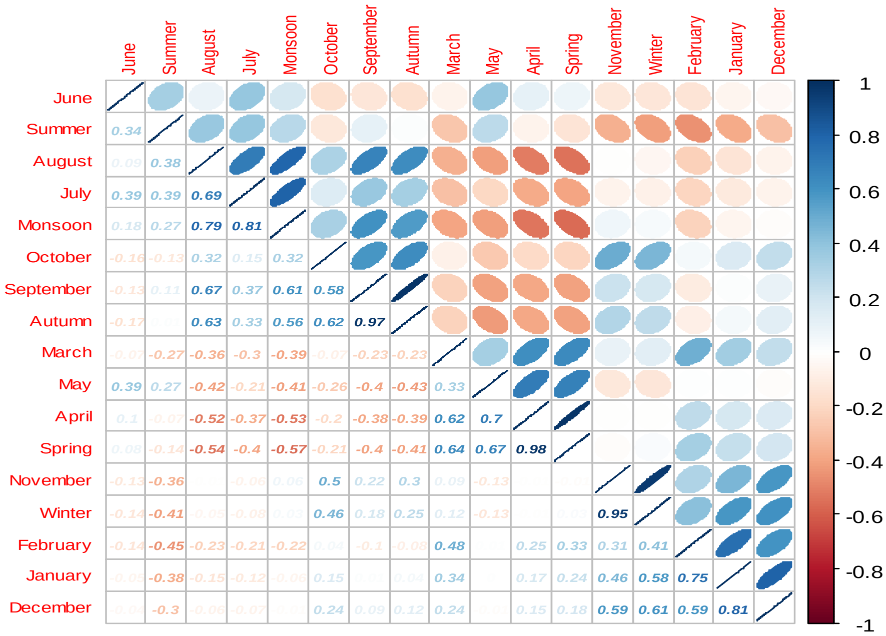

Figure 7. *Pairwise correlation plot of months and seasons based on plant species flowering phenological response (n = 287 plant species)*

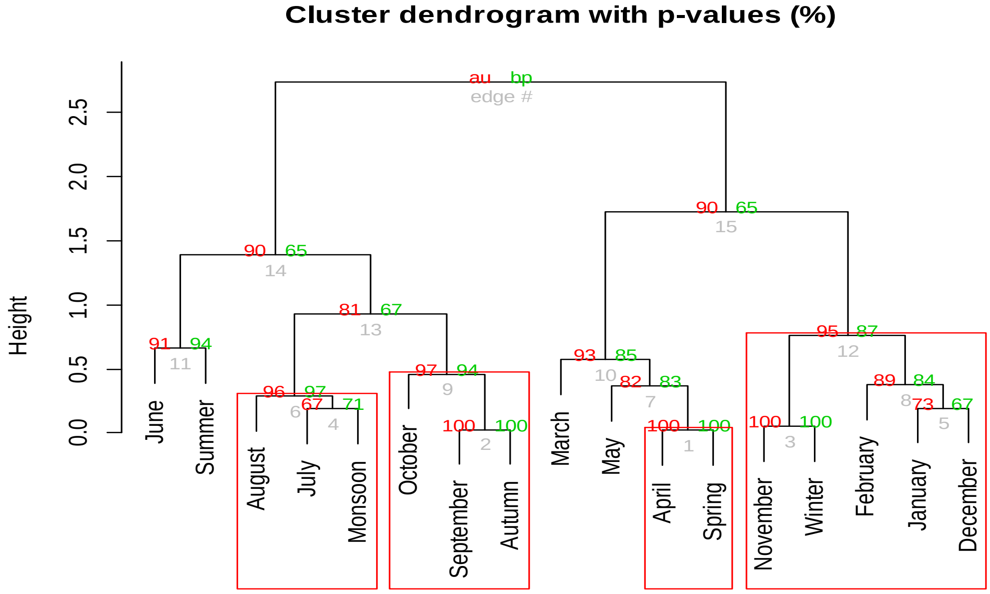

Figure 8. *Hierarchical clustering tree of months and seasons (distance method: correlation; linkage method: Ward) with AU/BP% values based on plant species flowering phenological response (Red colored rectangle around the clusters represents significant (p-value ≤ 0.05) response difference)*

Ordination analysis

The DCA results showed that the gradient length in the response data was above 4 SD (standard deviation of species turnover) for the first two DCA axes, hence, depicted that

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use of a unimodal like DCA is more appropriate in this study than say principal component analysis (PCA: a linear model). The DCA results also confirmed the results of hierarchical clustering, and the same four groups are found well distincntly distributed in the ordination space. After removal of highly collinear, final CCA model is comprised of four predictors, including minimum temperature, wind speed, precipitation, and soil moisture (25 cm below the soil surface). A total inertia of 1.38 was recorded in the flowering phenology response data, and about 63.7% (R^2: 0.637) variations were explained by the explanatory variables, and the adjusted explained variations were 51.6% (adjusted R^2: 0.516). The first two CCA axes cumulatively explained about 55% variations. A significantly high pseudo-canonical correlation ($r > 0.8$) value was observed for the first three CCA axes which depict that the selected predictors were important determinants, and there is no single important climatic gradient rather all the four were important in one way or another.

The overall CCA model results were significant (pseudo-F: 2.7; p-value < 0.002), and based on simple term effects testing, the mean minimum temperature was detected as leading driver (explained variations: 27.2%; p-value [adj]: 0.004) of the flowering phenological response. It was followed by wind speed, precipitation and soil moisture. In case of conditional (unique) term effect testing, precipitation surpassed wind speed in order of importance. The study area received maximum precipitation in the months July and August during monsoon, and the same months/season were found highly suitable for flowering by the vascular plant species. These results are confirmed by CCA, and precipitation was detected as second most important determinant followed by wind speed which might be another important determinant as prerequisite for successful pollination of many species. Similarly, soil moisture was another influential determinant. The CCA numerical and graphical results are presented in *Table 2* and *Fig. 9*, respectively. The CCA biplot of months/seasons and climatic predictors showed that minimum temperature was highly correlated with the months of June, July and August, and Monsoon season, whereas wind speed was relatively higher than the average for spring season including March and April months (*Fig. 9*).

Table 2. *Summary of canonical correspondence analysis results and contribution of climatic variables in driving of flowering phenological response*

Statistic	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.4545	0.3134	0.0598	0.0529
Explained variation (cumulative)	32.86	55.51	59.84	63.67
Pseudo-canonical correlation	0.9781	0.9449	0.8159	0.7173
Explained fitted variation (cumulative)	51.61	87.2	93.99	100
Simple Term Effects:				
Name	Explains %	pseudo-F	P	P(adj)
Min. Temp (°C)	27.2	5.6	0.002	0.004
Wind speed (m/sec)	23.5	4.6	0.002	0.004
Precipitation (mm)	7	1.1	0.33	0.438
Soil moisture (25cm; in fraction)	5.8	0.9	0.438	0.438
Conditional Term Effects:				
Name	Explains %	pseudo-F	P	P(adj)
Min. Temp (°C)	27.2	5.6	0.002	0.008
Precipitation (mm)	15.9	4.9	0.004	0.008
Wind speed (m/sec)	14.6	3.5	0.008	0.01067
Soil moisture (25cm; in fraction)	6	2	0.028	0.028

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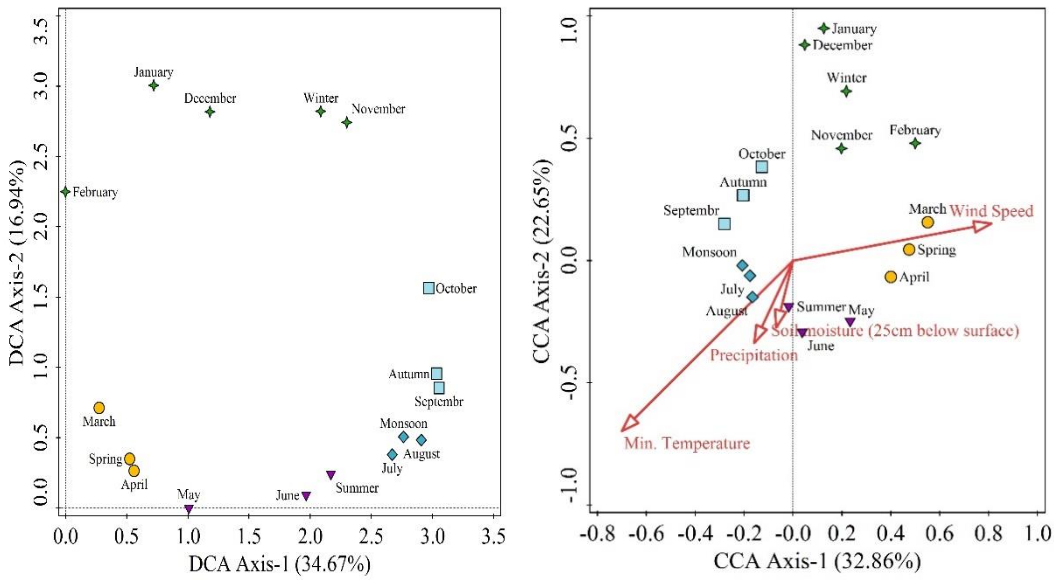

Figure 9. *DCA scatterplot and CCA biplot presenting the distribution pattern of months and seasons based on flowering response of plant species, and role of climatic variations respectively*

Discussion

Floristic classification and its importance

The study area of Dhirkot (AJ&K), Pakistan is a mountainous terrain, part of western Himalaya, and rich in floristic diversity. The present study was conducted to record the floristic composition of the area along with various attributes including biological spectra, leaf size spectra, flowering phenology and flowering phenological response of the vascular plant species along the prevailing climatic gradients.

