Assessing Climate Change Impacts on Floristic Diversity of Alpine Regions in West Himalaya

National Mission on Himalayan Studies

Final Technical Report (January 2019-March 2022)

Principal Investigator
Dr. K. Chandra Sekar

Co-Principal Investigator
Dr. G.C.S. Negi

Project Fellows
Puja Bhojak
Neha Thapliyal

G.B. Pant National Institute of Himalayan Environment (NIHE), Kosi-Katarmal, Almora

NMHS-Himalayan Institutional Project Grant

NMHS-FINAL TECHNICAL REPORT (FTR)

Demand-Driven Action Research and Demonstrations

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PROJECT TITLE:

ASSESSING CLIMATE CHANGE IMPACTS ON FLORISTIC DIVERSITY OF ALPINE REGIONS IN WEST HIMALAYA

Project Duration: *from* (**10.01.2019**) *to* (**31.03.2022**)

***Submitted to*:**
Er. Kireet Kumar
Scientist 'G' and Nodal Officer, NMHS-PMU
National Mission on Himalayan Studies, GBP NIHE HQs
Ministry of Environment, Forest & Climate Change (MoEF&CC), New Delhi
E-mail: nmhspmu2016@gmail.com; kireet@gbpihed.nic.in; kodali.rk@gov.in

***Submitted by*:**
Dr. K.Chandra Sekar, Scientist-F
G.B. Pant National Institute for Himalayan Environment,
Kosi-Katarmal, Almora- 263 643, Uttarakhand, India
Contact No: +91-9410344484
E-mail: kcsekar1312@rediffmail.com

NMHS-Final Technical Report (FTR) *template*

Demand-Driven Action Research Project

DSL: Date of Sanction Letter

2	1	1	2	**2**	**0**	**1**	**8**
d	d	m	m	y	y	y	y

DPC: Date of Project Completion

3	1	0	3	**2**	**0**	**2**	**2**
d	d	m	m	y	y	y	y

Part A: Project Summary Report

1. Project Description

i.	Project Reference No.	GBPNI/NMHS-2018-19/SG 11					
ii.	Type of Project	Small Grant		Medium Grant	√	Large Grant	
iii.	Project Title	Assessing Climate Change Impacts on Floristic Diversity of Alpine Regions in West Himalaya					
iv.	State under which Project is Sanctioned	Uttarakhand					
v.	Project Sites (IHR States covered) (Maps to be attached)	1) Lata valley, Chamoli* (Uttarakhand) 2) Chaudans valley, Pithoragarh** (Uttarakhand) 3) Byans valley, Pithoragarh** (Uttarakhand) (*Annexure VIIa & **Annexure VIIb)					
vi.	Scale of Project Operation	Local		Regional		Pan-Himalayan	
vii.	Total Budget/ Outlay of the Project	**Rs. 4444600.00 /-**					
viii.	Lead Agency	G B Pant National Institute of Himalayan Environment, Almora, Uttarakhand					

	Principal Investigator (PI)	Dr. K. Chandra Sekar, Scientist – F Mobile: +91-9410344484 Email: *kcsekar1312@rediffmail.com* G.B. Pant National Institute of Himalayan Environment, Kosi – Katarmal, Almora – 263 643, Uttarakhand, India
	Co-Principal Investigator (Co-PI)	Dr. G.C.S. Negi, Scientist – G Mobile: +91-7900200119 Email: negigcs@gmail.com G.B. Pant National Institute of Himalayan Environment, Kosi – Katarmal, Almora – 263 643, Uttarakhand, India
	Project Fellows	Puja Bhojak, Senior Project Fellow (13/03/2019 to 30/03/2022) Neha Thapliyal, Senior Project Fellow (14/03/2019 to 10/12/2021)
ix.	Project Implementing Partners	NA
	Key Persons / Point of Contacts with Contact Details, Ph. No, E-mail	Dr. K. Chandra Sekar, Scientist – F Mobile: +91-9410344484 Email: *kcsekar1312@rediffmail.com*

2. Project Outcomes

2.1. Abstract

Over the last three decades, climate warming has been a major topic of concern for ecologists and environmentalists with 74% of the observed temperature increase caused by human-induced radiative forcing, and less than 26% by unforced internal variability. Model projections of climate change impacts on floral diversity have suggested that habitats of plants, specifically the alpine life zones, could change drastically causing species range shifts and reshuffling of species composition and abundances. Furthermore, the Himalaya is reported to be warming at a much higher rate than global average, making it a hotspot for climate change studies. However, as per IPCC, the region remains data-deficient in terms of long-term climate data specifically on account of compatibility mismatch due to instrumentation and methodology. This calls for an urgent attention of researchers for long-term Ecological Monitoring (LTEM) in the region, following global standard methods. In view of this, a new LTEM site was established in alpine region of Lata valley, Chamoli following the Global Observation Research Initiative in Alpine Environment (GLORIA) protocol and floristic diversity of the region was analyzed. The site inhabited a total of 124 plant species belonging to 91 genera and 37 families, with 53 species recorded in usage as medicinal herbs by local people and 13 species under threatened categories as per IUCN, CAMP and RDB. There was a significant decrease in species richness with increasing altitude, with maximum species in KHR (88 species), followed by SAI (80 species), DON (67 species) and PUL (40 species). Through review of literature and interview with local inhabitant in the Lata valley, a total of 53 species were recorded in usage by local people for the treatment of various ailments. Resurveys of permanent observation sites was done after 5-years period to analyze changes in floristic diversity and its relation to temperature trends. In this context, previously established observation sites in Chaudans and Byans valley, Pithoragarh (Uttarakhand) were resurveyed in 2019 and 2021, respectively. Temporal trends in soil temperature showed a significant decreasing trend over a four-year period (p<0.05; decrease of 0.82 ºC from August 2015 to July 2019) in Chaudans, while in Byans the trend was significantly increasing (p<0.01; increase of 0.38ºC from October 2015 to September 2021). Temporal patterns in vegetation were represented by significant increase in plant cover (%) in all sites while species richness increased in KHA, GAN and SKN in Chaudans. While species richness decreased in north and west, in south it increased significantly and remained same in east. However, in Byans, there was significant (p<0.05) increase in plant cover, richness and diversity in all summits. Relating vegetation indices with soil temperature across the two surveys exhibited a significant positive correlation between species richness and diversity (r from 0.3 to 0.6, p< 0.05) in both valleys. However, plant cover percent showed no significant relationship with temperature trends in Byans valley, while it was positive in Chaudans. Thus, temporal trends in richness and diversity were related to corresponding temperature trends in both valleys, plant cover changes did not show significant relation with temperature trends in Byans valley. Of the total 105 species, a total of ten species (such as *Bistorta affinis*, *Bupleurum falcatum*, *Carex setosa*, *Poa alpina*, *Polygonum filicaule*, etc.) showed significant increase in their plant cover in 2019 as compared to that in 2015, while seven species exhibited a significant decrease (such as *Kobresia nepalensis, Taraxacum officinale, Rumex nepalensis,* etc.) (Table 21). Similarly, seven species exhibited a significant increase in their cover (%) from 2015 to 2021 in observation plots in Byans, among which the most predominant was *Danthonia cachemyriana* which increased in all the summits. We suggest that the observed trend in plant community dynamics responds to short term temperature and precipitation variability and time lags in plant community response. It may take much longer than one decade for the observed trends to become stable and statistically significant. Our study provides an important foundation of documenting profound changes in alpine plant communities, as global climate change continues.

2.2. Objective-wise Major Achievements

S. No.	Objectives	Quantifiable outputs
1.	To analyze the floristic diversity and plant community composition along altitude range in alpine landscapes of Uttarakhand, west Himalaya.	Database on floristic diversity patterns along altitude gradients in the alpine regions of Darma and Byans valley of Pithoragarh district, Uttarakhand west Himalaya was compiled. In Darma valley, a total of 286 taxa (283 species and 3 varieties) belonging to 161 genera and 55 families were documented. Among them, the angiosperms were distributed in 279 taxa (276 species and 3 varieties) under 55 families and 161 genera, whereas the Gymnosperms were distributed in 7 species under 03 families and 05 genera. Asteraceae (17 genera and 30 species) was reported as the most dominant family, followed by Ranunculaceae (13 genera and 29 species). Herbaceous taxa were the most dominant with 240 plant taxa, followed by 36 shrubs, 8 trees and 2 climbers. In Byans valley, a total of 371 taxa (364 species and 7 varieties) belonging to 197 genera and 63 families inhabited the alpine zone. Among them, the angiosperms were distributed in 364 taxa (357 species and 7 varieties) under 60 families and 192 genera, whereas the Gymnosperms were distributed in 7 species under 03 families and 05 genera. Asteraceae (18 genera and 33 species) was reported as the most dominant family, followed by Ranunculaceae (13 genera and 30 species) and Poaceae (13 genera and 24 species). Herbaceous taxa were the most dominant with 303 plant taxa, followed by 55 shrubs, 22 trees and 6 climbers. In both alpine landscapes, the plant species richness exhibited an apparent decrease with increasing altitude, with highest number of taxa in lower altitudes.
2.	To establish and strengthen Long-Term Ecological Monitoring site(s) following the Global Observation Research Initiative in Alpine Environments	• Resurvey of previously established Chaudans Valley Target Region (TR) was carried out in August 2019 after 5 years. A total of 107 vascular plants belonging to 72 genera and 35 families were documented in 64 observation plots, with a gradual decrease in species richness with increasing altitude of summits (Table 1*). The most represented families were Asteraceae and Scrophulariaceae with 14 and 12 species, respectively. The most abundant species overall in terms of Important Value index were were *Bistorta affinis* (20) and *Anaphalis contorta* (17) in BHT,

	(GLORIA) protocol for continuous monitoring of floristic diversity patterns in alpine environment.	*Geum elatum* (22) and *Bistorta affinis* (21) in KHA, *Carex setosa* (32) and *Hippolytia dolicophylla* (28) in GAN and *Bistorta vaccinifolia* (57) and *Kobresia nepalensis* (49) in SKN. Spatial patterns in beta diversity at multiple-sites revealed very low Sørensen dissimilarity among all the studied summits (Figure 1*). The nestedness component (β_{sne}) was found to be the largest contributor to the overall dissimilarity (Figure 1A*). Cluster analysis from the dissimilarity matrices of turnover revealed that east and west aspect of BHT is highly dissimilar from rest of the aspects, followed by west aspect of SKN (Figure 1B*). Cluster analysis obtained from dissimilarity matrices of nestedness showed that west aspects of KHA and GAN and north aspect of KHA are quite dissimilar from the rest of summit aspects. Also, west aspect of SKN which falls in the sub-nival zone, was highly dissimilar from the other aspects of the four summits (Figure 1C*). Analysis of various physico-chemical parameters of soil was done in order to document and monitor characteristics of soil under changing climate and its influence on vegetation (Table 2 & 3*). In KHA and GAN soil was mainly sandy while in BHT and SKN it was a mixed proportion of sand and silt (Figure 2*). The soil exhibited mild acidic nature in all the sites. Depth wise analysis revealed a decrease in moisture, organic carbon, and phosphorus content, while an increase in bulk density from 0-10 cm to 10-20 cm in all summits. Apart from this, organic carbon and potassium content (9.78 % and 0.66 %, respectively) was maximum in GAN, while nitrogen and phosphorus (2.20 g/kg and 9.97 ppm, respectively) was maximum in KHA (Table 3*). Soil temperature data obtained from the soil data loggers exhibited a significant decrease in temperature with increasing altitude of summits (highest in BHT- 7.41ºC and lowest in SKN- 2.52ºC). However, among aspects east direction exhibited highest temperature (7.43ºC) while it was lowest in north (4.42ºC) (Table 4*). Plant species richness exhibited a significant positive correlation with mean soil temperature and organic carbon. Furthermore, there was highly significant correlation between soil temperature, potassium and organic carbon content, potassium and nitrogen content (Figure 3*).

		***Details enclosed in Annexure VIII (Table 1 to 4; Figure 1 to 3)** • A Long-term monitoring site was established in Lata valley, Chamoli in 2020, following the standard GLORIA protocol consisting of four summits namely Kharak (KHR), Sainikharak (SAI), Donidhar (DON) and Pulan (PUL) along an altitude gradient above natural treeline and baseline vegetation data was documented (Table 5 & 6*). The site inhabited a total of 124 plant species belonging to 91 genera and 37 families. The most represented families were Asteraceae (16 species) and Rosaceae (13 species). There was a significant decrease in species richness with increasing altitude, with maximum species in KHR (88 species), followed by SAI (80 species), DON (67 species) and PUL (40 species). Phytosociological analysis also exhibited variation in species composition along altitude gradient, *i.e.*, KHR with 93% of vegetation cover was dominated by *Bistorta affinis* (IVI-29) and *Danthonia cachemyriana* (IVI-20); SAI with 81% cover was dominated by *D. cachemyriana* (IVI-21) and *Anaphalis contorta* (IVI-20); DON with 92% cover was dominated by *B. affinis* (IVI-22) and *D. cachemyriana* (IVI-18); and PHU with 78% cover was dominated *B. affinis* (IVI-45) and *Nardostachys grandiflora* (IVI-21) (Table 5 & Figure 4*). Among the total recorded species, a total of 13 species were considered threatened as per IUCN, CAMP and RDB among which three are Critically Endangered, 1 is Endangered, 3 are Vulnerable and 6 are Least Concern (Table 7*). In review of literature and interview with local inhabitant in the Lata valley, a total of 53 species were recorded in usage by local people for the treatment of various ailments (Figure 5*). Furthermore, analysis of various physico-chemical parameters of soil in the target region was done in order to document soil ecological processes under global change scenarios. Depth wise analysis revealed exhibited significantly higher moisture content at 0-10cm as compared to 10-20cm (Table 8*). Along altitude gradient, it followed an increasing trend with maximum value in PUL (47.37%) and minimum in KHR (39.67%) (Figure 6i*). Furthermore, North aspect exhibited the highest moisture content

		of 45.15 % and East aspect exhibited the lowest, *i.e.*, 39.80% (Figure 6ii). It was observed that the bulk density was significantly higher at 10-20cm depth than that at 0-10cm (Table 9*). Moving along the altitude gradient, bulk density decreased from KHR (0.81 g/cm3) to SAI (0.74 g/cm3) and then exhibited a significant increase with increasing altitude, *i.e.*, DON (0.85 g/cm3) and PUL (1.00 g/cm3) (Figure 7i*). Among aspect, bulk density was maximum in west (0.94 g/cm3), followed by south (0.86 g/cm3), north (0.81 g/cm3) and east (0.79 g/cm3) (Figure 7ii*). The soil samples of the summit sites exhibited acidic to mild acidic nature. Depth-wise analysis revealed significant variations in soil pH values at two different depths, *i.e.*, 0-10cm and 10-20cm, however there was no significant trend between the depths (Table 10*). pH value increased with altitude significantly from KHR to DON and decreased further to PUL (Figure 8i*). Among aspects pH was maximum in West aspect (5.36) and minimum in North aspect (5.05), while East and South aspect did not show significant difference (Figure 8ii*). Organic carbon content (%) significantly decreased with increasing soil depth (Table 11*). Analysis of soil organic carbon (%) in the target region showed that organic carbon content ranged from 0.77% (in SAI) to 1.08% (in DON and PUL) Figure 9i*). Among aspects, organic carbon was highest in East (1.09%), followed by South (1.04%), North (0.90%) and West (0.86%) (Figure 9ii*). Climatic data (temperature and precipitation) for Lata target region was taken from www.worldclim.org. Annual temperature (ºC) showed significant decreasing trend along altitude gradient ($p < 0.001;$ R^2= 0.98) and annual precipitation (mm) also decreased with increasing altitude of summit sites (R^2= 0.97) (Figure 10*). Correlation analysis between different environmental variables (*i.e.*, climate & soil parameters) revealed that temperature exhibited significant positive correlation with precipitation & OC and negative correlation with soil moisture & pH (Table 12*). Increase in temperature influences decomposition of organic matter causing increase in accumulation of acids which decrease soil pH. Furthermore, correlation analysis between species richness & the environmental variables revealed that only