A total of 287 vascular plant species were documented, and Poaceae was the leading family followed by Compositae and Lamiaceae. The present work showed a striking similarity with the floristic composition of Qalagai hills, Kabal valley, Swat (Ilyas et al., 2013) who also reported Poaceae (22 spp.) as dominant plant family followed by Compositae (16 spp.) and Lamiaceae (14 spp.). Similarly, Shaheen et al. (2015) also reported the same order of family richness from the western Himalayan subtropical forest stands of Kashmir. Other results similar to our findings include the work of Khan et al. (2014) from Shahbaz Garhi, district Mardan, Pakistan, Tanvir et al. (2014) from district Bagh, AJ&K, Pakistan, Khan et al. (2015) from district Kotli, AJ&K, Pakistan, and Khan et al. (2017) from Swat Ranizai, district Malakand, Khyber Pakhtunkhwa, Pakistan. The dominance of Poaceae and Compositae are due to their wide ecological amplitude within diverse habitat (Ibrahim et al., 2019). The common presence of grazing animals contributes to the spread of grasses. Grasses often quickly colonize any area (Attenborough, 1984). Similarly, Compositae is the largest family within angiosperms and possibly it is the most successful in evolutionary traits. Plant species of Compositae and Lamiaceae are economically and medicinally important in the western Himalaya, so people might transport them from one place to another resulting their quick spread to newly available habitats.

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Biological spectra and its significance

The biological (life form) classification results depicted the dominance of therophytes followed by hemicryptophytes, phanerophyte, geophytes, Chamaephytes, and lianas. These results closely resemble with the results of Qalagai hills, Kabal valley, Swat-Pakistan (Ilyas et al., 2013), who reported therophytes as dominant followed by hemicryptophytes and macrophanerophytes. Other similar results include the studies conducted by Khan et al. (2014) from Shahbaz Garhi, district Mardan, Pakistan, Shaheen et al. (2015) from the western Himalayan subtropical forests of Kashmir, Khan et al. (2019c) from Mandan, district Bannu, Pakistan, Ishaq et al. (2019) from Derikot Selai Pattay district Malakand, Pakistan, and sililarly match with many otheres (Malik, 1986; Malik and Malik, 2004; Ajaib et al., 2008; Nazir et al., 2014). Although, life form can be used as an indicator or response towards the climate, Raunkiaer (1934) suggested that anthropogenic disturbances also contribute towards life form variations. Therophytes are usually considered as characteristics of harsh environmental conditions and hemicryptophytes as indicators for the temperate region with cold humid climate (Cain and Castro, 1959; Shimwell, 1971; Batalha and Martins, 2002). Hence, the dominance of therophytes in the study area may also be due to population pressure, over grazing, land modification for terrace cultivation and deforestation (Shehzad et al., 1999; Ilyas et al., 2013). In addition, winter drought might be an important factor continuously pushing plant species to a therophytes life form, and the presence of perennating structures just under the soil surface (hemicryptophytes) to pass the unfavorable environment is also common. The dominance of hemicryptophytes might be due to the extreme cold environment in winter, as well as heavy biotic stress due to overgrazing and deforestation (Nazir et al., 2014). On the other hand, the reasonable contribution of phanerophytes showed that the study area provide an ample environment for Himalayan forest tree species, e.g., *Pinus wallichiana* A.B. Jacks., *Pinus roxburghii* Sarg., *Cedrus deodara* (Roxb. ex D. Don) G. Don, *Quercus baloot Griff., Quercus incana Bartram, Acacia nilotica (*L.*) Delile* (Khan et al., 2017). Overall the thero-hemicryptophytic flora of the study area shows adaptations to avoid the harsh and long winter season, although the conifers and few sclerophyllous plant species remain active around the year (Ilyas et al., 2013).

Leaf size spectra and its significance

The leaf size spectrum of the vascular flora was dominated by microphylls, followed by mesophylls, nanophylls, leptophylls, and macrophylls. Our results resemble with the study conducted in Swat Ranizai, district Malakand, Khyber Pakhtunkhwa, Pakistan (Khan et al., 2017). Similarly, Khan et al. (2011) reported the dominance of microphylls followed by mesophylls and nanophylls from Darra Adam Khel, Khyber Pakhtonkhwa, Pakistan. In addition, Ishaq et al. (2019) from Derikot Selai Pattay district Malakand, Pakistan, Khan et al. (2014) from Shahbaz Garhi, district Mardan, Pakistan also reported the dominance of microphylls, and in many other studies (Amjad, 2012; Ilyas et al., 2013; Ibrahim et al., 2019). Leaf sizes of microphylls, mesophylls and nanophylls classes dominate in the flora of Dhirkot. Large sized leaves (mesophylls and macrophylls) are characteristic of wet warmer climates coupled with high precipitation, while the dominancy of small sized leaves (microphylls) are common in degraded dry habitats coupled with cold climates. The appearance of microphylls and nanophylls in the study area might be an adaptation to arid conditions. The majority of study area faces a long

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drought period, especially during autumn and winter). Leaf size generally increases with increasing rainfall and declines with increasing irradiance and elevation (Khan et al., 2014). Therefore, the dominance of microphylls was positively associated with the increasing altitude, as also found by (Dewald and Steiner, 1986; Khan, 2013). Microphylls and nanophylls are the features of temperate regions (Cain and Castro, 1959; Shimwell, 1971), and climatically the study area of Dhirkot is also situated in the temperate zone. The dominance of mesophylls may be due to reasonable monsoon rainfall, and some unique microhabitats harboring rare and valuable plant species in the area (*Fig. 10*).

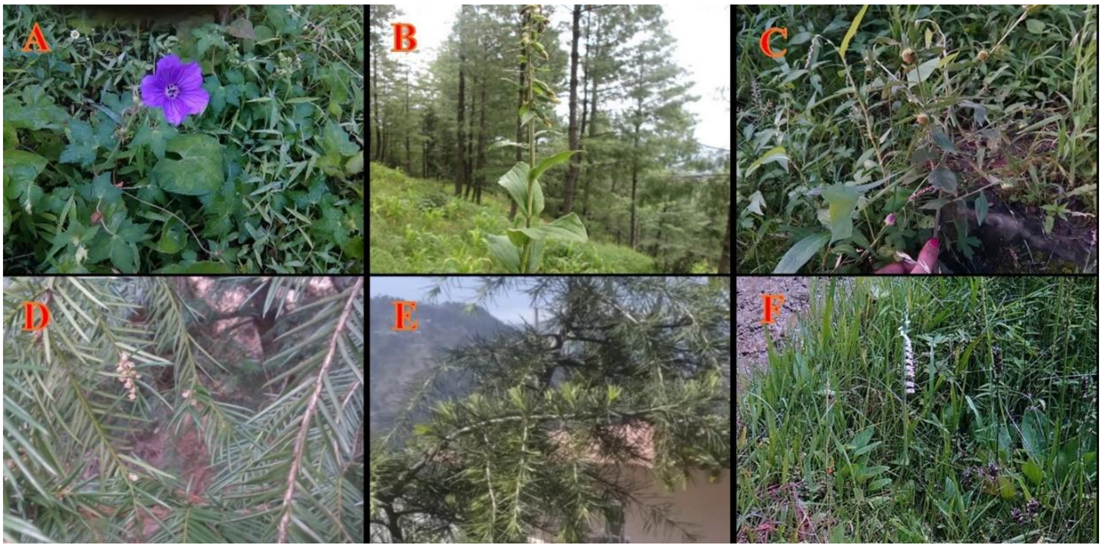

Figure 10. *A figure displaying some rare vascular plants in flowering phase (A) Geranium wallichianum (B) Epipactis helleborine (C) Carpesium cernuum (D) Taxus wallichiana and (E) Cedrus deodara (F) Spiranthes sinensis in the study area*