		temperature and precipitation exhibited significant positive correlation (*p<0.01*) with floristic diversity, while it was insignificant (*p>0.01*) with soil parameters (Figure 11*). ***Details enclosed in Annexure IX (Table 5 to 12; Figure 4 to 11)** • Resurvey of previously established Byans Valley Target Region (TR) was carried out in September 2021 after 6 years. A total of 41 vascular plants belonging to 29 genera and 20 families were documented in 64 observation plots. Among these, 38 were angiosperms and only three species are gymnosperms namely *Ephedra intermedia*, *Juniperus communis* and *Juniperus indica.* Of the total summit flora, 31 were herbs, and 10 shrubs namely *Berberis jaeschkeana, Cassiope fastigiata, Ephedra intermedia, Juniperus communis, Juniperus indica, Lonicera spinosa, Potentilla arbuscula* and *Salix flabellaris* etc. The most represented families were Asteraceae (5 species), Rosaceae (5 species) and Fabaceae (4 species). Maximum species richness was found in Kuti (16) followed by Syang (12), Chaga (11) and Eurong (11). Analysis of various physico-chemical parameters of soil was done in order to document and monitor characteristics of soil under changing climate and its influence on vegetation. • Soil temperature data obtained from the soil data loggers for the period of six years exhibited significant variation among summits as well as aspects. Among all summit Kuti had the highest soil temperature (7.1ºC), followed by Chaga(6.8ºC), Shyang (6.2ºC) and Eurong (5.4ºC) (Figure 5). Correlation analysis (calculated as Pearson's correlation) exhibited a significant relation between plant diversity indices (richness & H index) with altitude (*r*= -0.89* to -0.85**), air temperature (*r* = 0.77* to 0.90**), precipitation (*r* = 0.80* to 0.92**), pH (*r*= -0.78* to -0.89**) (Table 19). ***Details enclosed in Annexure X**
3.	To investigate the change in plant diversity patterns under the influence of climate change	• Soil temperature data for the period of five years was obtained from previously installed loggers during the resurvey of the observation sites in Chaudans and Byans valley in 2019 and 2022, respectively. While in Chaudans valley soil temperature averaged across the 15 data loggers showed a significant

	in different alpine sites.	decreasing trend over for four-year period (Linear regression, F= 0.32, df= 1, P= 0.05; August 2015 to July 2019), in Byans valley the trend was significantly increasing (Linear regression, F= 6.31, df= 1, P= 0.01; October 2015 to September 2021). Overall, annual mean soil temperature of Chaudans significantly decreased by 0.82 ºC from 2014 to 2019, while in Byans it increased by 0.38 ºC from 2015 to 2021 (Figure 12*). • Comparative analysis of species richness and cover between the survey of 2015 and 2019 of the Chaudans Valley Target Region, Pithoragarh (TR) was done. In the revisit, temporal patterns in community changes were represented by significant increase in plant cover (%) in all sites while species richness increased in KHA, GAN and SKN (Table 14a*). While species richness decreased in north and west, in south it increased significantly and remained same in east. The temporal variation between 2015 and 2019 of beta diversity revealed a significant contribution of both components of beta diversity to the overall dissimilarity**.** The south and east aspects of GAN and west aspect of SKN showed only replacement of species (species turnover) between 2015 and 2018, with highest turnover in SKN, thereby implying that no significant species loss or gain during a span of five years. In contrast, south of BHT, north of GAN and east of SKN exhibited only nestedness dominated dissimilarity. Moreover, the overall dissimilarity among these aspects was dominated by nestedness-resultant dissimilarity. Importantly, the west aspect of SKN showed high species turnover resultant dissimilarity (β_{sim}) and zero nestedness (β_{sne}), thereby implying that at this aspect relatively higher replacement of species occurred without loss or gain of species. Relating vegetation indices with soil temperature across the two surveys exhibited a significant positive correlation between species richness and diversity (r from 0.3 to 0.6, p< 0.05) in both valleys. However, plant cover percent showed no significant relationship with temperature trends in Byans valley, while it was positive in Chaudans (Figure 13*). Of the total 105 species, recorded in 2015, only four species showed a significant expansion (p< 0.05) to new plots namely *Euphorbia stracheyi*, *Phlomis bracteosa*, *Poa alpina*, *Polygonum filicaule*, while four

		reduced their plot occupancy, namely *Gypsophila ceratoides*, *Kobresia nepalensis*, *Pedicularis klotzschii*, *Trachydicum roylei* (Table 15*). Furthermore, a total of ten species (such as *Bistorta affinis*, *Bupleurum falcatum*, *Carex setosa*, *Poa alpina*, *Polygonum filicaule*, etc.) showed significant increase in their plant cover in 2019 as compared to that in 2015, while seven exhibited a significant decrease (such as *Kobresia nepalensis*, *Taraxacum officinale*, *Rumex nepalensis*, etc.) (Table 16*). • In the revisit, temporal patterns in community changes were represented by significant increase in plant cover, richness and diversity ($p<0.05$) in all summits. 12 species were newly recorded from observation plots in resurvey of Byans target region in 2021 (Table 22). A total of seven species exhibited a significant increase in their cover (%) from 2015 to 2021 in observation plots in Byans (Table 22), among which the most predominant was *Danthonia cachemyriana* which increased in all the summits. ***Details enclosed in Annexure XI (Table 14 to 16; Figure 12 to 13)**
4.	To build plant assessment and taxonomic identification capacity of master's students and researchers.	1. A twelve-day hands-on training course entitled "Vegetation Assessment, Herbarium Techniques and Statistical Analysis for Long-Term Ecological Monitoring" was organized by Center for Biodiversity Conservation and Management (CBCM) in GBP-NIHE headquarter starting from 24-02-2020 to 6-03-2020 (100 hours). A total of 33 research scholars (M.Sc. and PhD.) affiliated to 9 different institutions participated in the training program. The training program was focused on four major topics: a) Vegetation assessment; b) Herbarium techniques; c) RS and GIS applications in vegetation science; and d) Statistical methods. (Training 1*) 2. G.B. Pant National Institute of Himalayan Environment (NIHE), Kosi-Katarmal, Almora, in collaboration with the Department of Botany, Soban Singh Jeena University, Almora and financial assistance of the National Mission on Himalayan Studies (NMHS) organized a three-day field-oriented training course entitled "Plant Taxonomy, Vegetation Assessment and Statistical Analysis" from 25-March-2021 to 27-March-2021. A total of 83 participants (M.Sc./Ph.D. scholars) from the SSJ campus attended the training

		programme. Major domains covered in the training course included: a) Plant taxonomy: Classification, identification and cataloguing; b) Plant ecology: Methods of field surveys, data collection, analysis and interpretation in ecology and vegetation science; c) Plant conservation approaches, nursery management and plantation techniques; d) Statistical application in the field of plant sciences and ecology. (Training 2*) ***Details enclosed in Annexure XII**

2.3. Outputs in terms of Quantifiable Deliverables*

S. No.	Quantifiable Deliverables*	Monitoring Indicators*	Quantified Output/ Outcome achieved	Deviations made, if any
1.	Database on Floristic diversity. Soil characteristics and microbial biomass patterns along the 3 Altitudinal transects	Generated database on floristic diversity of two alpine landscapes along altitude gradient.	A total of 286 taxa (283 species and 3 varieties) belonging to 161 genera and 55 families were documented in Darma valley. Among them, 279 taxa (276 species and 3 varieties) were angiosperms, and 7 species were gymnosperms. A total of 371 taxa (364 species and 7 varieties) belonging to 197 genera and 63 families inhabited the alpine zone in Byans valley. Among them, the angiosperms were distributed in 364 taxa (357 species and 7 varieties) whereas the Gymnosperms were distributed in 7 species. Asteraceae was reported as the most dominant family in both transects. In both alpine landscapes, the plant species richness exhibited an apparent decrease with increasing altitude, with highest number of taxa in lower altitudes.	
2.	Establishment of GLORIA site and	Establishment of one new GLORIA site.	A Long-term monitoring site was established in Lata valley, Chamoli in 2020, following the standard GLORIA	

	strengthening/analyzing data on two other sites established earlier		protocol along an altitude gradient above natural treeline and baseline vegetation data was documented. The site inhabited a total of 124 plant species belonging to 91 genera and 37 families. The most represented families were Asteraceae (16 species) and Rosaceae (13 species). Among these, 13 species were considered threatened as per IUCN, CAMP and RDB among which three are Critically Endangered, 1 is Endangered, 3 are Vulnerable and 6 are Least Concern and a total of 53 species were recorded in usage by local people for the treatment of various ailments.	
3.	Change detection in comparison with earlier datasets of two landscapes.	Developed change detection datasets of two landscapes	Comparative analysis of species richness, diversity and cover between the surveys in 2014 and 2019 of the Chaudans target region and 2015 and 2021 of Byans target region was done. In the revisit, temporal patterns in community changes were represented by significant increase in plant cover by 6%, species richness by 2% and species diversity by 3%. Temporal trends in soil temperature were obtained during the resurvey of the observation sites in Chaudans and Byans valley in 2019 and 2022, respectively. While in Chaudans valley soil temperature significantly decreased by 0.82 ºC from 2015 to 2019, in Byans valley it increased by 0.38 ºC from 2015 to 2021.	
4.	Capacity building programme on GLORIA	Two capacity building programmes organised	A 12-day hands-on training course entitled “Vegetation Assessment, Herbarium Techniques and Statistical Analysis for Long-Term Ecological	

	protocol (target: 100 researchers/masters students)	(Researchers/ master students trained- 116)	Monitoring" was organized from 24-02-2020 to 6-03-2020 (100 hours). A total of 33 research scholars (M.Sc. and PhD.) affiliated to 9 different institutions participated in the training program. In collaboration with the Department of Botany, Soban Singh Jeena University, Almora a three-day field-oriented training course entitled "Plant Taxonomy, Vegetation Assessment and Statistical Analysis" from 25-March-2021 to 27-March-2021. A total of 83 participants (M.Sc./Ph.D. scholars) from the SSJ campus attended the training programme.	

(*) As stated in the Sanction Letter issued by the NMHS-PMU.

2.4. Strategic Steps with respect to Outcomes (in bullets)

S. No.	Particulars	Number/ Brief Details	Remarks/ Attachment
1.	New Methodology developed	NA	NA
2.	New Models/ Process/ Strategy developed	NA	NA
3.	New Species identified	NA	NA
4.	New Database established	Primary data on floristic information of the selected alpine sites was summarised. A total of 286 taxa belonging to 161 genera and 55 families were documented in Darma valley and 371 taxa belonging to 197 genera and 63 families inhabited the alpine zone in Byans valley.	
5.	New Patent, if any	NA	NA
	I. Filed (Indian/ International)		

S. No.	Particulars	Number/ Brief Details	Remarks/ Attachment
	II. Granted (Indian/ International)		
	III. Technology Transfer(if any)		
6.	Others (if any)	NA	NA

3. Technological Intervention

S. No.	Type of Intervention	Brief Narration on the interventions	Unit Details (No. of villagers benefited / Area Developed)
1.	Development and deployment of indigenous technology	NA	NA
2.	Diffusion of High-end Technology in the region	NA	NA
3.	Induction of New Technology in the region	NA	NA
4.	Publication of Technological / Process Manuals	NA	NA
	Others (if any)	NA	NA

4. New Data Generated over the Baseline Data

S. No.	New Data Details	Status of Existing Baseline	Additionality and Utilisation New data
1.	Baseline vegetation information of the established plots.	Several studied sites were explored for vegetation data on ecological perspectives for the first time.	This baseline information will provide primary database for further long-term monitoring of the alpine sites in order to assess their dynamics under the climate change scenario.

2.	15 plant species were documented as threatened as per IUCN, and 53 species were recorded in usage by local people for the treatment of various ailments.	This documentation is a significant addition to the population status of threatened plants in Indian Himalayan Region.	The information on threatened and medicinal plants can be used by conservation policy makers for prioritization of species at higher risk of extinction and regulation sustainable extraction of valuable plants.
3.	Baseline information on the physico-chemical properties of soil of the established plots.	Studied sites were explored for soil properties for the first time.	This baseline database will provide primary datasets to investigate the relationship between vegetation composition and soil parameters as well as for long-term monitoring of the alpine sites in order to assess their dynamics under the climate change scenario.

5. Demonstrative Skill Development and Capacity Building/ Manpower Trained

S. No.	Type of Activities	Details with number	Activity Intended for	Participants/Trained			
				SC	**ST**	**Woman**	**Total**
1.	Workshops	**02**	Build plant assessment and taxonomic identification capacity of master's students and researchers.			**95**	**116**
2.	On Field Trainings		-do-				
3.	Skill Development						
4.	Academic Supports	**02**	Registered for PhD			**02**	**02**
	Others (if any)						

6. Linkages with Regional & National Priorities (SDGs, INDC, etc)/ Collaborations

S. No	Linkages /collaboration	Details	No. of Publications/ Events Held	Beneficiaries
1.	Sustainable Development Goal (SDG)	As per the Niti Aayog's Sustainable Development of Indian Himalayan Region, the 53 medicinal plants identified might help in developing local markets, alternative livelihoods, documentation of traditional practices under the Aayush Scheme. It will strengthen the traditional and conventional healthcare systems. In addition, the 15 threatened plant species identified		
		corresponds to the SDG goal 15: Life on Land and its conservation. The baseline database provided through this study will help in assessing vegetation dynamics of highly vulnerable alpine ecosystems to climate change which corresponds to the Goal 13: Climate Action of SDGs.		
2.	Climate Change/INDC targets	The Himalaya are listed in the vulnerable regions to climate change under the INDC. The primary database will strengthen the NAPCC's mission of safeguarding the Himalayan glaciers, mountain ecosystems and biodiversity.		
3.	International Commitment			
4.	Bilateral engagements			
5.	National Policies			
6.	Others collaboration			

7. Project Stakeholders/ Beneficiaries and Impacts

S. No.	Stakeholders	Support Activities	Impacts
1.	Gram Panchayats		
2.	Govt Departments (Agriculture/ Forest)		
3.	Villagers		

4.	SC Community		
5.	ST Community		
6.	Women Group	Awareness through workshops and training programmes	Vegetation assessment and taxonomic identification capacity of master's students and researchers were build.
	Others (if any)		

8. Financial Summary (Cumulative)

S. No.	Financial Position/Budget Head	Funds Received	Expenditure/ Utilized	% of Total cost
I.	Salaries/Manpower cost	1375243	1427536	100
II.	Travel	854957	494023	57.78
III.	Expendables &Consumables	388000	337577	87
IV.	Contingencies	226336	136826	60.45
V.	Activities & Other Project cost	460229	429907	93.41
VI.	Institutional Charges	-	-	-
VII.	Equipments	1100000	587326	53.39
	Total	4404765	3413195	77.48
	Interest earned	32683		
	Grand Total	4437448		

* Please attach the consolidated and audited Utilization Certificate (UC) and Year wise Statement of Expenditure (SE) separately, *ref.* **Annexure I.**

9. Major Equipment/ Peripherals Procured under the Project** (if any)

S. No.	Name of Equipments	Cost (INR)	Utilisation of the Equipment after project
1.	Geo-precision M-log 5W simple (PT 1000, 35 nos.) with wireless dongle (01 no.)	587326	The dataloggers are installed in Byans and Lata valley and will be monitored the climate parameters

Details should be provided in details **(*ref* Annexure III &IV).