Climatic determinants of flowering phenology

The flowering phenology results showed that a majority of species were found in flowering phase during the month of July, followed by August, June, and September. Our results match with Vashistha et al. (2009) and Khan et al. (2018) who conveyed that majority of plant species pass through their flowering phase during July and August in the Western Himalayan regions of India and Muzaffarabad, AJ&K, Pakistan respectively. The results of this study are positively associated with the temporal climatic variations (especially temperature and monsoon rainfall) of the study area. CCA (simple term effects testing) results depicted the significant importance of four predictors including minimum temperature, wind speed, precipitation, and soil moisture (25 cm below the soil surface), whereas conditional (unique) term effects testing suggested the order of importance as mean minimum temperature followed by precipitation, wind speed and soil moisture. Many workers detected the importance and significance of temperature to the plant phenological responses (Dewald and Steiner, 1986; Badeck et al., 2004; Peñuelas et al., 2004; Ahas and Aasa, 2006; Estrella and Menzel, 2006) particularly in high altitude areas. Similarly, Khan et al. (2018) concluded that variations in the minimum temperature are more important than the maximum temperature in driving the flowering phenological variations. Precipitation was the second important determinant of the flowering

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phenological response in the study area, and Pearson (2019) reported the similar effect of precipitation on both spring and fall-flowering events from Southeast USA. Wind plays an important role in the dispersal of winged seeds over long distance (Heydel et al., 2015), and was also observed as a central factors. Our findings are alike to Khan et al. (2018) in this regard. The majority of plant species flowers in summer (July, August and June) season, so it is predicted that the months of May and June provide the essential prerequisite photo-thermic stimulus. The highest flowering phenological response of plant species from July to August can also be correlated with maximum precipitation in these months (monsoon season) resulting in higher soil moisture which in turn might resulted in required resource mobilization in the soil of the study area. A few plant species were also found in flowering stage in December to February (in winters) months depicting their unique evolutionary capabilities.

This study found that western Himalayan forests are richly diverse, and lead by Poaceae, Compositae, and Lamiaceae members. Similalrly, there is dominancy of therophytic life form and microphyllous leaf size characteristics of the vascular plant species in the study area. July and August months or monsoon season was detected as the most suitable time for plant species to pass their flowering phase, and SFR was found strongly correlated with the current climate of the study area. Intiation of flowering response was bimodal, first peak is detected in the month of April and second one in June. There were four significant groups of months/seasons linked to SFR, and monsoon season is the leading one. Mean minimum temperature, precipitation, wind speed and soil moisture in order were detected as leading drivers of flowering phenological response of the recorded plant species in the study area.

Conclusions and Recommendations

The study area (Dhirkot, AJ&K Pakistan) harbors high plant species richness characteristics of the floristically rich and highly diverse western Himalaya of Pakistan. The dominancy of therophytic and microphyll classes suggested that the study area is under heavy anthropogenic pressure and harbors unique climatic conditions. Minimum temperature, precipitation, wind speed and soil moisture (in order) were the most important climatic determinants of flowering phenology of the recorded plant species. Based on these findings we further predict that any change especially in temperature and precipitation in the area will change flowering phenological response which might prove detrimental. The resultant negative impact on many extremely rare, endangered and endemic flora including *Cedrus deodara, Taxus wallichiana, Notholirion thomsonianum, Epipactis helleborine, Aristolochia punjabensis, Jurinea dolomiaea, Swertia chirayita, Mimosa himalayana*, *Paeonia emodi* and *Skimmia laureola* might result in biodiversity loss. The study area needs effective management and conservation plans for sustainable development, and future studies that focus on determination of ecological niche variations of valuable plant species under predicted climate change scenarios are required. The population of invasive alien plant species like *Ailanthus altissima*, *Broussonetia papyrifera, Erigeron bonariensis, Lantana camara,* and *Parthenium hysterophorus* needed to be continuously monitored in the study area.

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Author contributions. NK was involved in field data collection, and preparation of the preliminary draft; AMK developed study design, and did multivariate data analyses, results interpretation, revision and formating, NZ was involved in methodology, ZS did literature search, RWB did language editing and corrections, and RQ conceived the idea and overall supervised all the research activities.

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APPENDIX

Supplementary Data Table 1. *Floristic list of the vascular plants species of Dhirkot, district Bagh, and their various attributes*

Family	Species names and Voucher No.	Local name	Habit	Life forms	Leaf spectra	Phenology	Status
			Pteridophytes				
Aspleniaceae	*Asplenium dalhousiae* Hook. / NK98	Alaf jarhi	H	G	Mep	Jun-Dec	Native [Ra, NI]
Dryopteridaceae	*Dryopteris ramosa* (C. Hope) C. Chr. / NK99	Kunji	H	G	Map	Jun-Sep	Native [Ra, NI]
Pteridaceae	*Adiantum capillus-veneris* L. / NK100	Kakwai	H	G	Mip	May-Aug	Native [Ra, NI]
	Adiantum raddianum C. Presl / NK101	Parsoshan	H	G	Mep	Jun-Sep	Introduced [Ra, NI]
	Adiantum venustum D. Don / NK102	Kakwai	H	G	Mip	May-Aug	Native [VC, NI]
	Onychium japonicum (Thunb.) Kunze / NK103	Kunji	H	G	Map	Jun-Sep	Introduced [Ra, NI]
	Pteris cretica L. / NK104	Nanoor	H	Hc	Map	Jun-Aug	Native [Co, NI]
	Pteris vittata L. / NK105	Nanoor	H	G	Map	Jun-Aug	Native [Co, NI]
			Gymnosperms				
Pinaceae	*Cedrus deodara* (Roxb.ex D. Don) G.Don / NK106	Deyaar	T	Mp	Lep	Oct-Nov	Native [Ra, NI]
	Pinus roxburghii Sarg. / NK107	Chir	T	Mp	Lep	Mar-Apr	Native [VC, NI]
	Pinus wallichiana A.B.Jacks. / NK108	Beyaarh	T	Mp	Lep	Apr-Jun	Native [VC, NI]
Taxaceae	*Taxus wallichiana* Zucc. / NK109	Tooni	T	Ms	Lep	Feb-Mar	Native [Ra, NI]
			Monocotyledons				
Araceae	*Arisaema jacquemontii* Blume / NK110	Sap booti, Cobra plant	H	G	Mep	Jun-Jul	Native [Ra, NI]
	Sauromatum venosum (Dryand. ex Aiton) Kunth / NK111.	Adbees	H	G	Mep	Apr-May	Native [Co, NI]

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Family	Species names and Voucher No.	Local name	Habit	Life forms	Leaf spectra	Phenology	Status
Commelinaceae	*Commelina benghalensis* L. / NK112	Kanteri, Chura	H	Th	Mip	Jun-Sep	Native Co, NI
Cyperaceae	*Carex brunnea* Thunb. / NK113	Kangri malla	H	Th	Nap	Jul-Aug	Native Ra, NI
	Cyperus arenarius Retz. / NK114	Unavailable	H	G	Nap	Mar-May	Native Co, NI
	Cyperus compressus L. / NK115	Elegant sedge	H	Th	Lep	Jul-Oct	Native C0, NI
	Cyperus difformis L. / NK116	Daila	H	Hc	Nap	Jul-Oct	Native Co, NI
	Cyperus iria L. / NK117	Bhoian	H	Th	Mip	May-Oct	Native VR, NI
	Cyperus niveus Retz. / NK118	Snow white	H	Hc	Nap	Apr-Jun	Native Ra, NI
	Cyperus rotundus L. / NK119	Nagarmotha	H	G	Nap	Apr-Oct	Native Co, In
	Cyperus serotinus Rottb. / NK120	Unavailable	H	Th	Nap	Jul-Sep	Native Ra, NI
	Eriophorum comosum (Wall.) Nees / NK121	Babya	H	Hc	Mip	Jul-Sep	Native VC, NI
	Fimbristylis bisumbellata (Forssk.) Bubani / NK122	Choti bhuini	H	Th	Nap	Jul-Oct	Native Co, NI
	Fimbristylis dichotoma (L.) Vahl / NK123	Choti bhuini	H	G	Nap	Aug-Oct	Native Co, NI
Liliaceae	*Notholirion thomsonianum* (Royle) Stapf / NK124	Hazara lily	H	G	Mip	Apr-May	Native Ra, NI
	Tulipa clusiana DC. / NK125	Kakarh mula	H	G	Mip	Mar-May	Native Co, NI
Orchidaceae	*Epipactis helleborine* (L.) Crantz / NK126	Koka maki	H	G	Mip	Jun-Aug	Native Ra, NI
	Spiranthes sinensis (Pers.) Ames / NK127	Chitti batti	H	G	Nap	May-Sep	Introduced VR, NI
Poaceae	*Agrostis canina* L. / NK128	Kaah	H	Th	Nap	Jul-Aug	Native VC, NI
	Agrostis gigantea Roth / NK129	Kaah	H	Hc	Mip	Jun-Aug	Native VC, NI
	Apluda mutica L. / NK130	Ghagari	H	Hc	Nap	Aug-Nov	Native Co, NI
	Aristida funiculata Trin. & Rupr. / NK131	Lamb	H	Th	Mip	Jun-Sep	Native Co, NI