10. Quantification of Overall Project Progress

S. No.	Parameters	Total (Numeric)	Remarks/ Attachments/ Soft copies of documents
1.	IHR States Covered	*1*	

2.	Project Site/ Field Stations Developed	*3*	Annexure VIIa & VIIb
3.	New Methods/ Modeling Developed		
4.	No. of Trainings arranged	*2*	Annexure XII
5.	No of beneficiaries attended trainings		
6.	Scientific Manpower Developed (Phd/M.Sc./JRF/SRF/ RA):	*2*	
7.	SC stakeholders benefited	-	-
8.	ST stakeholders benefited	-	-
9.	Women Empowered	-	-
10.	No of Workshops Arranged along with level of participation	-	-
11.	On field Demonstration Models initiated	-	-
12.	Livelihood Options promoted	-	-
13.	Technical/ Training Manuals prepared	-	-
14.	Processing Units established	-	-
15.	No of Species Collected	-	-
16.	New Species identified	-	-
17.	New Database generated (Types):	-	-
	Others (if any)	-	-

11. Knowledge Products and Publications:

S. No.	Publication/ Knowledge Products	*Number*		*Total Impact Factor*	*Remarks/* Enclosures
		National	International		
1.	Journal Research Articles/ Special Issue:	-	02	16.5 (communicated)	In Geology, Ecology and Landscapes; and Global Change Biology
2.	Book Chapter(s)/ Books:				
3.	Technical Reports				
4.	Training Manual (Skill Development/ Capacity Building)				
5.	Papers presented in				

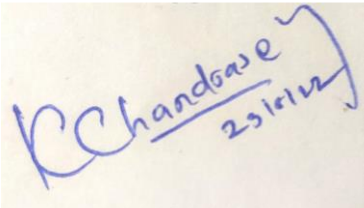
S. No.	Publication/ Knowledge Products	*Number*		*Total Impact Factor*	*Remarks/* Enclosures
		National	International		
	Conferences/Seminars				
6.	Policy Drafts/Papers				
7.	Others:				

* Please append the list of KPs/ publications (with impact factor and further details) with due Acknowledgement to NMHS.

12. Recommendation on Utility of Project Findings, Replicability and Exit Strategy

Particulars	Recommendations
Utility of the Project Findings	The present study empirically explored the vegetation dynamics on alpine mountain summits in Uttarakhand Himalaya in order to fill the knowledge gaps that stem from the limited research data on warming-induced biodiversity changes in rapidly warming Himalaya. Further, the study provides long-term climate data of the region compatible and comparable with global climate datasets in terms of instrumentation and methodology. Although an increase in species richness might sound positive as species enrichment, it is an equally alarming signal because as new thermophilic species become established at higher summits, local species extinctions will likely result from competitive displacement of cold climate specialists by potentially more vigorous lower elevation generalists that benefit from warming, rather than from habitat loss directly through warming. Therefore, increase in species richness is expected to be a transient phenomenon that hides the accumulation of extinction debt.
Replicability of Project	The current biodiversity change in the alpine summits in Himalayan Mountain ecosystems can have rapid and widespread consequences for ecosystem functioning, which merits detailed investigation in near future. The novel research insights will provide crucial baseline data to undertake qualitative/quantitative analyses of vegetation-climate dynamics in the Himalaya. More importantly, re-sampling of the summits in near future will furnish robust results on the impacts of climate change on alpine plant diversity in this ecologically fragile Himalayan region.

Exit Strategy	We suggest that the observed trend in plant community dynamics responds to short term temperature and precipitation variability and time lags in plant community response. It may take much longer than one decade for the observed trends to become stable and statistically significant. While the study provides an important foundation of documenting profound changes in alpine plant communities under global climate change, continuous monitoring is suggested for important policy making. The suggestions and recommendations could be used by the government officials by taking feedback from the experts and the local people. Some collaborative efforts of scientific institutions and government officials could make a strong hypothesis for the conservation and management of natural resources. It would be helpful for the policy making.



(**PROJECT PROPONENT/ COORDINATOR**)

Place: GBP-NIHE, Headquarter, Kosi, Almora

Date: 23/08/2022

Annexure-I

Consolidated and Audited Utilization Certificate (UC) and Statement of Expenditure (SE)

For the Period: January, 2019 to March, 2022

1.	Title of the project/Scheme/Programme:	Assessing Climate Change Impacts on Floristic Diversity of Alpine Regions in west Himalaya
2.	Name of the Principle Investigator & Organization:	Dr. K. C. Sekar (Scientist-F) (G.B. Pant National Institute of Himalayan Environment Kosi Katarmal Almora)
3.	NMHS-PMU, G.B. Pant National Institute of Himalayan Environment, Kosi-Katarmal, Almora, Uttarakhand Letter No. and Sanction Date of the Project:	GBPNI/NMHS-2018-19/SG/11/173 Date.21.12.2018
4.	Amount received from NMHS-PMU, G.B. Pant National Institute of Himalayan Environment, Kosi-Katarmal, Almora, Uttarakhand during the project period (Please give number and dates of Sanction Letter showing the amount paid):	GBPNI/NMHs-2018-19/SG/11/173 Date.21.12.2018 **Rs. 21,52,200.00** GBPNI/NMHS-2018-19/SG/11/173/218/35 Date.30.06.2020 **Rs. 98,400.00** GBPNI/NMHS-2018-19/SG/11/173/218/35/165 Date. 06.11.202202 **Rs. 12,67,200.00** GBPNI/NMHS-2018-19/SG/11/173/218/35/165/126/88 Date. 09.11.2021 **Rs. 8,86,965.00** **Total grant received of Rs. = 44,04,765.00**
5.	Total amount that was available for expenditure incurred during the project period: (F.Y 2018-19 to 2021-22)	**Rs. 44,04,765.00**
6.	Actual expenditure incurred during the project period: (F.Y 2018-2019 to 2021-22)	F.Y 2018-2019 Rs. 19,833.00 F.Y 2019-2020 Rs. 15,40,675.00 F.Y 2020-2021 Rs. 11,27,824.00 F.Y 2020-2021 Rs. 7,24,863.00 **Total expenditure of Rs. 34,13,195.00**
7.	Unspent Balance amount refunded, if any (Please give details of Cheque no. etc.):	**Rs. 9,27,252.00** **(Rs. 4,14,578 recurring & Rs. 5,12,674.00 non-recurring grant)**
8.	Balance amount available at the end of the project: 31.03.2022	**Rs. 64,318.00**
9.	Balance Amount:	**Rs. 64,318.00**
10.	Accrued bank Interest: F.Y 2018-19 to 2021-22	**Rs. 32,683.00***

***Rs. 27,040/- refunded to funding agency vide cheque no. 048448 dated 27.11.2020**

Certified that the expenditure of Rs. 34,13,195.00 (**Rupees Thirty Four lakh thirteen thousand one hundred ninety five only**) mentioned against Sr. No. 6 was actually incurred on the project/scheme for the purpose it was sanctioned.

Date: /05/2022

(Signature of Principal Investigator)	(Signature of Account Officer)	Signature of Head of the Institution)
	लेखा धिकारी. Accounts Officer. गो.ब.पन्त राष्ट्रीय हिमालय पर्यावरण संस्थान G. B. Pant National Institute of Himalayan Environment (NIHE) को.सी कटारमल अल्मोड़ा-263643 Kosi Katarmal, ALMORA-263643	निदेशक, Director, गो.ब.पन्त राष्ट्रीय हिमालय पर्यावरण संस्थान G. B. Pant National Institute of Himalayan Environment (NIHE) को.सी कटारमल, अल्मोड़ा-263643 Kosi Katarmal, ALMORA-263643

OUR REF. No.

ACCEPTED AND COUNTERSIGNED

Date:

COMPETENT AUTHORITY

NATIONAL MISSION ON HIMALAYAN STUDIES (GBP NIHE)

Statement of Consolidated Expenditure

[G. B. Pant National Institute of Himalayan Environment]

Statement showing the expenditure of the period from : **January, 2019 to March, 2022**
Sanction No. and Date : GBPNI/NMHS-2018-19/SG/11/173/218/35 date. 21.12.2018

1. Total outlay of the project : **Rs. 44,44,600.00**
2. Date of Start of the Project : **10.01.2019**
3. Duration : **3 year 3 months**
4. Date of Completion : **31.03.2022**

a) Amount received during the project period : **Rs. 44,04,765.00**

b) Total amount available for Expenditure : **Rs. 44,04,765.00**

Sr. No.	Budget head	Amount received F.Y 2018-19 to 2021-22	Expenditure F.Y 2018-19 to 2021-22	Amount Balance/ excess expenditure
1	Salaries	13,75,243.00	14,27,536.00	-52,293.00
2	Equipment	11,00,000.00	5,87,326.00	5,12,674.00
3	Travel	8,54,957.00	4,94,023.00	3,60,934.00
4	Consumable	3,88,000.00	3,37,577.00	50,423.00
5	Contingency	2,26,336.00	1,36,826.00	89,510.00
6	Activities & other project cost	4,60,229.00	4,29,907.00	30,322.00
7	Institutional charges	0.00	0.00	0.00
8	**Total**	**44,04,765.00**	**34,13,195.00**	**9,91,570.00**
			Amount refunded to funding agency	-9,27,252.00
			Actual balance as on 31.03.2022	64,318.00

Certified that the expenditure of **Rs. 34,13,195.00 (Rupees Thirty four lakh thirteen thousand one hundred** ninety five only) mentioned against Sr. No. 8 was actually incurred on the project/scheme for the purpose it was sanctioned.

Date: /05/2022

S Chandrasekhar 12/5

(Signature of Principal Investigator)

(Signature of Account Officer)
लेखाधिकारी,
Accounts Officer.
गो. ब. पंत राष्ट्रीय हिमालय पर्यावरण संस्थान
G. B. Pant National Institute of Himalayan Environment (NIHE)
कोसी कटारमल, अल्मोड़ा-263643
Kosi Katarmal, ALMORA-263643

(Signature of Head of the Institution)
निदेशक,
Director,
गो. ब. पंत राष्ट्रीय हिमालय पर्यावरण संस्थान
G. B. Pant National Institute of Himalayan Environment (NIHE)
कोसी कटारमल, अल्मोड़ा-263643
Kosi Katarmal, ALMORA-263643

OUR REF. No.
ACCEPTED AND COUNTERSIGNED
Date:
COMPETENT AUTHORITY
NATIONAL MISSION ON HIMALYAN STUDIES (GBPNIHE)

गोविन्द बल्लभ पन्त राष्ट्रीय हिमालय पर्यावरण संस्थान
G.B. Pant National Institute of Himalayan Environment (NIHE)
कोसी–कटारमल, अल्मोड़ा–263 643, उत्तराखण्ड, भारत
Kosi-Katarmal, Almora 263 643, Uttarakhand, India

Annexure-II

Consolidated Interest Earned Certificate

G. B. Pant National Institute of Himalayan Environment Kosi-Katarmal, Almora (UK)

Sl.No	Financial year	Received interest amount
1	2018-19	-
2	2019-20	20,708.00
3	2020-21	10,368.00
4	2021-22	1,607.00
	Total	**32,683.00***

*Rs. 27,040/- refunded to funding agency vide cheque no.048448 dated 27.11.2020

Signature of P.I

Signature of Account Officer

लेखाधिकारी
Accounts Officer.
गो.ब.पन्त राष्ट्रीय हिमालय पर्यावरण संस्थान
G. B. Pant National Institute of Himalayan Environment (NIHE)
कोसी कटारमल अल्मोड़ा-263643
K... ALMORA ...

Annexure-III

Consolidated Assets Certificate

Assets Acquired Wholly/ Substantially out of Government Grants

(Register to be maintained by Grantee Institution)

Name of the Sanctioning Authority: National Mission on Himalayan Studies

1. Sl. No. GBPNI/NMHS-2018-19/SG 11; Dated: 21/12/2018
2. Name of Grantee Institution: G.B. Pant National Mission Institute of Himalayan Environment
3. No. & Date of sanction order: GBPNI/NMHS-2018-19/SG 11; Dated: 21/12/2018
4. Amount of the Sanctioned Grant: Rs. 11,00000/- (Equipment Head)
5. Brief Purpose of the Grant: For purchasing soil data loggers
6. Whether any condition regarding the right of ownership of Govt. in the property or other assets acquired out of the grant was incorporated in the grant-in-aid Sanction Order: No
7. Particulars of assets actually credited or acquired Geo-Precision MLog-5W (35 nos.) and 1 Wireless dongle
8. Value of the assets as on Rs. 5,87,326.00/-
9. Purpose for which utilised at present soil temperature data recording
10. Encumbered or not ------
11. Reasons, if encumbered ------
12. Disposed of or not ------
13. Reasons and authority, if any, for disposal ------
14. Amount realised on disposal ------

Any Other Remarks: ------

(PROJECT INVESTIGATOR)

(Signed and Stamped)

(HEAD OF THE INSTITUTION)

(Signed and Stamped)

निदेशक,
Director,
गो.ब.पन्त राष्ट्रीय हिमालय पर्यावरण संस्थान
G. B. Pant National Institute of Himalayan Environment (NIHE)
कोसी कटारमल, अल्मोड़ा-263643
Kosi Katarmal, ALMORA-263643

(ACCOUNT OFFICER)

(Signed and Stamped)

लेखाधिकारी,
Accounts Officer,
गो.ब.पन्त राष्ट्रीय हिमालय पर्यावरण संस्थान
G. B. Pant National Institute of Himalayan Environment (NIHE)
कोसी कटारमल अल्मोड़ा-263643
Kosi Katarmal, ALMORA-263643

Annexure-IV

List or Inventory of Assets/ Equipment/ Peripherals

S. No.	Name of Equipment	Quantity	Sanctioned Cost	Actual Purchased Cost	Purchase Details
1.	Geo-precision M-log 5W simple (PT 1000) with wireless dongle (01 no.)	35 nos. and 1 no.	1100000	587326	Stock page no. 255-II/24.12.19 Order no: GBPI/Datalogger/NMHS-SG/KCS/19-20/1917

K Chandrasekhar 1-1-21

(PROJECT INVESTIGATOR)

(Signed and Stamped)

(FINANCE OFFICER)

लेखाधिकारी,
Accounts Officer
गो.ब.पन्त राष्ट्रीय हिमालय पर्यावरण संस्थान
G. B. Pant National Institute of Himalayan Environment (NIHE)
कोसी कटारमल, अल्मोड़ा-263643
Kosi Katarmal, ALMORA-263643

(Signed and Stamped)

(HEAD OF THE INSTITUTION)

निदेशक,
Director,
गो.ब.पन्त राष्ट्रीय हिमालय पर्यावरण संस्थान
G. B. Pant National Institute of Himalayan Environment (NIHE)
कोसी कटारमल, अल्मोड़ा-263643
Kosi Katarmal, ALMORA-263643

(Signed and Stamped)

गोविन्द बल्लभ पन्त राष्ट्रीय हिमालयी पर्यावरण संस्थान
G.B. Pant National Institute of Himalayan Environment (NIHE)
कोसी–कटारमल, अल्मोड़ा– 263643, उत्तराखण्ड
Kosi-Katarmal, Almora- 263 643, Uttarakhand

To,

The Convener, Mountain Division
Ministry of Environment, Forest & Climate Change (MoEF&CC)
Indira Paryavaran Bhawan
Jor Bagh, New Delhi-110003

Sub.: Transfer of Permanent Equipment purchased under Research Project titled "**Assessing climate change impacts on floristic diversity of alpine regions in West Himalaya**" funded under the NMHS Scheme of MoEF&CC – reg.

Sir/ Madam,

This is hereby certified that the following permanent equipment purchased under the aforesaid project have been transferred to the Implementing Organization/ Nodal Institute after completion of the project:

1. Geo-Precision M-Log 5W simple data logger with dongle (Data logger – 35; dongle- 01)

*Details enclosed in Annexure IV

Head of Implementing Organization:
Name of the Implementing Organization:
Stamp/ Seal:
Date:

निदेशक,
Director,
गो. ब. पन्त राष्ट्रीय हिमालय पर्यावरण संस्थान
G. B. Pant National Institute of Himalayan Environment (NIHE)
को. कटारमल, अल्मोड़ा-263643
Kosi Katarmal, ALMORA-263643

Copy to:

1. The Nodal Officer, NMHS-PMU, National Mission on Himalayan Studies (NMHS), G.B. Pant National Institute of Himalayan Environment (NIHE), Kosi-Katarmal, Almora, Uttarakhand-263643

Annexure-VI

Details, Declaration and Refund of Any Unspent Balance

Please provide the details of refund of any unspent balance and transfer the balance amount through RTGS (Real-Time Gross System) in favor of **NMHS GIA General**.

Kindly note the further Bank A/c Details as follows:

Name of NMHS A/c: NMHS GIA General

Bank Name & Branch: Central Bank of India (CBI), Kosi Bazar, Almora, Uttarakhand 263643

IFSC Code: CBIN0281528

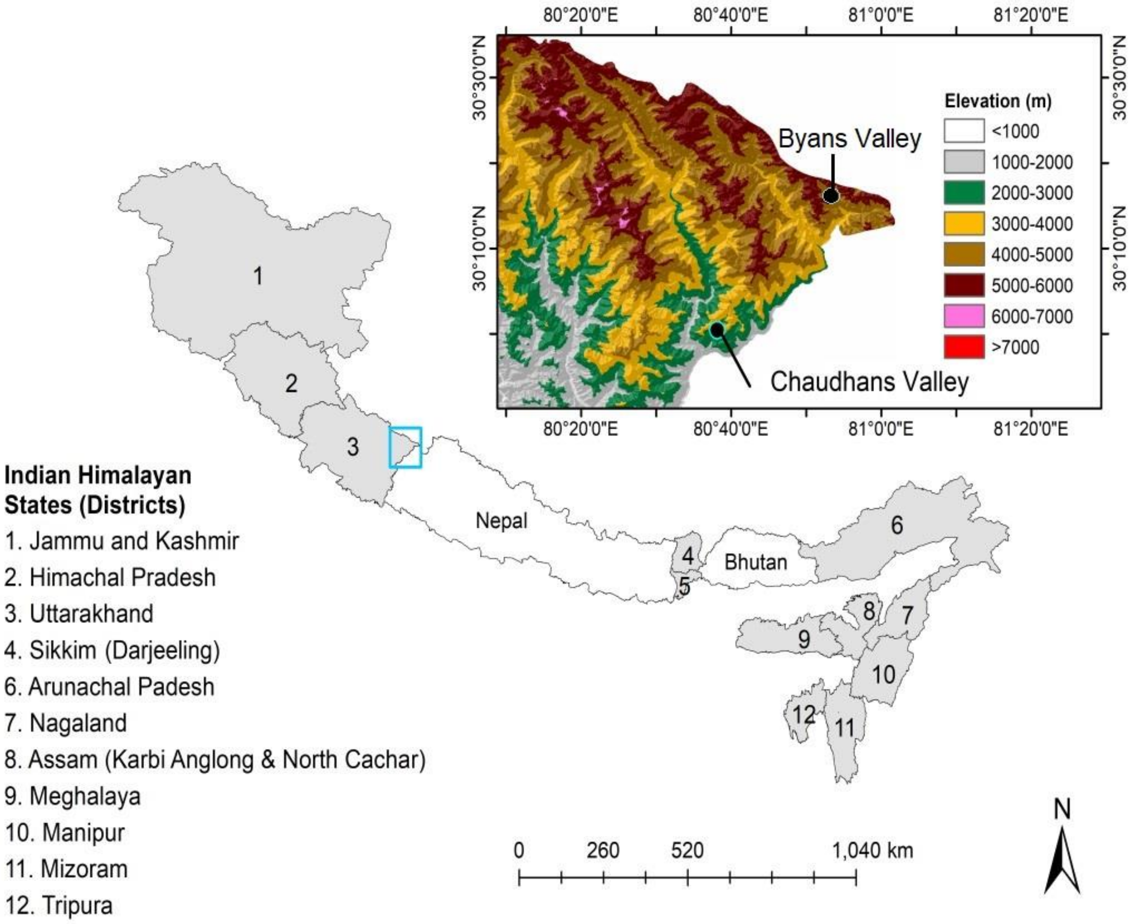
Account No.: 3530505520 (Saving A/c)

Refund amount: Rs. 24,070/- (cheque no. 048448 dated 27/11/2020

In case of any queries/ clarifications, please contact the NMHS-PMU at e-mail: nmhspmu2016@gmail.com

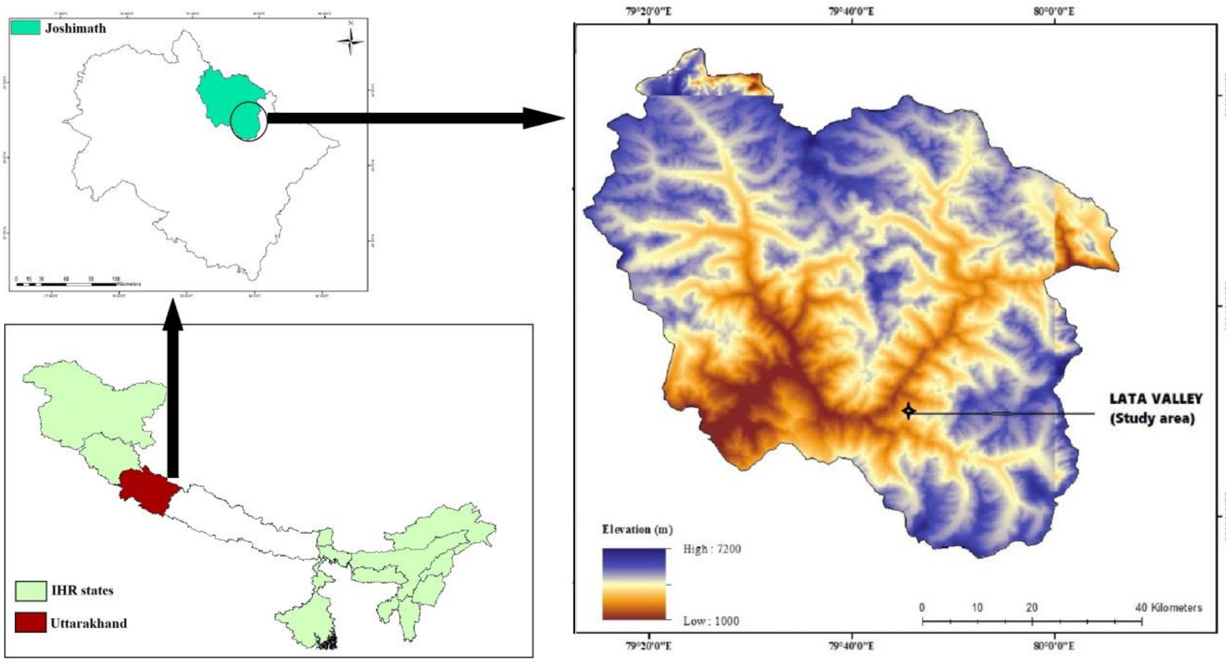
Annexure VIIa

Map of Target regions Byans and Chaudans, west Himalaya.



Annexure VIIb

Map of target region in Lata-kharak, Chamoli, west Himalaya.



Annexure VIII

Table 1. Vegetation composition pattern of the summit sites of GLORIA Target Region in Chaudans Valley.

Locality **(Summit code)**	**Altitude and location**	**Vegetation zone** **(IVI)**	**Plant species richness**
Bhairav Ghati (BHT)	**3337 m** Lat: 30º02.782' N Long: 80º39.122'E	Lower alpine- above treeline; *Bistorta affinis* (19.50) and *Anaphalis contorta* (16.72)	75 plant taxa (59 genera and 28 families)
Kharangdhang (KHA)	3881 m Lat: 30º02.927'N Long: 80º39.320'E	Transition between the lower and upper alpine; *Geum elatum* (21.62) and *Bistorta affinis* (21.04)	51 plant taxa (42 genera and 27 families)
Ganglakhan (GAN)	4060 m Lat: 30º03.113'N Long: 80º39.575'E	Upper alpine; the top region; *Carex setosa* (31.61) and *Hippolytia dolicophylla* (27.90)	38 plant taxa (29 genera and 18 families)
Sekhuakhan (SKN)	4266 m Lat: 30º03.783'N Long: 80º39.927'E	Transition between the upper alpine and nival; *Bistorta vaccinifolia* (56.63) and *Kobresia nepalensis* (48.83)	32 plant taxa (27 genera and 19 families)

Table 2. Soil characteristics in four summit areas of Chaudans GLORIA Target Region.

Sites	Aspect	Depth	pH	Moisture (%)	Bulk Density
BHT	N	0-10	6.56±0.03	39.43±0.16	0.96±0.06
		10-20	6.45±0.09	34.36±1.08	1.00±0.08
	S	0-10	6.60±0.07	34.92±0.51	0.86±0.05
		10-20	5.65±0.02	23.66±0.34	1.08±0.14
	E	0-10	6.46±0.04	31.65±1.45	0.96±0.15
		10-20	5.93±0.03	29.44±1.15	1.03±0.05
	W	0-10	6.09±0.03	31.22±0.79	0.89±0.09
		10-20	6.04±0.04	30.12±1.01	0.93±0.01
KHA	N	0-10	5.19±0.04	40.69±0.76	0.67±0.16
		10-20	6.37±0.09	29.19±0.40	0.69±0.03
	S	0-10	4.41±0.08	39.86±0.45	0.55±0.12
		10-20	6.35±0.11	15.37±0.52	0.57±0.02
	E	0-10	5.24±0.15	38.73±0.47	0.61±0.07
		10-20	5.44±0.13	29.77±1.03	0.63±0.03
	W	0-10	6.80±0.06	53.53±1.11	0.59±0.11
		10-20	6.99±0.01	36.23±1.09	0.62±0.09
GAN	N	0-10	6.20±0.04	33.18±0.29	0.83±0.19
		10-20	6.33±0.18	24.35±0.28	0.84±0.08
	S	0-10	6.93±0.01	35.07±0.41	0.94±0.07
		10-20	6.61±0.17	33.97±0.12	0.97±0.12
	E	0-10	6.35±0.03	41.32±0.44	0.88±0.04

		10-20	6.86±0.04	35.31±0.38	0.88±0.08
	W	0-10	6.45±0.08	45.77±0.37	0.81±0.07
		10-20	5.83±0.02	32.88±0.22	0.89±0.02
SKN	N	0-10	6.57±0.02	37.27±0.69	0.86±0.09
		10-20	6.33±0.02	26.87±0.07	1.20±0.07
	S	0-10	6.51±0.01	42.16±0.83	0.94±0.03
		10-20	5.96±0.02	32.94±0.70	1.21±0.08
	E	0-10	6.45±0.04	45.32±0.51	0.79±0.11
		10-20	6.65±0.28	33.34±0.42	0.87±0.12
	W	0-10	6.85±0.05	40.11±0.23	0.93±0.03
		10-20	5.92±0.06	31.91±0.52	0.97±0.02

BHT- Bhairav Ghati; KHA- Kharangdhang; GAN- Ganglakhan; SKN- Sekuakhan.
N- North; S- South; E- East; W= West.

Table 3. Chemical characteristics of soil in the four summit areas of Chaudans GLORIA Target Region.

Sites	Aspect		Organic carbon (%)	Nitrogen (gm/kg)	Phosphorus (ppm)	Potassium (%)
BHT	N	0-10	9.75±0.04	1.36±0.12	6.31±0.28	0.54±0.05
		10-20	9.13±0.04	0.46±0.11	3.59±0.96	0.35±0.05
	S	0-10	9.86±0.23	1.24±0.02	9.25±0.07	0.55±0.05
		10-20	9.68±0.04	1.23±0.05	3.60±1.32	0.54±0.07
	E	0-10	9.79±0.30	1.80±0.26	7.27±0.83	0.76±0.10
		10-20	9.62±0.38	0.92±0.44	3.17±1.06	0.48±0.13
	W	0-10	9.83±0.28	1.71±0.15	7.17±0.16	0.56±0.07
		10-20	9.36±0.08	1.38±0.11	5.43±0.97	0.59±0.06
KHA	N	0-10	9.89±0.05	2.53±0.03	18.52±0.65	0.52±0.03
		10-20	9.37±0.15	1.96±0.05	12.53±2.90	0.50±0.07
	S	0-10	9.44±0.66	2.03±0.19	7.60±0.16	0.54±0.06
		10-20	8.33±0.07	1.86±0.03	7.15±0.06	0.60±0.02
	E	0-10	9.46±0.08	2.51±0.07	9.95±0.87	0.71±0.07
		10-20	9.02±0.04	1.99±0.31	9.52±1.19	0.70±0.10
	W	0-10	9.82±0.12	2.73±0.09	10.48±0.99	0.67±0.04
		10-20	9.51±0.03	2.01±0.22	4.77±1.00	0.57±0.09
GAN	N	0-10	9.77±0.25	2.35±0.21	9.02±0.43	0.59±0.02
		10-20	9.55±0.04	1.84±0.02	6.13±0.18	0.63±0.03
	S	0-10	9.94±0.17	2.23±0.01	7.90±0.56	0.75±0.04
		10-20	9.26±0.04	1.76±0.03	7.76±1.74	0.74±0.09
	E	0-10	9.87±0.19	2.08±0.12	8.69±0.31	0.72±0.01
		10-20	9.14±0.05	1.87±0.12	5.47±1.69	0.73±0.02
	W	0-10	9.90±0.07	1.53±0.01	6.41±1.22	0.56±0.03