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Family	Species names and Voucher No.	Local name	Habit	Life forms	Leaf spectra	Phenology	Status
	Arundinella nepalensis Trin. / NK132	Garali	H	G	Mip	Sep-Nov	Native VC, NI
	Arundo donax L. / NK133	Nari	H	Hc	Map	Jun-Oct	Native Co, In
	Avena fatua L. / NK134	Jwaan seela	H	Th	Nap	May-Aug	Native VC, NI
	Brachiaria ramosa (L.) Stapf / NK135	Kanderi	H	Th	Mip	Jul-Oct	Native Co, NI
	Brachypodium sylvaticum (Huds.) P. Beauv. / NK136	Bitkaai	H	Th	Mip	Jun-Sep	Native VC, NI
	Bromus catharticus Vahl / NK137	Tank	H	Hc	Mip	Apr-Jun	Introduced VC, NI
	Chrysopogon gryllus (L.) Trin. / NK138	Bari kaah	H	Hc	Nap	Jun-Aug	Native VC, NI
	Chrysopogon serrulatus Trin. / NK139	Jargi kaah	H	Hc	Nap	Jun-Aug	Native Co, NI
	Cymbopogon jwarancusa (Jones) Schult. / NK140	Khawi	H	Hc	Nap	Mar-May	Native Ra, NI
	Cynodon dactylon (L.) Pers. / NK141	Khabbal	H	Hc	Lep	Whole year	Native VC, NI
	Dactylis glomerata L. / NK142	Samaki	H	Hc	Mip	Jul-Aug	Native Co, NI
	Dactyloctenium aegyptium (L.) Willd. / NK143	Madhani kaah	H	Th	Nap	Jul-Oct	Native Ra, NI
	Dichanthium annulatum (Forssk.) Stapf / NK144	Murgha kaah	H	Hc	Lep	Mar-Oct	Native Co, NI
	Digitaria sanguinalis (L.) Scop. / NK145	Tarakhni malla	H	Hc	Mip	Jul-Sep	Native VC, NI
	Digitaria violascens Link / NK146	Tarakhni malla	H	Hc	Mip	Jul-Aug	Native VC, NI
	Echinochloa colona (L.) Link / NK147	Malla kaah	H	Th	Mip	May-Sep	Native Co, NI
	Eleusine indica (L.) Gaertn. / NK148	Goose grass	H	Th	Mip	Jun-Aug	Native Co, NI
	Eragrostis pilosa (L.) P. Beauv. / NK149	Barboori	H	Th	Mip	Jul-Oct	Native VC, NI

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Family	Species names and Voucher No.	Local name	Habit	Life forms	Leaf spectra	Phenology	Status
	Heteropogon contortus (L.) P. Beauv. ex Roem. & Schult. / NK150	Sureli	H	Hc	Mip	Jun-Oct	Native VC, NI
	Leptochloa panicea (Retz.) Ohwi / NK151	Kaah	H	Th	Mip	Sep-Nov	Native VC, NI
	Oplismenus compositus (L.) P.Beauv. / NK152	Malla	H	Hc	Mip	Aug-Sep	Native Co, NI
	Oplismenus undulatifolius (Ard.) Roem. & Schult. / NK153	Malla	H	Hc	Mip	Aug-Sep	Native VC, NI
	Paspalidium flavidum (Retz.) A.Camus / NK154	Kangna	H	Hc	Mip	Jul-Oct	Native Co, NI
	Paspalum distichum L. / NK155	Daila	H	Hc	Nap	Apr-May	Introduced Ra, NI
	Pennisetum flaccidum Griseb. / NK156	Manehra kaah	H	Hc	Mip	Jun-Oct	Native VC, NI
	Pennisetum glaucum (L.) R. Br. / NK157	Phulai	H	Hc	Mip	Jun-Aug	Introduced Co, NI
	Pennisetum orientale Rich. / NK158	Phulai	H	Hc	Mip	Apr-Oct	Native Co, NI
	Phalaris minor Retz. / NK159	Dumbi sitti	H	Th	Mip	Mar-May	Native Co, NI
	Piptatherum munroi (Stapf ex Hook. f.) Mez / NK160	Smilo grass	H	Hc	Mip	Jun-Sep	Native VC, NI
	Poa annua L. / NK161	Kaah	H	Th	Mip	Mar-Sep	Native VC, NI
	Polypogon viridis (Gouan) Breistr. / NK162	Pochar	H	Hc	Mep	May-Aug	Native VC, NI
	Saccharum spontaneum Linn. / NK163	Kamath	H	Hc	Mip	Jul-Sep	Native VC, NI
	Setaria pumila (Poir.) Roem. & Schult. / NK164	Kangri mallo	H	Th	Mip	Jun-Oct	Native VC, In
	Setaria viridis (L.) P. Beauv. / NK165	Kangrel	H	Th	Mip	Jun-Sep	Native VC, NI
	Sorghum halepense (L.) Pers. / NK166	Barru kaah	H	G	Mip	May-Oct	Native VC, In

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Family	Species names and Voucher No.	Local name	Habit	Life forms	Leaf spectra	Phenology	Status
	Themeda anathera (Nees ex Steud.) Hack. / NK167	Samaki	H	Hc	Nap	Jun-Oct	Native [VC, NI]
	Tragus berteronianus Schult. / NK168	Unavailable	H	Th	Nap	Nov-Apr	Native [Ra, NI]
		Dicotyledons					
Acanthaceae	*Dicliptera bupleuroides* Nees / NK169	Somni	H	Hc	Nap	Jun-Oct	Native [VC, NI]
	Dicliptera paniculata (Forssk.) I. Darbysh. / NK170	Toot tallo	H	Th	Mip	Dec-Feb	Native [VC, NI]
	Justicia adhatoda L. / NK171	Bekarh	S	Np	Mep	Jul-Oct	Native [VC, NI]
	Strobilanthes urticifolia Wall. ex Kuntze / NK172	Bekarhi	H	Ch	Mep	Jun-Oct	Native [VC, In]
Adoxaceae	*Viburnum grandiflorum* Wall. ex DC / NK173	Guch	S	Np	Mep	Nov-Jun	Native [VC, NI]
Amaranthaceae	*Achyranthes aspera* L. / NK174	Puth kanda	H	Ch	Mip	Jul-Oct	Native [VC, In]
	Alternanthera pungens Kunth / NK175	Bakharha	H	Th	Mip	Aug-Oct	Introduced [Co, NI]
	Amaranthus caudatus L. / NK176	Baghi ganehr	H	Th	Mep	May-Aug	Introduced [Co, NI]
	Amaranthus hybridus L. / NK177	Surkh ganehr	H	Th	Mip	Jul-Oct	Introduced [VC, In]
	Amaranthus retroflexus L. / NK178	Ganehr	H	Th	Mip	Jul-Sep	Introduced [Co, NI]
	Amaranthus viridis L. / NK179	Ganehr	H	Th	Mip	Mar-Oct	Introduced [VC, In]
	Chenopodium album L. / NK180	Bathwa	H	Th	Mip	May-Oct	Native [VC, In]
	Digera muricata (L.) Mart. / NK181	Tandla	H	Th	Mip	Aug-Sep	Native [Co, NI]
Anacardiaceae	*Cotinus coggygria* Scop. / NK182	Pann	S	Np	Mip	Apr-May	Native [Co, NI]
Apiaceae	*Bupleurum falcatum* L. / NK183	Patti	H	Hc	Nap	Jun-Oct	Native [Co, NI]

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Family	Species names and Voucher No.	Local name	Habit	Life forms	Leaf spectra	Phenology	Status
	Conium maculatum L. / NK184	Morkach	H	Hc	Mip	Jun-Aug	Native [Co, NI]
	Foeniculum vulgare Mill. / NK185	Saunf	H	Hc	Nap	Aug-Oct	Native [VR, NI]
	Pimpinella stewartii Nasir / NK186	Unavailable	H	Ch	Nap	Jun-Aug	Native [Co, NI]
Apocynaceae	*Nerium oleander* L. / NK187	Kaneera	S	Np	Mip	Apr-Oct	Native [VC, In]
Araliaceae	*Hedera helix* L. / NK188	Batkal, Harhbamal	C	L	Mip	Oct-Apr	Native [Co, NI]
Aristolochiaceae	*Aristolochia punjabensis* Lace / NK189	Kutyari, kuttay booti	S	Np	Mip	Jun-Jul	Native [Ra, NI]
Balsaminaceae	*Impatiens edgeworthii* Hook. f. / NK224	Bantil	H	Th	Mep	Jul-Sep	Native [VC, NI]
Berberidaceae	*Berberis lycium* Royle / NK225	Sumbal	S	Np	Nap	Apr-Jun	Native [VC, NI]
Boraginaceae	*Cynoglossum lanceolatum* Forssk. / NK226	Churoon	H	Th	Mip	Jun-Aug	Native [VC, NI]
	Cynoglossum wallichii Var. *glochidiatum* (Wall. ex Benth.) Kazmi / NK227	Phulari jarhi	H	Th	Mip	May-Aug	Native [VC, NI]
Brassicaceae	*Capsella bursa-pastoris* (L.) Medik. / NK228	Ban paincha	H	Th	Mip	May-Jul	Native [VC, In]
	Conringia orientalis (L.) Dumort. / NK229	Ban sariyaan	H	Th	Mip	Apr-May	Native [Co, NI]
	Lepidium apetalum Willd. / NK230	Duda patti	H	Th	Mip	Apr-Jun	Native [VC, NI]
	Lepidium didymum L. / NK231	Jangli hallon	H	Th	Mip	Mar-Jun	Introduced [Ra, NI]
	Sinapis arvensis L. / NK232	Ban sariyaan	H	Th	Mip	Apr-Jun	Native [Co, NI]
	Sisymbrium irio L. / NK233	Ban hailyan	H	Th	Mip	Mar-May	Native [Co, NI]
Buxaceae	*Sarcococca saligna* (D. Don) Müll-Arg. / NK234	Nairi	S	Np	Mip	Sep-Apr	Native [VC, NI]
Campanulaceae	*Campanula pallida* Wall. / NK235	Beli flower	H	Th	Nap	Apr-Jul	Native [Ra, NI]

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Family	Species names and Voucher No.	Local name	Habit	Life forms	Leaf spectra	Phenology	Status
Cannabaceae	*Cannabis sativa* L. / NK236	Bhang	H	Th	Mep	Apr-Sep	Native [VC, In]
	Celtis australis L. / NK237	Kharik	T	Ms	Mip	Mar-May	Native [Ra, NI]
Caprifoliaceae	*Valeriana jatamansi* Jones / NK238	Mushkbala	H	G	Mip	Mar-May	Native [Co, NI]
	Lonicera quinquelocularis Hard. / NK239	Phutt	S	Mc	Mip	Apr-Jul	Native [Co, NI]
Caryophyllaceae	*Silene conoidea* L. / NK240	Dabbri	H	Th	Nap	Mar-Apr	Native [Ra, NI]
	Stellaria media (L.) Vill. / NK241	Lausari	H	Th	Nap	Apr-Aug	Native [VC, In]
Celastraceae	*Gymnosporia royleana* Wall. ex M.A. Lawson / NK242	Patakhi	S	Np	Nap	Sep-Jan	Native [Ra, NI]
Compositae	*Achillea millefolium* L. / NK190	Sultan booti	H	Th	Mip	Jul-Sep	Native [VC, NI]
	Anaphalis triplinervis (Sims) Sims ex C.B. Clarke / NK191	Unavailable	H	G	Mip	Jul-Oct	Native [VR, NI]
	Artemisia absinthium L. / NK192	Chaoo	H	Ch	Mip	Jun-Sep	Native [Ra, NI]
	Artemisia scoparia Waldst. & Kitam. / NK193	Marua	H	Ch	Lep	Jul-Nov	Native [Ra, NI]
	Artemisia vulgaris L. / NK194	Chaoo	H	Ch	Mip	Aug-Nov	Native [Co, NI]
	Aster alpinus L. / NK195	Alpine aster	H	Th	Mip	May-Jun	Introduced [VR, NI]
	Aster flaccidus Bunge / NK196	Unavailable	H	Th	Nap	Jul-Sep	Native [Co, NI]
	Bidens bipinnata L. / NK197	Surela	H	Th	Mip	Jun-Oct	Introduced [VC, In]
	Bidens pilosa L. / NK198	Surela	H	Th	Mip	May-Oct	Introduced [VC, In]
	Carpesium abrotanoides L. / NK199	Unavailable	H	Np	Mep	Sep-Nov	Native [Co, NI]
	Carpesium cernuum L. / NK200	Unavailable	H	Th	Mep	Jun-Aug	Native [VC, NI]
	Cirsium arvense (L.) Scop. / NK201	Tattaar	H	Th	Mep	Aug-Oct	Native [Co, In]

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	Erigeron bonariensis L. / NK202	Neeli booti	H	Th	Nap	Jun-Nov	Introduced [VC, In]
	Erigeron trilobus (Decne.) Boiss. / NK203	Paleet	H	Th	Lep	Sep-Oct	Native [Ra, NI]
	Galinsoga parviflora Cav. / NK204	Gallant soldiers	H	Th	Mip	Jul-Oct	Introduced [VC, In]
	Gerbera gossypina (Royle) Beauverd / NK205	Phutkola	H	Hc	Mep	May-Jul	Native [VC, NI]
	Himalaiella heteromalla (D. Don) Raab-Straube / NK206	Gwaal mula	H	Hc	Mip	Jun-Aug	Native [VC, NI]
	Jurinea dolomiaea Boiss. / NK207	Gugal toof	H	Hc	Mip	Jul-Sep	Native [VR, NI]
	Kalimeris altaica (Willd.) Nees ex Fisch. Mey. & Ave-Lall. / NK208	Unavailable	H	Th	Nap	Jul-Oct	Native [Co, NI]
	Launaea nudicaulis Hook. f. / NK209	Dudhal	H	Th	Mep	Apr-Jun	Native [Ra, NI]
	Leontopodium himalayanum DC. / NK210	Silver star	H	Th	Nap	Jul-Oct	Native [VR, NI]
	Myriactis nepalensis Less. / NK211	Thuke phool	H	Th	Mip	Apr-Nov	Native [VC, NI]
	Myriactis wightii DC. / NK212	Thuke phool	H	Th	Mip	Jul-Nov	Native [Co, NI]
	Parthenium hysterophorus L. / NK213	Gandi booti	H	Th	Nap	Apr-Aug	Introduced [VC, In]
	Phagnalon rupestre (L.) DC. / NK214	Unavailable	H	Th	Mip	Mar-May	Native [VR, NI]
	Prenanthes brunoniana Wall. ex DC. / NK215	Duddal	H	Th	Mep	Aug-Sep	Native [VC, NI]
	Siegesbeckia orientalis L. / NK216	Yellow crown beared	H	Th	Mep	Oct-Nov	Native [Co, NI]
	Silybum marianum (L.) Gaertn. / NK217	Kandyari	H	Th	Mep	Feb-Apr	Native [VC, In]
	Solidago virgaurea L. / NK218	Woundwort	H	Hc	Mip	Jul-Oct	Native [Co, NI]
	Sonchus asper (L.) Hill / NK219	Dudhal	H	Th	Mep	Mar-Oct	Native [VC, NI]

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	Sonchus oleraceus (L.) L. / NK220	Dudhal	H	Th	Mep	Mar-Jun	Native Co, NI
	Tagetes minuta L. / NK221	Sadbarga	H	Th	Mip	Oct-Nov	Introduced VC, In
	Taraxacum campylodes G.E. Haglund / NK222	Hand	H	Hc	Mip	Mar-Sep	Introduced VC, In
	Xanthium strumarium L. / NK223	Kandeli	H	Th	Mep	Aug-Oct	Introduced VC, In
Convolvulaceae	*Convolvulus arvensis* L. / NK243	Do tilla	C	L	Mip	May-Sep	Native VC, NI
	Cuscuta australis R. Br. / NK244	Neela taari	C	L	Lep	Aug-Oct	Introduced Ra, NI
	Cuscuta reflexa Roxb. / NK245	Neela taari	C	L	Lep	Aug-Oct	Native Co, NI
	Ipomoea carnea Jacq. / NK246	Jangli bekarh	S	Np	Mep	Jul-Nov	Introduced Ra, NI
	Ipomoea purpurea (L.) Roth / NK247	Eerh	C	Th	Mep	Jul-Sep	Introduced Co, NI
Cornaceae	*Cornus macrophylla* Wall. / NK248	Qandar	T	Ms	Mep	Apr-Jun	Native VR, NI
Cucurbitaceae	*Solena amplexicaulis* (Lam.) Gandhi / NK249	Gwal khakhri	C	L	Mep	Apr-Jul	Native VR, NI
Ebenaceae	*Diospyros kaki* L.f. / NK250	Mota amlook	T	Ms	Mep	May-Aug	Introduced Co, NI
	Diospyros lotus L. / NK251	Amlook	T	Ms	Mep	May-Jun	Native VC, NI
Elaeagnaceae	*Elaeagnus umbellata* Thunb. / NK252	Kankoli	S	Mc	Mip	May-Jun	Native Co, NI
Euphorbiaceae	*Euphorbia granulata* Forssk. / NK253	Hazar dani	H	Th	Lep	Jun-Sep	Native Co, NI
	Euphorbia helioscopia L. / NK254	Dhudal	H	Th	Nap	Jan-Jul	Native VC, In
	Euphorbia heterophylla L. / NK255	Milk weed	H	Th	Mip	Aug-Sep	Introduced Co, NI
	Euphorbia hirta L. / NK256	Dudhali	H	Th	Nap	Jul-Dec	Introduced Co, In
	Euphorbia prostrata Aiton / NK257	Hazaar dani	H	Th	Lep	Apr-Oct	Introduced Co, NI
	Mallotus philippensis	Kamela	T	Mc	Mep	Mar-May	Native Co, NI