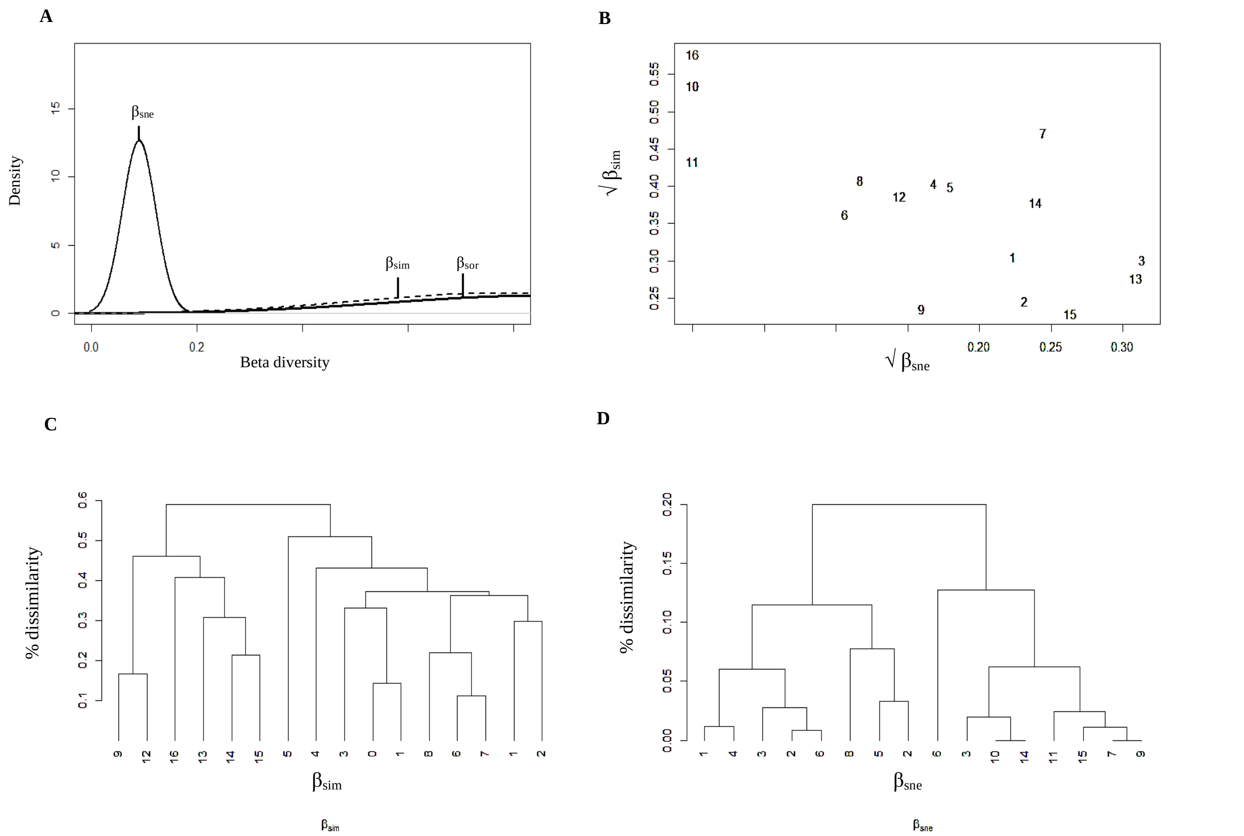
		10-20	9.54±0.02	1.12±0.02	5.28±1.85	0.55±0.03
SKN	N	0-10	8.91±0.07	0.24±0.04	7.88±0.91	0.57±0.03
		10-20	7.25±0.10	0.40±0.08	7.03±0.86	0.65±0.1
	S	0-10	8.11±0.13	0.54±0.36	5.58±0.09	0.39±0.11
		10-20	7.41±0.24	1.03±0.54	8.54±0.18	0.52±0.02
	E	0-10	9.63±0.10	1.08±0.16	8.58±1.29	0.56±0.03
		10-20	8.58±0.04	1.12±0.01	7.72±0.47	0.48±0.04
	W	0-10	7.33±0.12	0.66±0.41	4.64±1.12	0.36±0.12
		10-20	7.23±0.07	0.73±0.15	7.19±0.72	0.47±0.02

BHT- Bhairav Ghati; KHA- Kharangdhang; GAN- Ganglakhan; SKN- Sekuakhan.
N- North; S- South; E- East; W= West.

Table 4: Soil temperature (mean ± standard deviation) across four summits and four cardinal directions in Chaudans Target Redion depicted obtained from 2015-2019 period.

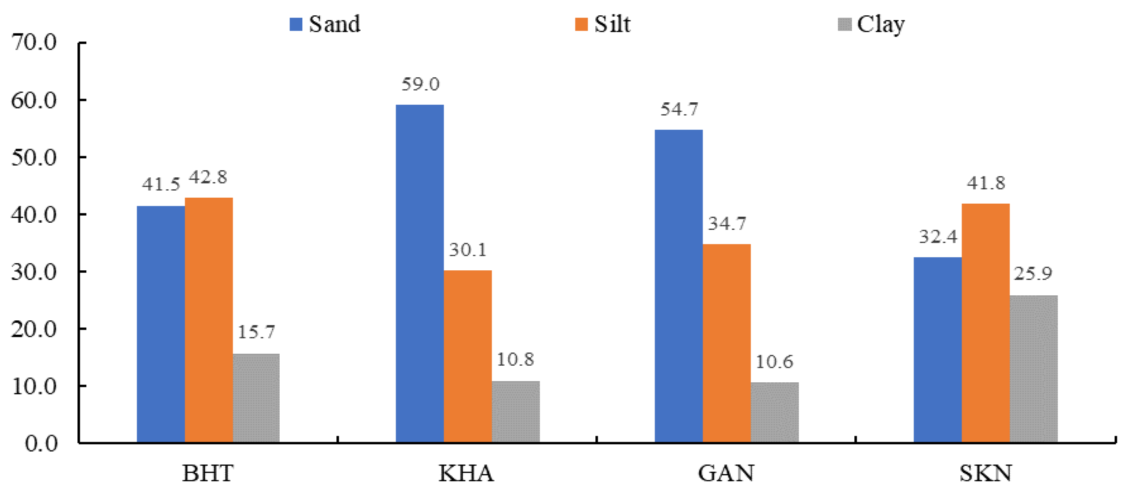
Summit code	Temperature (ºC)		
	Min	Mean	Max
BHT	0.59±4.30	7.41±4.30	13.40±5.99
KHA	-0.85±4.82	5.54±4.82	12.82±7.28
GAN	-0.29±4.85	5.93±4.85	13.63±7.70
SKN	-6.09±5.31	2.52±5.31	12.02±9.50
N	-3.28±5.43	4.42±5.43	13.09±5.43
S	0.21±4.01	6.31±4.01	12.56±4.01
E	0.88±4.31	7.43±4.31	13.35±4.31
W	-3.18±5.22	4.46±5.22	12.97±5.22

BHT- Bhairav Ghati; KHA- Kharangdhang; GAN- Ganglakhan; SKN- Sekuakhan.
N- North; S- South; E- East; W= West.



1-BHTN; 2-BHTS; 3-BHTE; 4-BHTW; 5-KHAN; 6-KHAS; 7-KHAE; 8-KHAW; 9-GANN; 10-GANS; 11-GANE; 12-GANW; 13-SKNN; 14-SKNS; 15-SKNE; 16-SKNW.

Figure 1. Multiple-site dissimilarities across the four studied summits and four aspects north (N), south (S), east (E) and west (W) on each summit. A- Partitioning of β_{sor} (total dissimilarity) into β_{sim} (turnover) and β_{sne} (nestedness). B- Comparison of square root transformed β_{sim} and β_{sne} between 2015 and 2019 for the summits and aspects. Average clustering of C- β_{sim} and D- β_{sne} among summits and aspects



BHT= Bhairavghati; KHA=Kharangdhang; GAN=Ganglakhan; SKN=Sekhuakhan

Figure 2: Texture of soil sampled from four summit sites in Chaudans valley.

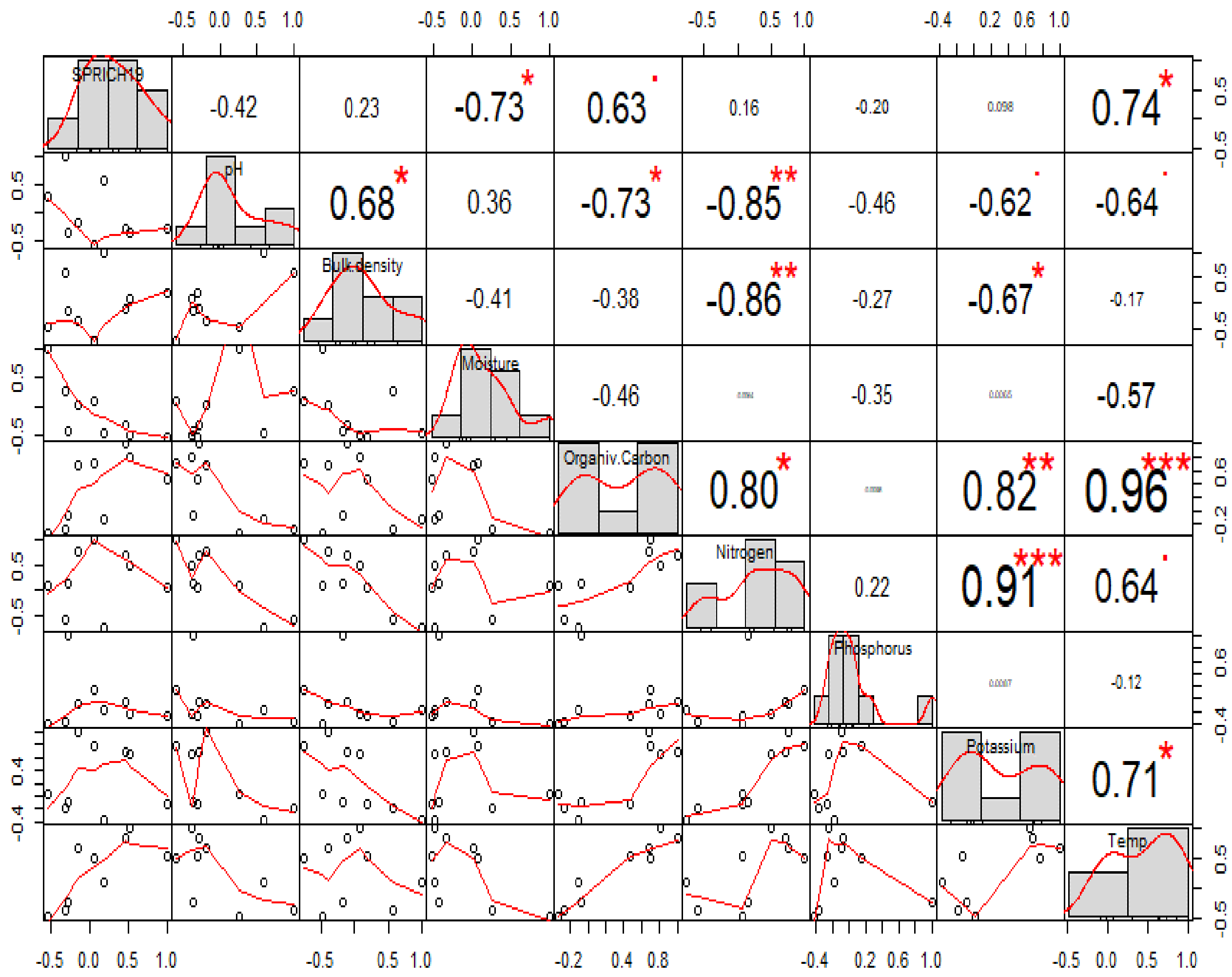


Figure 3. Pearson's Correlation between soil parameters and species richness. (Significant differences are indicated as '*'for P < 0.001, '**' P < 0.01, '*' P < 0.05, and '.' for P < 0.1**

Annexure - IX

Table 5. Vegetation composition pattern of the summit sites of GLORIA Target Region in Lata Valley.

Locality (Summit code)	Altitude & location	Vegetation zone	Plant species richness; Dominant species (IVI)
Kharak (KHR)	3820 m 30º29'41.47" N 79º45'12.20" E	Lower alpine- above treeline	88 species; *Bistorta affinis* (29) and *Danthonia cachemyriana* (20)
Sainikharak (SAI)	3923 m 30º29'28.79" N 79º45'14.97" E	Transition between the lower and upper alpine	80 species; *D. cachemyriana* (21) and *Anaphalis contorta* (20)
Donidhar (DON)	4030 m 30º29'35.14" N 79º45'20.16" E	Upper alpine- the top region	67 species; *B. affinis* (22) and *D. cachemyriana* (18)
Pulang (PUL)	4269 m 30º29'39.01" N 79º45'42.63" E	Transition between the upper alpine and nival	40 species; *B. affinis* (45) and *Nardostachys grandiflora* (21)

Table 6: Floristic diversity of the GLORIA Target Region in Lata valley.

Plant Taxa	Family	KHR	SAI	DON	PUL
Aletris pauciflora (Klotzsch) Hand. - Mazz.	Melanthiaceae		+		
Allium stracheyi Baker	Liliaceae	+		+	
Anaphalis contorta (D. Don) Hook. f.	Asteraceae	+	+	+	+
Anemone obtusiloba D. Don	Ranunculaceae	+	+	+	+
Anemone polyanthes D. Don	Ranunculaceae		+		
Anemone rupicola Cambess.	Ranunculaceae	+	+		
Arabis auriculata Lam.	Brassicaceae	+	+		
Arenaria bryophylla Fernald	Caryophyllaceae		+		
Arenaria festucoides Benth.	Caryophyllaceae	+			
Arenaria serpyllifolia L.	Caryophyllaceae	+			
Arnebia benthamii (Wall. *ex* G. Don) I.M. Johnst.	Boraginaceae	+	+	+	
Aster diplostephioides (DC.) Benth. *ex* C.B. Clarke	Asteraceae	+	+	+	+
Astragalus himalensis Jacquem. *ex* Baker	Fabaceae		+		
Bergenia stracheyi (Hook. f. & Thomson) Engl.	Saxifragaceae	+	+	+	+
Bistorta affinis (D. Don) Greene	Polygonaceae	+	+	+	+
Bistorta amplexicaulis (D. Don)	Polygonaceae		+		

Greene					
Bistorta vacciniifolia (Wall. *ex* Meisn.) Greene	Polygonaceae		+		+
Bistorta vivipara (L.) Gray	Polygonaceae	+	+	+	+
Bromus japonicus Houtt.	Poaceae		+		
Bupleurum falcatum L.	Apiaceae	+	+	+	+
Caltha palustris L.	Ranunculaceae	+			
Carex infuscata Nees	Cyperaceae	+	+		
Carex setosa Boott	Cyperaceae	+	+	+	+
Cassiope fastigiata (Wall.) D. Don	Ericaceae	+	+	+	
Cicerbita macrorhiza (Royle) Beauverd	Asteraceae		+	+	
Corydalis cashmeriana Royle	Fumariaceae	+	+		
Corydalis flabellata Edgew.	Fumariaceae				+
Cotoneaster microphyllus Wall. *ex* Lindl.	Rosaceae	+	+	+	
Cremanthodium ellisii (Hook. f.) Kitam.	Asteraceae	+	+	+	+
Cyananthus lobatus Wall. *ex* Benth.	Campanulaceae	+	+	+	+
Danthonia cachemyriana Jaub. & Spach	Poaceae	+	+	+	+
Delphinium brunonianum Royle	Ranunculaceae		+		
Dryopteris barbigera (T. Moore ex Hook.) Kuntze	Dryopteridacea	+	+	+	
Elsholtzia eriostachya (Benth.) Benth.	Lamiaceae	+		+	
Epilobium royleanum Hausskn.	Onagraceae			+	+
Erigeron semibarbatus DC.	Asteraceae		+		
Eritrichium villosum (Ledeb.) Bunge	Boraginaceae	+	+		
Euphorbia stracheyi Boiss.	Euphorbiaceae	+		+	
Euphrasia himalayica Wettst.	Scrophulariaceae			+	+
Sanguisorba diandra (Wall.) Nordborg	Rosaceae	+			
Falconeria himalaica Hook. f.	Scrophulariaceae		+		
Fragaria nubicola Lindl. *ex* Lacaita	Rosaceae		+		+
Galium aparine L.	Rubiaceae	+			
Gentiana venusta (G. Don) Griseb.	Gentianaceae		+		+
Geranium collinum Steph. *ex* Willd.	Geraniaceae	+	+	+	

Geranium nepalense Sweet	Geraniaceae	+	+	+	+
Geranium wallichianum D. Don *ex* Sweet	Geraniaceae	+	+	+	
Geum elatum Wall. *ex* G. Don	Rosaceae	+		+	+
Gypsophila cerastioides D. Don	Caryophyllaceae	+	+	+	
Heracleum candicans Wall. *ex* DC.	Apiaceae	+			
Hippolytia dolicophylla (Kitam.) K. Bremer & Humphries	Asteraceae				+
Impatiens leggei Pusalkar & D.K. Singh	Balsaminaceae	+	+		
Impatiens scabrida DC.	Balsaminaceae	+			
Juncus concinnus D. Don	Juncaceae	+		+	+
Juncus membranaceus Royle	Juncaceae	+	+	+	
Juniperus communis L.	Cupressaceae	+		+	
Dolomiaea macrocephala DC.	Asteraceae	+		+	
Kobresia laxa Nees	Cyperaceae	+		+	
Kobresia nepalensis (Nees) Kük.	Cyperaceae	+		+	+
Lactuca dubyaea C.B. Clarke	Asteraceae	+	+	+	
Lamium album L.	Lamiaceae		+		
Leibnitzia pusilla (DC.) S. Gould	Asteraceae	+	+		
Leontopodium jacotianum Beauverd	Asteraceae			+	+
Ligularia arnicoides DC. *ex* Royle	Asteraceae	+		+	
Lloydia longiscapa Hook.	Liliaceae	+			
Lomatogonium carinthiacum (Wulfen) Rchb.	Gentianaceae			+	
Malaxis muscifera (Lindl.) Grubov	Orchidaceae		+		
Morina longifolia Wall. *ex* DC.	Caprifoliaceae	+	+	+	
Nardostachys grandiflora DC.	Caprifoliaceae		+		
Oxygraphis polypetala (D. Don) Hook. f. & Thomson	Ranunculaceae		+		
Parochetus communis Buch.-Ham. *ex* D. Don	Fabaceae	+			
Parnassia kumaonica Nekrass.	Parnassiaceae	+	+		
Parnassia nubicola Wall. *ex* Royle	Parnassiaceae	+	+	+	+
Pedicularis gracilis Wall. *ex* Benth.	Scrophulariaceae	+	+	+	
Pedicularis pectinata Wall. *ex* Benth.	Scrophulariaceae	+	+	+	
Pedicularis punctata Decne.	Scrophulariaceae	+	+	+	

Pedicularis trichoglossa Hook. f.	Scrophulariaceae	+	+		
Phlomis bracteosa Royle *ex* Benth.	Lamiaceae	+	+		
Picrorhiza kurrooa Royle	Scrophulariaceae		+		+
Plantago depressa Willd.	Plantaginaceae		+		
Pleurospermum brunonis (DC.) C.B. Clarke	Apiaceae	+			
Poa alpina L.	Poaceae	+	+	+	+
Poa annua L.	Poaceae	+	+		
Polygonatum multiflorum (L.) All.	Liliaceae	+		+	
Polygonum filicaule Wall. *ex* Meisn.	Polygonaceae		+		
Polygonum polystachyum Wall. *ex* Meisn.	Polygonaceae	+		+	
Polystichum thomsonii (Hook. f.) Bedd.	Dryopteridaceae			+	
Ponerorchis chusua (D. Don) Soo	Orchidaceae	+			
Potentilla argyrophylla Wall. *ex* Lehm.	Rosaceae	+	+	+	+
Potentilla atrosanguinea G. Lodd. *ex* D. Don	Rosaceae			+	+
Potentilla biflora D.F.K. Schltdl.	Rosaceae	+	+		
Potentilla cuneata Wall. ex Lehm.	Rosaceae	+	+	+	
Potentilla cuneifolia Bertol.	Rosaceae	+	+	+	
Potentilla microphylla D. Don	Rosaceae				+
Primula denticulata Sm.	Primulaceae	+	+	+	
Ranunculus hirtellus Royle	Ranunculaceae	+	+		
Rheum moorcroftianum Royle	Polygonaceae			+	
Rhodiola bupleuroides (Wall. *ex* Hook. f. & Thomson) S.H. Fu	Crassulaceae	+		+	+
Rhododendron anthopogon D. Don	Ericaceae			+	+
Rhododendron campanulatum D. Don	Ericaceae	+		+	
Rhododendron lepidotum Wall. *ex* G. Don	Ericaceae	+	+		
Rosa macrophylla Lindl.	Rosaceae	+			
Rumex nepalensis Spreng.	Polygonaceae	+		+	
Salix sp.	Salicaceae	+	+	+	
Saussurea obvallata (DC.) Sch. Bip.	Asteraceae				+
Saussurea taraxifolia (Lindl.) DC.	Asteraceae	+			+

Saxifraga flagellaris Willd. *ex* Sternb.	Saxifragaceae		+	+	+
Saxifraga sp.	Saxifragaceae	+	+	+	+
Sedum multicaule Wall. *ex* Lindl.	Crassulaceae		+		
Selinum elatum M. Hiroe	Apiaceae	+			
Selinum wallichianum (DC.) Raizada & H.O. Saxena	Apiaceae	+	+	+	
Senecio chrysanthemoides DC.	Asteraceae	+		+	
Sibbaldia cuneata Hornem. *ex* Kuntze	Rosaceae	+	+		+
Sibbaldia parviflora Willd.	Rosaceae	+	+	+	
Silene vulgaris (Moench) Garcke	Caryophyllaceae	+		+	
Stellaria media (L.) Vill.	Caryophyllaceae		+		+
Swertia chirata Buch.-Ham. *ex* C.B. Clarke	Gentianaceae		+	+	+
Swertia ciliata (D. Don *ex* G. Don) B.L. Burtt	Gentianaceae	+		+	
Swertia cuneata Wall. *ex* D. Don	Gentianaceae	+			
Swertia petiolata D. Don	Gentianaceae		+		
Swertia speciosa Wall.	Gentianaceae		+		
Taraxacum officinale F.H. Wigg.	Asteraceae	+		+	
Thalictrum alpinum L.	Ranunculaceae	+	+		
Trachydium roylei Lindl.	Apiaceae	+	+	+	+
Valeriana hardwickii Wall.	Valerianaceae		+		
Veronica biloba L.	Scrophulariaceae	+			
Viola biflora L.	Violaceae	+	+	+	+

Table 7: Diversity of threatened plants of the GLORIA Target Region in Lata valley.

Species name	**Threat Status**	**Species cover (%)**			
		KHR	SAI	DON	PUL
Arnebia benthamii	CR	4.5	3.8	2.5	
Nardostachys grandiflora	CR			11	57
Picrorhiza kurrooa	CR		1		5
Saussurea obvallata	EN				5
Allium stracheyi	VU	5.5		3	
Bergenia stracheyi	VU		9.2		16
Malaxis muscifera	VU	1.2			

Juniperus communis	LC			50	
Silene vulgaris	LC	2.5	4.5		
Rhododendron anthopogon	NT	66.4	25	171	381
Rhododendron campanulatum	NT	1.5		3	
Rhododendron lepidotum	NT			4.2	6.2

CR- Critically Endangered; EN- Endangered; VU- Vulnerable; LC- Least Concern; NT- Near Threatened

Table 8. Soil moisture content (%) in GLORIA Target Region in Lata valley along four aspects at depths 0-10cm and 10-20cm.

Aspect	**Contour line (m)**	**Depth (cm)**	**Soil moisture (%)**			
			KHR	**SAI**	**DON**	**PUL**
HSP		**0-10**	43.27 ± 0.07	43.53 ± 0.07	54.90 ± 0.20	46.83 ± 0.23
		10 20	38.17 ± 0.13	37.69 ± 0.26	53.90 ± 0.13	40.26 ± 0.07
North	**5m**	**0-10**	43.48 ± 0.20	48.66 ± 0.07	44.51 ± 0.07	47.99 ± 0.07
		10 20	40.23 ± 0.17	39.23 ± 0.11	47.39 ± 0.07	46.10 ± 0.13
	10m	**0-10**	57.49 ± 0.37	49.74 ± 0.07	57.83 ± 0.07	40.01 ± 0.13
		10 20	49.82 ± 0.07	41.83 ± 0.07	28.43 ± 0.07	39.63 ± 0.20
South	**5m**	**0-10**	36.69 ± 0.07	35.12 ± 0.11	43.68 ± 0.07	54.01 ± 0.20
		10 20	38.35 ± 0.07	30.39 ± 0.24	41.51 ± 0.13	43.55 ± 0.33
	10m	**0-10**	42.00 ± 0.07	35.46 ± 0.27	38.20 ± 0.07	56.76 ± 0.20
		10 20	38.27 ± 0.07	33.73 ± 0.35	32.54 ± 0.07	43.07 ± 0.13
East	**5m**	**0-10**	33.33 ± 0.39	35.03 ± 0.13	43.21 ± 0.07	62.88 ± 0.20
		10 20	28.60 ± 0.17	34.78 ± 0.17	34.28 ± 0.07	51.12 ± 0.13
	10m	**0-10**	34.92 ± 0.24	32.14 ± 0.30	43.63 ± 0.20	52.72 ± 0.07
		10 20	28.77 ± 0.33	32.20 ± 0.33	41.87 ± 0.20	43.30 ± 0.13
West	**5m**	**0-10**	36.91 ± 0.07	54.83 ± 0.17	50.58 ± 0.07	52.37 ± 0.20
		10 20	32.15 ± 0.07	51.71 ± 0.13	37.45 ± 0.07	45.29 ± 0.07
	10m	**0-10**	44.69 ± 0.12	44.82 ± 0.20	38.82 ± 0.07	45.56 ± 0.07
		10-20	46.95 ± 0.07	38.98 ± 0.07	35.11 ± 0.13	41.20 ± 0.17

Table 9. Bulk density (g/cm^3) in GLORIA Target Region in Lata valley along four aspects at depths 0-10 cm and 10-20 sm (KHR- Kharak; SAI- Sainikharak; DON- Donidhar; PUL- Pulan).

Aspect	Contour line (m)	Depth (cm)	KHR	SAI	DON	PUL
HSP		**0-10**	0.93 ± 0.007	0.80 ± 0.001	0.51 ± 0.015	1.00 ± 0.002
		10 20	1.07 ± 0.003	0.87 ± 0.001	0.55 ± 0.015	1.13 ± 0.001
North	**5m**	**0-10**	0.81 ± 0.005	0.69 ± 0.013	0.67 ± 0.007	0.88 ± 0.001
		10 20	0.67 ± 0.002	1.10 ± 0.011	0.78 ± 0.003	1.02 ± 0.001
	10m	**0-10**	0.54 ± 0.007	0.66 ± 0.015	0.52 ± 0.010	1.11 ± 0.001
		10 20	0.51 ± 0.003	0.94 ± 0.004	0.97 ± 0.001	1.12 ± 0.003
South	**5m**	**0-10**	0.78 ± 0.005	0.96 ± 0.001	0.68 ± 0.003	0.94 ± 0.001
		10 20	1.11 ± 0.001	0.79 ± 0.004	1.00 ± 0.001	1.22 ± 0.001
	10m	**0-10**	0.75 ± 0.002	0.42 ± 0.002	0.83 ± 0.001	0.79 ± 0.007
		10 20	0.90 ± 0.001	0.45 ± 0.002	1.05 ± 0.001	1.02 ± 0.001
East	**5m**	**0-10**	0.63 ± 0.001	0.51 ± 0.001	0.70 ± 0.002	0.64 ± 0.005
		10 20	0.86 ± 0.001	0.92 ± 0.001	1.13 ± 0.001	0.76 ± 0.001
	10m	**0-10**	0.80 ± 0.001	0.56 ± 0.004	0.98 ± 0.001	0.85 ± 0.001
		10 20	0.67 ± 0.001	0.58 ± 0.002	0.99 ± 0.001	1.11 ± 0.001
West	**5m**	**0-10**	0.81 ± 0.001	0.60 ± 0.013	0.71 ± 0.006	1.09 ± 0.001
		10 20	1.07 ± 0.001	0.94 ± 0.001	1.04 ± 0.002	1.01 ± 0.001
	10m	**0-10**	0.81 ± 0.001	0.59 ± 0.003	0.93 ± 0.002	1.11 ± 0.001
		10 20	0.93 ± 0.001	0.99 ± 0.001	1.18 ± 0.002	1.26 ± 0.001

Table 10. pH of soil sampled along altitude gradient in the different aspects at depths 0-10cm and 10-20cm in GLORIA Target Region in Lata valley.

			Soil pH			
Aspect	**Contour line (m)**	**Depth (cm)**	**KHR**	**SAI**	**DON**	**PUL**
HSP		**0-10**	4.76 ± 0.05	5.16 ± 0.06	5.55 ± 0.05	5.34 ± 0.02

		10 20	5.19 ± 0.11	5.38 ± 0.10	5.25 ± 0.06	5.35 ± 0.01
North	**5m**	**0-10**	5.94 ± 0.11	5.46 ± 0.07	5.27 ± 0.19	5.57 ± 0.02
		10 20	5.39 ± 0.02	5.64 ± 0.09	4.94 ± 0.01	4.72 ± 0.03
	10m	**0-10**	3.22 ± 0.12	4.53 ± 0.22	5.04 ± 0.04	5.60 ± 0.05
		10 20	3.64 ± 0.13	4.99 ± 0.22	5.83 ± 0.04	4.99 ± 0.10
South	**5m**	**0-10**	5.73 ± 0.09	5.37 ± 0.05	5.01 ± 0.02	5.44 ± 0.03
		10 20	4.18 ± 0.08	5.81 ± 0.15	4.96 ± 0.04	5.56 ± 0.16
	10m	**0-10**	4.14 ± 0.11	5.48 ± 0.12	4.80 ± 0.29	5.40 ± 0.20
		10 20	5.05 ± 0.18	5.12 ± 0.05	5.71 ± 0.14	4.09 ± 0.02
East	**5m**	**0-10**	4.21 ± 0.05	4.79 ± 0.02	5.44 ± 0.01	5.56 ± 0.05
		10 20	3.35 ± 0.04	5.01 ± 0.03	5.46 ± 0.21	5.03 ± 0.04
	10m	**0-10**	5.97 ± 0.03	4.61 ± 0.16	5.48 ± 0.124	5.06 ± 0.31
		10 20	3.95 ± 0.27	4.55 ± 0.16	5.43 ± 0.17	5.26± 0.03
West	**5m**	**0-10**	4.64 ± 0.02	4.13 ± 0.10	6.16 ± 0.11	4.64 ± 0.13
		10 20	4.16 ± 0.04	5.46 ± 0.08	6.46 ± 0.17	5.90 ± 0.16
	10m	**0-10**	5.68 ± 0.18	5.13 ± 0.07	5.77 ± 0.09	5.51 ± 0.07
		10 20	5.20 ± 0.07	5.66 ± 0.07	5.34 ± 0.09	5.89 ± 0.19

KHR- Kharak; SAI- Sainikharak; DON- Donidhar; PUL- Pulan

Table 11. Soil organic carbon content (%) along altitude gradient in the different aspects at depths 0-10cm and 10-20cm in GLORIA Target Region in Lata valley.