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	(Lam.) Müll.Arg. / NK258						
	Ricinus communis L. / NK259	Arind	H	Mc	Mep	Jun-Sep	Introduced [VC, In]
Fagaceae	*Quercus baloot* Griff. / NK274	Parungi	T	Ms	Mep	Apr-May	Native [VC, NI]
	Quercus incana Bartram / NK275	Reen	T	Ms	Mep	Apr-May	Native [VC, NI]
Gentianaceae	*Gentiana squarrosa* Ledeb. / NK276	Unavailable	H	Th	Nap	Apr-Sep	Native [VC, NI]
	Swertia angustifolia Buch.-Ham. ex D. Don / NK277	Choratta	H	Th	Mip	Jun-Nov	Native [VC, NI]
	Swertia chirayita (Roxb.) Buch.-Ham. ex C.B.Clarke / NK278	Choratta	H	Th	Mip	Jul-Oct	Native [Ra, NI]
Geraniaceae	*Geranium nepalense* Sweet / NK279	Rattan doi	H	Hc	Mip	Apr-Sep	Native [Co, NI]
	Geranium wallichianum D. Don ex Sweet / NK280	Rattan do	H	Th	Mip	Jul-Sep	Native [VC, NI]
Hypericaceae	*Hypericum perforatum* L. / NK281	Sharan gulab	H	Ch	Nap	Jun-Sep	Native [Co, NI]
Juglandaceae	*Juglans regia* L. / NK282	Akhor	T	Ms	Mep	Feb-Apr	Native [VC, NI]
Lamiaceae	*Ajuga integrifolia* Buch.-Ham / NK283	Ratti booti	H	Hc	Mip	Mar-Jun	Native [Ra, NI]
	Ajuga parviflora Benth. / NK284	Ratti booti	H	Th	Mep	Mar-Jun	Native [Co, NI]
	Callicarpa macrophylla Vahl / NK285	Ukkal	T	Ms	Mep	Jul-Nov	Native [Co, NI]
	Clinopodium debile (Bunge) Kuntze / NK286	Unavailable	H	Hc	Nap	Aug-Sep	Native [VR, NI]
	Clinopodium umbrosum (M. Bieb.) Kuntze / NK287	Unavailable	H	Hc	Nap	May-Jul	Native [VC, NI]
	Clinopodium vulgare L. / NK288	Unavailable	H	Th	Mip	Mar-Jul	Native [Co, NI]
	Isodon coetsa (Buch.-Ham. ex	Unavailable	H	Ch	Mip	Aug-Sep	Native [VC, NI]

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Family	Species names and Voucher No.	Local name	Habit	Life forms	Leaf spectra	Phenology	Status
	D. Don) Kudo / NK289						
	Isodon rugosus (Wall. ex Benth.) Codd / NK290	Pissu maar	S	Np	Mip	Mar-Oct	Native [VC, NI]
	Mentha arvensis L. / NK291	Bareena	H	Hc	Mip	Jul-Sep	Native [Co, NI]
	Mentha longifolia (L.) L. / NK292	Pootna, chitta podina	H	Hc	Mip	May-Nov	Native [Co, NI]
	Micromeria biflora (Buch.-Ham. ex D. Don) Benth. / NK293	Jarhi	H	Hc	Lep	Mar-Nov	Native [VC, NI]
	Nepeta cataria L. / NK294	Cat mint	H	Hc	Mep	Jun-Jul	Native [Co, NI]
	Nepeta govaniana (Wall. ex Benth.) Benth. / NK295	Ladori	H	Hc	Nap	Jul-Sep	Native [Ra, NI]
	Nepeta laevigata (D. Don) Hand.-Mazz. / NK296	Unavailable	H	Hc	Mip	Jun-Aug	Native [Co, NI]
	Origanum vulgare L. / NK297	Maskanna	H	Hc	Nap	Jun-Oct	Native [VC, NI]
	Prunella vulgaris L. / NK298	Nariya	H	Hc	Mip	Jun-Aug	Native [Co, NI]
	Rydingia limbata (Benth.) Scheen & V. A. Albert / NK299	Chitta jand	S	Np	Mip	Apr-May	Native [Co, NI]
	Salvia canariensis L. / NK300	Kathra	H	Hc	Mip	Apr-Jul	Native [Co, NI]
	Salvia moorcroftiana Wall. ex Benth. / NK301	Kathra	H	Hc	Mep	May-Jun	Native [Ra, NI]
	Salvia nubicola Wall. ex Sweet / NK302	Noorchari	H	Hc	Mep	Jun-Oct	Native [Ra, NI]
	Scutellaria grossa Wall. / NK303	Mastiari	H	Hc	Mip	Jul-Sep	Native [Co, NI]
	Thymus linearis Benth. / NK304	Chikal	H	Ch	Lep	Jul-Aug	Native [Ra, NI]
Leguminosae	*Acacia nilotica* (L.) Delile / NK260	Kikar	T	Ms	Mip	Mar-Aug	Native [VC, In]
	Astragalus grahamianus Benth. / NK261	Kala kandyara	H	Ch	Mep	Apr-Aug	Native [Ra, NI]
	Crotalaria medicaginea Lam. / NK262	Sinji	H	Th	Mip	Mar-Aug	Native [Co, NI]

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Family	Species names and Voucher No.	Local name	Habit	Life forms	Leaf spectra	Phenology	Status
	Dalbergia sissoo DC. / NK263	Tahli, Sheesham	T	Ms	Mip	Mar-May	Native [Co, NI]
	Desmodium elegans DC. / NK264	Chamkath	S	Np	Mep	Jun-Sep	Native [Ra, NI]
	Indigofera heterantha Brandis / NK265	Jandh	S	Np	Lep	May-Jul	Native [VC, In]
	Indigofera linifolia (L. f.) Retz. / NK266	Nikki kawati	H	Th	Nap	Jul-Oct	Native [Ra, NI]
	Lespedeza juncea var. *sericea* (Thunb.) Lace & Hauech / NK267	Jandi	H	Ch	Nap	Jul-Oct	Native [VC, NI]
	Lespedeza bicolor Turcz. / NK268	Chamkaath	S	Np	Mep	Jul-Sep	Native [Ra, NI]
	Lotus corniculatus L. / NK269	Peela palti	H	Hc	Nap	Apr-Aug	Native [Co, NI]
	Medicago polymorpha L. / NK270	Maina	H	Th	Mip	Mar-May	Native [VC, In]
	Mimosa himalayana Gamble / NK271	Arai	S	Np	Nap	Jun-Aug	Native [Ra, NI]
	Oxytropis lapponica (Wahlenb.) Gay / NK272	Jandi	H	Ch	Nap	Jun-Aug	Native [Ra, NI]
	Trifolium repens L. / NK273	Khatimal	H	Hc	Mip	Apr-Jul	Native [VC, In]
Linaceae	*Linum corymbulosum* Rchb. / NK305	Tangra	H	Ch	Mip	Mar-Jun	Native [Ra, NI]
Lythraceae	*Punica granatum* L. / NK306	Daarhu	S	Np	Mip	Apr-Jun	Native [VC, NI]
Malvaceae	*Corchorus tridens* L. / NK307	Unavailable	H	Th	Mip	Jul-Nov	Native [Ra, NI]
	Grewia optiva J.R. Drumm. ex Burret / NK308	Taman	T	Ms	Mep	Apr-Sep	Native [Co, NI]
	Malva neglecta Wallr. / NK309	Sonchal	H	Th	Mip	Jun-Sep	Native [Co, NI]
	Malvastrum coromandelianum (L.) Garcke / NK310	Gogi booti	H	Th	Mip	Jun-Sep	Introduced [Co, NI]
Meliaceae	*Melia azedarach* L. / NK311	Daraik	T	Ms	Mep	Mar-Apr	Introduced [VC, In]
Moraceae	*Broussonetia papyrifera* (L.)	Jangli toot	T	Ms	Mep	Mar-Aug	Introduced [VC, In]