Aspect	Contour line (m)	Depth (cm)	Organic carbon content (%)			
			KHR	**SAI**	**DON**	**PUL**
HSP		**0-10**	0.36 ± 0.01	0.79 ± 0.02	1.19 ± 0.09	1.36 ± 0.02
		10 20	0.76 ± 0.08	0.37 ± 0.01	0.90 ± 0.13	0.72 ± 0.01
North	**5m**	**0-10**	0.45 ± 0.03	0.99 ± 0.01	1.14 ± 0.09	1.17 ± 0.03
		10 20	0.75 ± 0.05	0.58 ± 0.02	0.95 ± 0.08	1.06 ± 0.03
	10m	**0-10**	0.99 ± 0.02	1.18 ± 0.03	0.90 ± 0.08	1.30 ± 0.02
		10 20	0.92 ± 0.06	0.69 ± 0.02	0.54 ± 0.08	0.80 ± 0.01
South	**5m**	**0-10**	1.54 ± 0.09	1.07 ± 0.03	1.44 ± 0.02	1.13 ± 0.04
		10 20	0.79 ± 0.03	0.97 ± 0.02	1.24 ± 0.03	1.00 ± 0.01
	10m	**0-10**	0.84 ± 0.05	0.60 ± 0.01	1.34 ± 0.02	1.21 ± 0.02
		10 20	0.73 ± 0.04	0.54 ± 0.01	1.20 ± 0.06	1.10 ± 0.02
East	**5m**	**0-10**	0.80 ± 0.02	1.16 ± 0.02	1.05 ± 0.07	1.82 ± 0.04
		10 20	0.69 ± 0.03	1.10 ± 0.01	1.10 ± 0.14	1.36 ± 0.04
	10m	**0-10**	1.33 ± 0.09	0.60 ± 0.02	1.04 ± 0.11	1.73 ± 0.03
		10 20	1.48 ± 0.08	0.41 ± 0.01	0.73 ± 0.15	1.00 ± 0.02
West	**5m**	**0-10**	1.46 ± 0.07	1.16 ± 0.02	1.20 ± 0.20	0.76 ± 0.01
		10 20	0.39 ± 0.03	0.34 ± 0.01	1.13 ± 0.03	0.70 ± 0.01
	10m	**0-10**	0.84 ± 0.05	0.80 ± 0.02	1.25 ± 0.03	0.63 ± 0.01
		10 20	0.95 ± 0.05	0.51 ± 0.01	1.05 ± 0.14	0.53 ± 0.02

Table 12: Correlation between different environmental variables ($p<0.01$*; $p<0.001$) in Lata valley Target region.**

	Temperature	Precipitation	Moisture	Bulk density	pH	OC
Temperature	1	**	**		*	*
Precipitation	0.68	1	*	*		
Moisture	-0.78	-0.65	1			
Bulk density	-0.44	-0.60	0.33	1	*	
pH	-0.55	-0.42	0.24	0.51	1	*
OC	0.73	-0.27	0.13	0.22	0.61	1

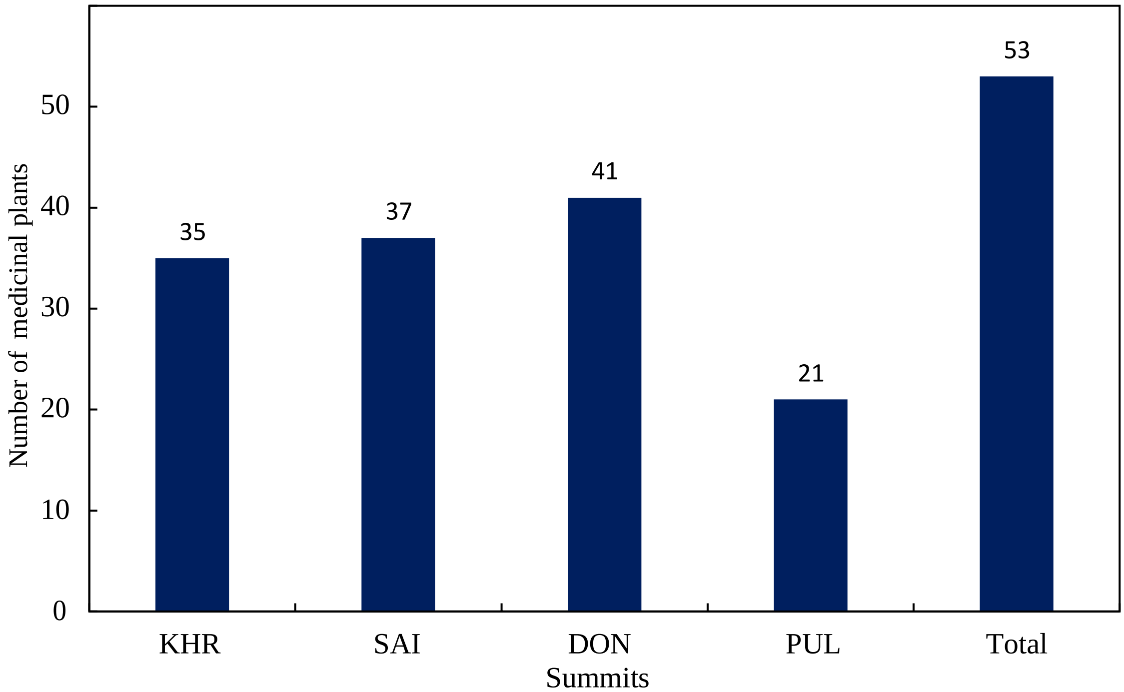


Figure 5. Diversity of medicinal plants at different summits of GLORIA target regionin Lata.

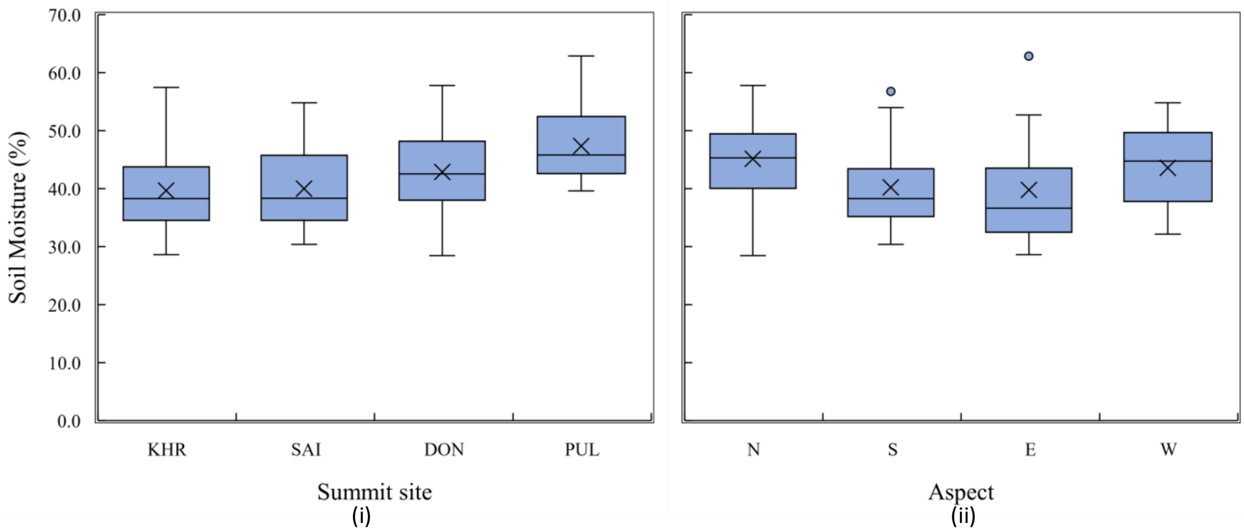


Figure 6. Soil moisture (%) variation with respect to (i) Altitude and (ii) Aspect in theGLORIA Target Region in Lata valley.

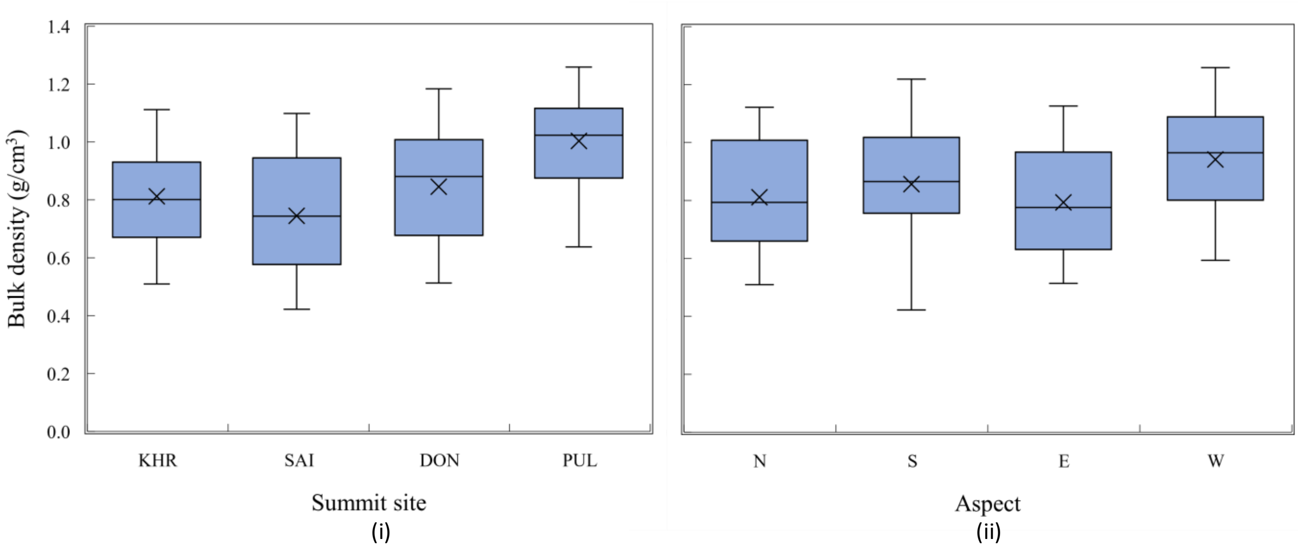


Figure 7. Bulk density (g/cm^3) variation with respect to (i) Altitude and (ii) Aspect in the GLORIA Target Region in Lata valley.

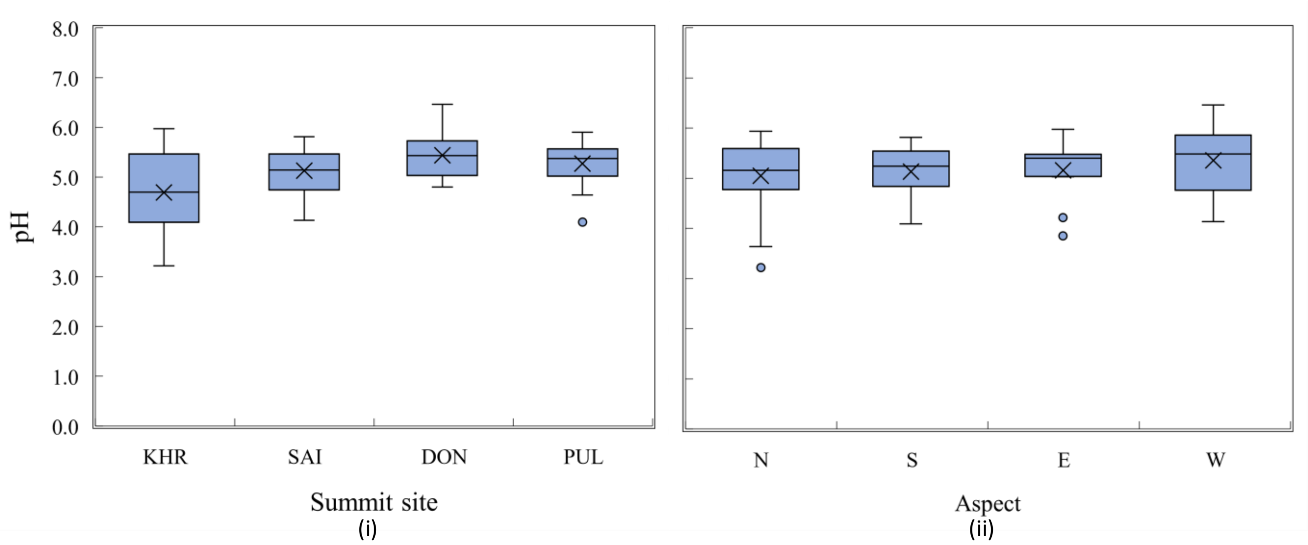


Figure 8. Soil pH variation with respect to (i) Altitude and (ii) Aspect in the GLORIATarget Region in Lata valley.

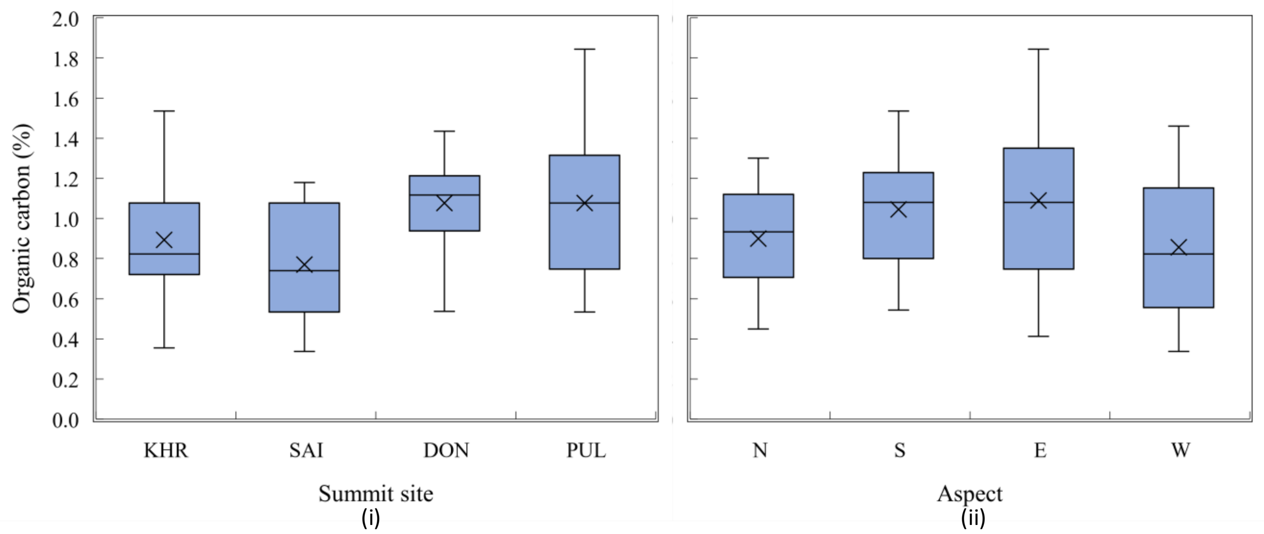


Figure 9. Soil organic carbon content (%) variation with respect to (i) Altitude and (i)Aspect in the GLORIA Target Region in Lata valley.

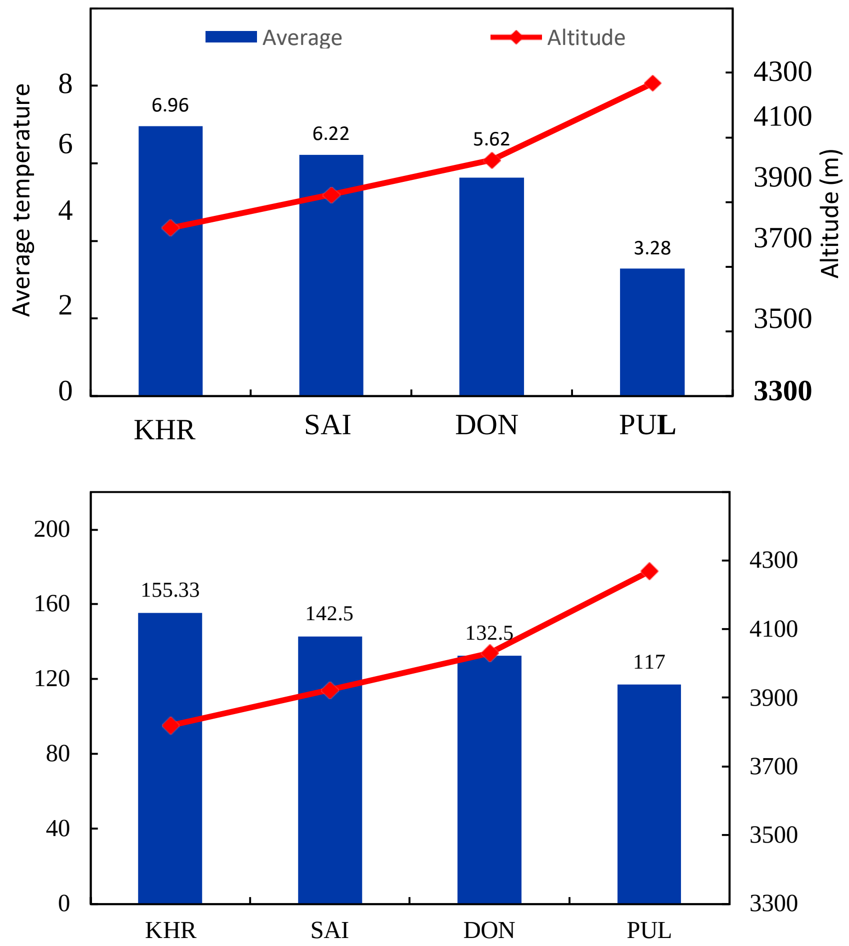


Figure 10. Spatial variation in mean annual temperature (^{o}C) & precipitation (mm) in Lata valley Target region.