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Family	Species names and Voucher No.	Local name	Habit	Life forms	Leaf spectra	Phenology	Status
	L'Her. ex Vent. / NK312						
	Ficus carica L. / NK313	Teen patri phagwari	T	Mc	Mep	Apr-Dec	Native [Co, NI]
	Ficus palmata Forssk. / NK314	Phagwari	T	Ms	Mep	May-Sep	Native [VC, NI]
	Ficus sarmentosa Buch.-Ham. ex. Sm. / NK315	Dadday veil	C	L	Mip	May-Sep	Native [VR, NI]
	Morus alba L. / NK316	Shaitoot	T	Ms	Mep	Apr-Sep	Introduced [VR, NI]
	Morus nigra L. / NK317	Toot	T	Ms	Mep	Mar-Jul	Introduced [Ra, NI]
Oleaceae	*Jasminum humile* L. / NK318	Chamba	S	Np	Mep	Apr-Jun	Native [Co, NI]
	Olea ferruginea Wall. ex Aitch. / NK319	Kaoo	T	Ms	Nap	Apr-May	Native [VC, NI]
Onagraceae	*Oenothera rosea* L' Her. ex Aiton / NK320	Ratt mundia	H	Th	Mip	Apr-Sep	Introduced [VC, In]
Oxalidaceae	*Oxalis corniculata* L. / NK321	Khatti booti	H	Hc	Nap	Mar-Oct	Introduced [VC, In]
Paeoniaceae	*Paeonia emodi* Royle / NK322	Mameikh	H	G	Mep	May-Jun	Native [VR, NI]
Papaveraceae	*Fumaria indica* (Hausskn.) Pugsley / NK323	Shatra papra	H	Th	Mip	Mar-Jun	Native [Co, NI]
Passifloraceae	*Passiflora caerulea* L. / NK324	Garhi wala phool	C	L	Mep	Jul-Sep	Introduced [VR, NI]
Phyllanthaceae	*Leptopus cordifolius* Decne. / NK325	Karukni	S	Np	Mip	Jul-Oct	Native [VC, NI]
Phytolaccaceae	*Phytolacca latbenia* (Moq.) H. Walter / NK326	Parth, Kala kaath	T	Ms	Mep	Jun-Aug	Native [VR, NI]
Plantaginaceae	*Plantago lanceolata* L. / NK327	Batti	H	Hc	Mip	Jul-Sep	Native [VC, In]
	Plantago major L. / NK328	Isamgol	H	Hc	Mep	Aug-Sep	Native [VC, In]
	Veronica persica Poir. / NK329	Lazarh	H	Th	Mip	Feb-May	Introduced [Co, NI]
Platanaceae	*Platanus orientalis* L. / NK330	Chinaar	T	Ms	Mep	Apr-May	Introduced [VR, NI]
Polygalaceae	*Polygala abyssinica* R. Br. ex Fresen. / NK331	Unavailable	H	Ch	Nap	Mar-Sep	Native [Co, NI]

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Family	Species names and Voucher No.	Local name	Habit	Life forms	Leaf spectra	Phenology	Status
Polygonaceae	*Persicaria amplexicaulis* (D. Don) Ronse Decr. / NK332	Masloon	H	Hc	Mep	Jun-Sep	Native [Co, NI]
	Persicaria barbata (L.) H. Hara / NK333	Nariya	H	Th	Mip	Jun-Sep	Native [VC, NI]
	Persicaria lapathifolia (L.) Delarbre / NK334	Pani ka malla	H	Th	Mip	Jun-Sep	Native [Co, NI]
	Persicaria nepalensis (Meisn.) Miyabe / NK335	Mezarh	H	Hc	Mip	Jun-Sep	Native [VC, In]
	Polygonum aviculare L. / NK336	Darubra	H	Th	Nap	Mar-Sep	Native [Co, NI]
	Polygonum plebeium R. Br. / NK337	Banali	H	Th	Lep	May-Aug	Native [Co, NI]
	Rumex nepalensis Spreng. / NK338	Hulla	H	Th	Mep	Jun-Sep	Native [VC, In]
	Rumex hastatus D. Don / NK339	Chukki, Chukhri	S	Ch	Mip	Jun-Oct	Native [Co, In]
Portulacaceae	*Portulaca oleracea* L. / NK340	Kulfa	H	Th	Nap	May-Aug	Native [Co, NI]
Primulaceae	*Anagallis arvensis* var *arvensis* L. / NK341	Billi booti	H	Th	Nap	Feb-May	Native [Co, NI]
	Anagallis arvensis var. caerulea (L.) Gouan / NK342	Billi booti	H	Th	Nap	Feb-May	Native [Co, NI]
	Androsace rotundifolia Hardwicke / NK343	Akh jarhi	H	Hc	Mip	Apr-Aug	Native [Co, NI]
	Myrsine africana L. / NK344	Khukhan	S	Np	Nap	Mar-May	Native [VC, NI]
Ranunculaceae	*Clematis grata* Wall. / NK345	Chitta jand	C	L	Mip	Aug-Sep	Native [Co, NI]
	Ranunculus laetus Wall. ex Hook. f & J.W. Thomson / NK346	Khandbarya, Chambal booti	H	Th	Mep	Jun-Jul	Native [VC, NI]
Rhamnaceae	*Ziziphus jujuba* Mill. / NK347	Barri	S	Mc	Mip	Jun-Jul	Introduced [Co, NI]
Rosaceae	*Agrimonia eupatoria* L. / NK348	Jalebi booti	H	Th	Mep	Jul-Aug	Introduced [Ra, NI]
	Cotoneaster roseus Edgew. / NK349	Loon	T	Mc	Nap	May-Jun	Native [Ra, NI]

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Family	Species names and Voucher No.	Local name	Habit	Life forms	Leaf spectra	Phenology	Status
	Duchesnea indica (Andrews) Focke / NK350	Budi meva	H	Hc	Nap	Mar-Oct	Native [VC, NI]
	Fragaria vesca L. / NK351	Kanechi	H	Hc	Mip	Apr-Jun	Native [VC, NI]
	Prunus persica (L.) Batsch / NK352	Aaroon	T	Mc	Mip	Feb-Apr	Introduced [VC, In]
	Pyrus pashia Buch.-Ham. ex D.Don / NK353	Batangi	T	Mc	Mip	Apr-Jun	Native [Co, NI]
	Rosa webbiana Wall. ex Royle / NK354	Chahl	S	Np	Mep	Jun-Aug	Native [VC, NI]
	Rubus ellipticus Sm. / NK355	Peela akhra	S	Np	Mep	Apr-Jun	Native [VC, NI]
	Rubus niveus Thunb. / NK356	Pakanah	S	Np	Mep	Apr-Jun	Native [VC, In]
	Rubus ulmifolius Schott / NK357	Akhra	S	Np	Mip	Apr-Jul	Introduced [VR, NI]
Rubiaceae	*Galium divaricatum* Pourr. ex Lam. / NK358	Boora	H	Th	Lep	May-Jun	Native [VC, NI]
	Rubia manjith Roxb. ex Fleming / NK359	Khuratan	H	L	Mip	Jun-Nov	Native [VC, NI]
Rutaceae	*Skimmia laureola* Franch. / NK360	Challei	S	Np	Mip	Apr-Jun	Native [VC, NI]
	Zanthoxylum armatum DC. / NK361	Timbar	S	Mc	Mip	Mar-Apr	Native [Co, NI]
Salicaceae	*Populus deltoides* Marshall / NK362	Safeda	T	Mp	Mep	Apr-Jun	Native [Co, In]
	Salix alba L. / NK363	Beesa	T	Mp	Mip	Apr-May	Introduced [Ra, NI]
Sapindaceae	*Dodonaea viscosa* (L.) Jacq. / NK364	Sanatha	S	Np	Mip	Jan-Mar	Native [VC, In]
	Aesculus indica (Wall. ex Cambess.) Hook. / NK365	Bankhor	T	Ms	Mep	Apr-May	Native [Ra, NI]
Saxifragaceae	*Bergenia ciliata* (Haw.) Sternb. / NK366	Batt peya, Zakham e hayaat	H	Hc	Mep	Mar-May	Native [Ra, NI]
Scrophulariaceae	*Verbascum thapsus* L. / NK367	Jangli tambaku	H	Th	Mep	Jun-Aug	Native [Co, In]
Simaroubaceae	*Ailanthus altissima* (Mill.) Swingle / NK368	Darawiya	T	Mp	Map	May-Jun	Introduced [VC, In]

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Family	Species names and Voucher No.	Local name	Habit	Life forms	Leaf spectra	Phenology	Status
Solanaceae	*Datura stramonium* L. / NK369	Datura	H	Np	Mep	Jun-Jul	Introduced [VC, In]
	Physalis minima L. / NK370	Jangli tamatar	H	Th	Mip	Aug-Oct	Introduced [Co, NI]
	Solanum americanum Mill. / NK371	Kach mach	H	Th	Mip	Jun-Oct	Introduced [Ra, NI]
	Solanum pseudocapsicum L. / NK372	Marcholi	S	Th	Mip	Apr-Jul	Introduced [Ra, NI]
	Solanum surattense Burm. f. / NK373	Kandiari	H	Hc	Mip	Whole year	Native [Co, In]
	Solanum villosum Mill. / NK374	Kach mach	H	Th	Mip	Jul-Sep	Native [Co, NI]
	Withania somnifera (L.) Dunal / NK375	Aksoon	H	Ch	Mep	Whole year	Native [Ra, NI]
Verbenaceae	*Glandularia aristigera* (S.Moore) Tronc. / NK376	Unavailable	H	Th	Lep	Sep-Apr	Introduced [VR, NI]
	Lantana camara L. / NK377	Panj phulli	S	Np	Mip	Whole year	Introduced [Co, In]
	Verbena officinalis L. / NK378	Pamukh	H	Th	Mip	Jun-Sep	Native [Ra, NI]
Violaceae	*Viola canescens* Wall. / NK379	Gul naqsh	H	Hc	Mip	Mar-Jun	Native [VC, NI]
	Viola odorata L. / NK380	Gul naqsh	H	Hc	Mip	Mar-Jul	Introduced [Ra, NI]
Vitaceae	*Vitis vinifera* L. / NK381	Daakh	C	L	Mep	May-Jul	Introduced [VR, NI]
Urticaceae	*Debregeasia saeneb* (Forssk.) Hepper & J.R.I. Wood / NK382	Sindhari	S	Np	Mep	Mar-Jun	Native [Co, NI]
	Parietaria judaica L. / NK383	Unavailable	H	Th	Mip	Jul-Aug	Native [VR, NI]
	Urtica dioica L. / NK384	Bichu booti	H	G	Mip	May-Sep	Native [Ra, NI]

Legend: *Habit: H= Herb, S= Shrub, T= Tree, C= Climber; **Life forms: Mp= Megaphanerophyte, Ms= Mesophanerophyte, Mc= Microphanerophyte, Np= Nanophanerophyte, Ch= Chaemephyte, Hc= Hemicryptophyte, G= Geophyte, Th= Therophyte; ***Leaf spectra: Lep= Leptophyll, Nap= Nanophyll, Mip= Microphyll, Mep= Mesophyll, Map= Macrophyll; ****Status: VC=Very Common (Frequency of occurrence =.75-100%), Co=Common (Frequency of occurrence =.50-75%), Ra=Rare (Frequency of occurrence =.25-50%), VR=Very Rare (Frequency of occurrence =.0-25%), IN=Invassive, NI=Noninvassive.

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Supplementary Data Table 2. *Monthly temporal climatic variations (Mean ± SD (Min-Max)) in the study area from March-2015 to February-2018 (3 years)*

Months	Min. Temp (°C)	Max. Temp (°C)	PPT (mm)	Spe. Hum. (g/kg)	Soil Moist. (frac.)	Wind Speed (m/sec)	Shortwave Rad. (W/M²)	Longwave Rad. (W/M²)
January	1.1±0.99 (-0.35-2)	12.87±2.99 (9.68-16.4)	107.52±104.55 (4.26-264.45)	2.8±0.84 (1.7-3.59)	0.32±0.04 (0.27-0.34)	3.27±0.23 (3.03-3.52)	13.95±2.87 (10.62-17.11)	341.78±8.25 (331.65-350.65)
February	2.26±1.26 (0.04-2.99)	14.33±2.81 (10.16-17.18)	198.99±132.14 (69.82-415.55)	3.97±0.48 (3.36-4.47)	0.34±0.03 (0.3-0.38)	3.59±0.14 (3.42-3.79)	16.38±2.92 (13.89-20.85)	349.92±9.09 (334.85-357.26)
March	5.14±1.43 (3.64-6.95)	18.01±2.5 (16.35-22.35)	251.54±156.91 (93.49-508.13)	5.17±0.66 (4.23-6.01)	0.36±0.03 (0.31-0.38)	3.54±0.14 (3.36-3.71)	19.72±2.14 (18.03-23.06)	368.03±10.25 (361.12-384.95)
April	9.29±0.43 (8.8-9.86)	25.09±1.35 (22.75-26.01)	193.26±80.56 (118.46-284.41)	6.71±0.62 (6.27-7.68)	0.35±0.02 (0.33-0.38)	3.48±0.22 (3.22-3.79)	26.8±1.38 (25.27-28.62)	399.14±4.51 (391.62-402.74)
May	13.23±0.84 (12.32-14.24)	30.09±0.65 (29.38-30.98)	106.65±41.6 (60.53-163.46)	6.93±0.84 (6.14-8.09)	0.33±0.01 (0.32-0.34)	3.47±0.14 (3.27-3.6)	30.78±1.11 (28.85-31.68)	427.15±4.44 (422.75-434.19)
June	16.76±1 (15.58-17.86)	33.04±1.11 (31.32-34.04)	68.56±36.94 (32.69-117.61)	8.1±1.45 (6.24-9.61)	0.3±0.01 (0.29-0.31)	3.38±0.26 (3.19-3.74)	32.1±1.11 (30.34-33.33)	450.29±6.39 (440.07-456.16)
July	18.25±0.38 (17.88-18.83)	29.12±0.97 (27.66-30.25)	481.82±100.86 (381.29-625.72)	14.78±1.09 (13.28-16.31)	0.36±0.02 (0.35-0.38)	2.32±0.24 (1.96-2.6)	31.1±1.6 (29.36-33.23)	440.6±3.19 (436.13-444.57)
August	16.9±0.43 (16.5-17.59)	28.38±0.77 (27.21-29.22)	353.7±123.42 (200.57-528.17)	14.3±0.97 (13.02-15.09)	0.39±0.02 (0.37-0.4)	2.41±0.14 (2.25-2.61)	30.29±1.09 (28.79-31.37)	431.58±2.57 (428.56-434.94)
September	14.3±0.83 (13.17-15.37)	28.55±0.53 (28.12-29.42)	64.13±15.82 (45.86-89.15)	9.2±1.2 (7.8-10.33)	0.33±0.01 (0.32-0.35)	2.84±0.08 (2.75-2.94)	28.48±0.42 (28.19-29.16)	421.79±3 (417.79-424.79)
October	10.46±1.14 (8.92-11.8)	25.7±2.15 (24.06-28.3)	53.87±56.48 (1.23-133.12)	4.89±0.85 (3.85-5.68)	0.31±0.02 (0.29-0.33)	3.1±0.14 (2.94-3.31)	22.63±1.84 (20.39-24.59)	399.22±8.82 (389.85-410.34)
November	5.83±0.98 (5.01-7.46)	19±2.45 (16.81-22.08)	60.14±47.82 (10.37-117.96)	3.47±0.9 (2.46-4.28)	0.31±0.04 (0.27-0.35)	3.5±0.29 (3.02-3.72)	16.05±2.24 (14.07-19.14)	367.9±8.17 (361-379.58)
December	2.87±1.47 (1.74-5.35)	16.17±2.38 (14.63-20.33)	37.47±23.2 (2.79-55.87)	2.44±0.45 (1.8-3.03)	0.3±0.03 (0.27-0.33)	3.34±0.25 (3.08-3.74)	15.54±0.93 (14.71-17.02)	352.41±9.26 (345.56-368.11)

Legends: Min. Temp = Mean minimum temperature; Max. Temp. = Mean maximum temperature; PPT = Mean precipitation; Spe. Hum. = Mean specific humidity; Soil Moist. = Mean soil moisture (below 5cm); Shortwave/Longwave Rad. = Mean shortwave/longwave radiations

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Supplementary Data Table 3. *GPS data of study locations*

No.	Study location	Longitude (East)	Latitude (North)
1	Arja1	73.66294867	33.97807
2	Arja2	73.67143619	33.98500396
3	Azam Nagar1	73.58753339	34.02468598
4	Azam Nagar2	73.59279973	34.00840741
5	Benj1	73.684812	34.045877
6	Benj2	73.68481246	34.0558
7	Chamyati1	73.51381315	34.0590691
8	Chamyati2	73.52695797	34.06288953
9	Chamyati3	73.54115746	34.06611085
10	Dhirkot1	73.57682243	34.03068903
11	Dhirkot2	73.57880889	34.02406129
12	Ghaziabad1	73.629676	33.991651
13	Ghaziabad2	73.62939449	33.98326068
14	Kanyati1	73.58634701	34.07441619
15	Kanyati2	73.57519198	34.0691501
16	Kohala1	73.5067886	34.09299635
17	Kohala2	73.5143939	34.09728174
18	Munasa1	73.51824205	34.08089177
19	Munasa2	73.52186825	34.08944362
20	Neela Butt1	73.591492	33.999812
21	Neela Butt2	73.57714147	33.99911363
22	North1	73.53210804	34.12355846
23	North2	73.5380138	34.11987237
24	Padder Mastoo1	73.63636299	34.0177996
25	Padder Mastoo2	73.65317164	34.02406422
26	Sanghar Bathara1	73.54928172	34.0982717
27	Sanghar Bathara2	73.55761023	34.09329579
28	Sanghar Bathara3	73.57150737	34.089422
29	South1	73.56751493	33.93229927
30	South2	73.57392639	33.91939993
31	South3	73.57610508	33.940425
32	South4	73.5779541	33.97623264
33	Sudhan Gala1	73.67467431	34.00685613
34	Sudhan Gala2	73.66437067	34.00651954
35	Taal Gayat1	73.61570527	34.02274768
36	Taal Gayat2	73.60374374	34.03465304
37	Timroota Pail1	73.62656789	34.00408794
38	Timroota Pail2	73.60862241	33.99616598

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