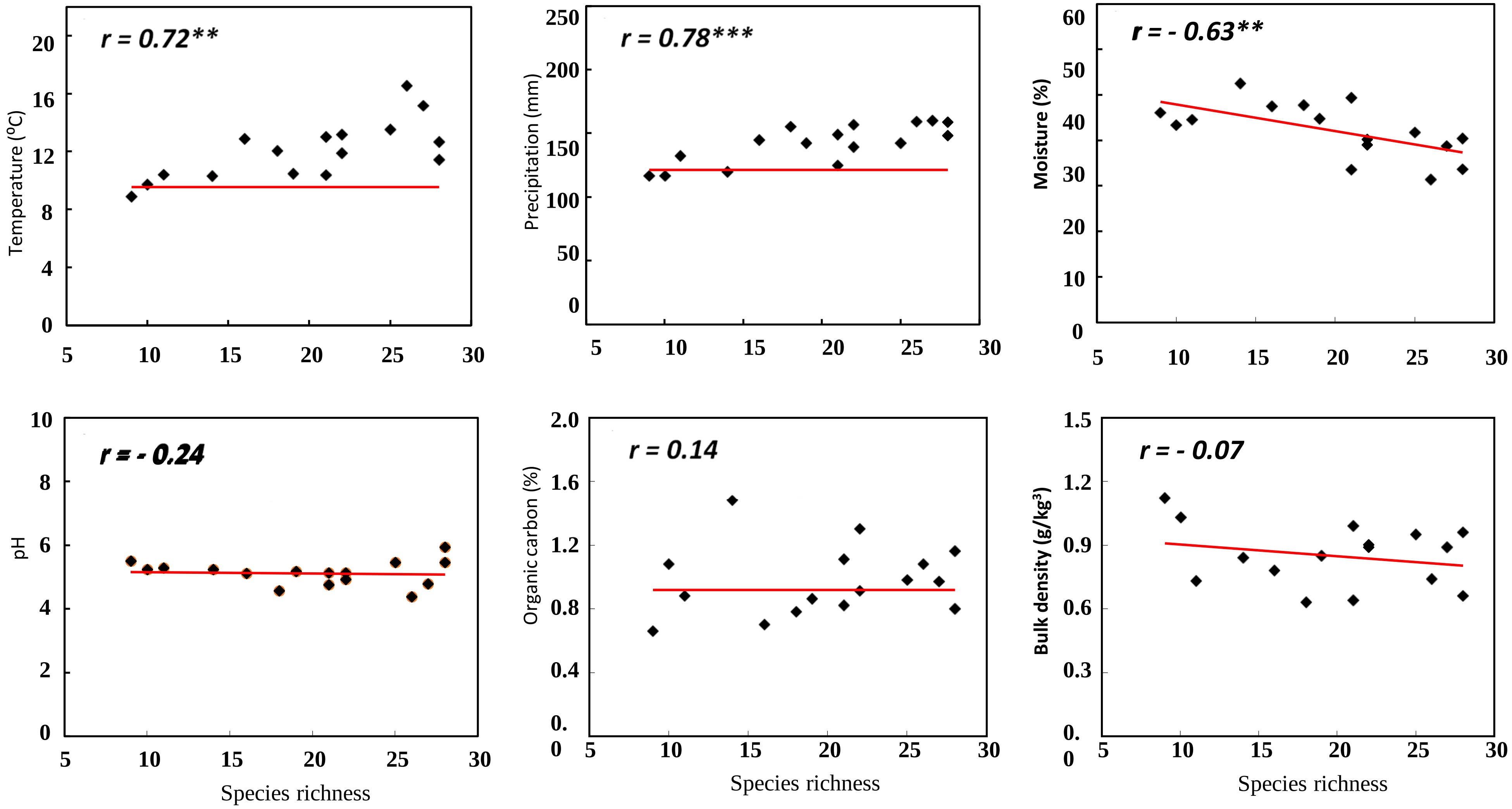


Figure 11: Correlation analysis between species richness and different environmental variables (climatic and soil parameters) in Latavalley Target region (*p<0.01; *p<0.001***).**

Annexure X

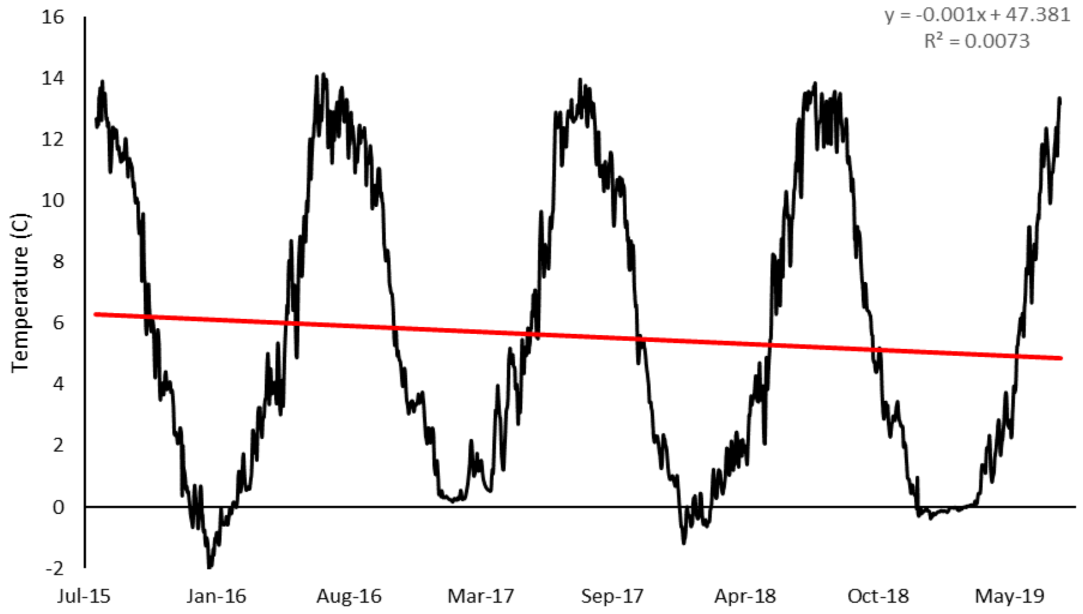
Table 13: Soil temperature (mean ± standard deviation) across four summits and four cardinal directions in Byans Target Redion depicted obtained from 2015-2021 period.

Summit code	Temperature (ºC)		
	Min	Mean	Max
SHY	-3.85±3.31	6.19±1.30	19.17±4.09
KUT	-2.79±4.12	6.89±4.82	19.06±5.08
CHA	-6.81±2.05	5.83±2.85	18.68±3.70
EUR	-4.38±4.31	5.38±.31	18.06±3.00
N	-4.63±1.43	4.64±2.43	18.64±3.43
S	-2.25±3.01	7.41±2.01	18.96±1.01
E	-4.04±3.31	6.34±3.31	19.05±1.31
W	-4.92±4.22	5.08±4.22	18.34±5.36

SHY- Shyang; KUT- Kutti; CHA- Chaga; EUR- Eurong
N- North; S- South; E- East; W= West.

Annexure XI

a)



b)

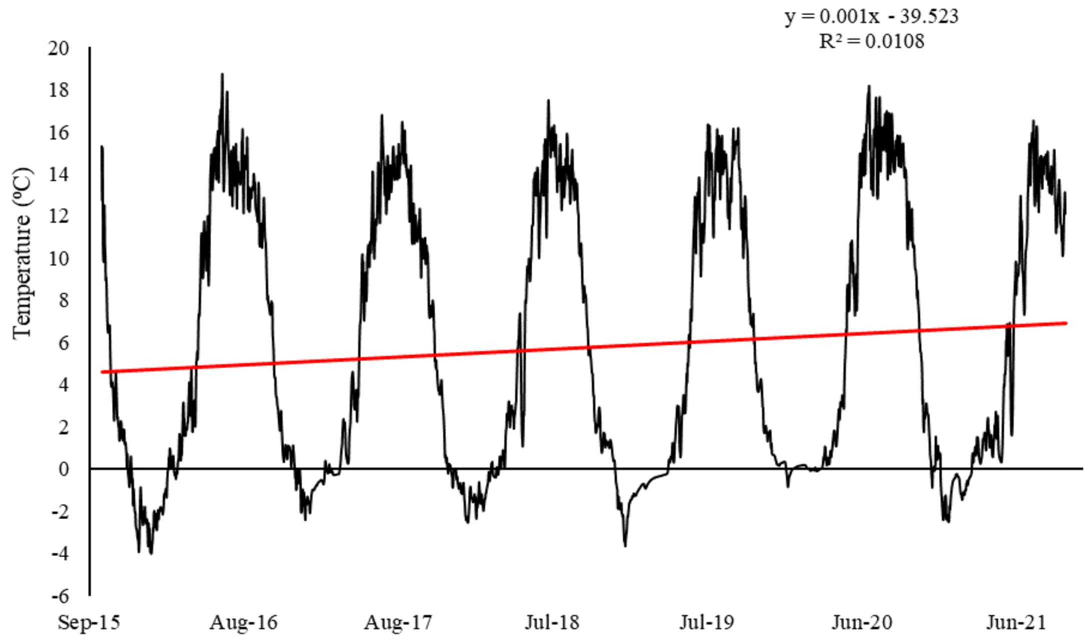


Figure 12: Soil temperature trends over years in (a) Chaudans and (b) Byans observation sites (*p<0.05*).

Table 14. Temporal changes in plant species richness and diversity indices along with dominant plant taxa in the GLORIA target region in:

a) Chaudans valley

Summit Code	Species richness		Plant cover (%)		H index		Evenness		Dominant species (IVI)	
	S14	RS19	S14	RS19	S14	RS19	S14	RS19	S14	RS19
BHT	78	75	88	92	2.93	2.84	0.92	0.92	*D. cachmeriyana* (15.99), *G. wallichianum* (15.24), *T. officinale* (14.13), *A. obtusiloba* (13.92) and *B. affinis* (13.30)	*B. affinis* (19.50), *A. contorta* (16.72), T. officinale (14.81), *B. falcatum* (14.30) and *G. wallichianum* (13.89),
KHA	50	51	95	100	2.55	2.71	0.87	0.92	*G. elatum* (25.06), *B. affinis* (23.72), *O. polypetala* (23.47), *T. officinale* (21.24) and *T. roylei* (16.29)	*G. elatum* (21.62), *B. affinis* (21.04), *P. filicaule* (17.87), *G. nepalense* (15.07) and *T. roylei* (14.52)
GAN	33	38	90	95	2.05	2.11	0.82	0.85	*H. dolicophylla* (40.64), *K. nepalensis* (36.83), *C. lobatus* (28.78), *B. vaccinifolia* (21.23), *T. roylei* (17.71)	*C. setosa* (31.61), *H. dolicophylla* (27.91), *C. lobatus* (24.67), *K. nepalensis* (24.30) and *G. elatum* (22.49)
SKN	27	32	61	69	1.70	1.83	0.76	0.81	*B. vaccinifolia* (56.83), *K. nepalensis* (52.48), *P. microphylla* (37.01), *O. polypetala* (18.97) and *G. elatum* (18.54)	*B. vaccinifolia* (56.63), *K. nepalensis* (48.83), *O. polypetala* (19.41), *G. elatum* (18.43) and *P. microphylla* (17.55)

BHT- Bhairav Ghati; KHA- Kharangdhang; GAN- Ganglakhan; SKN- Sekuakhan

S14- Survey 2014; RS19- Resurvey-2019

Figure 13 Correlation of species richness, diversity and plant cover in relation to mean soil temperature for baseline (S1) and resurvey (S2) in (A) Chaudans and (B) Byans valley. ******p* **< 0.001, **** ***p*** **< 0.01.**

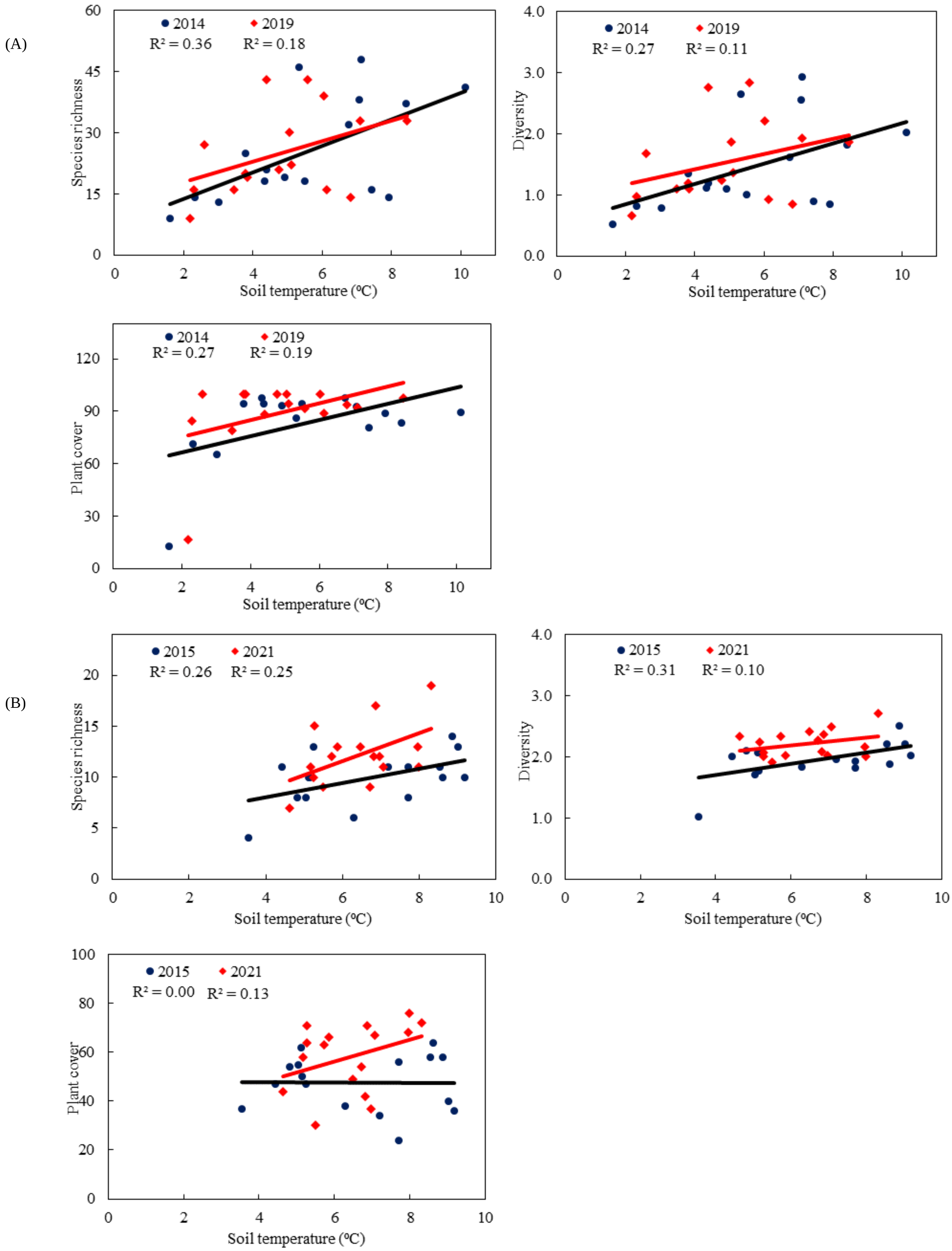


Table 15. Significant changes in species occurrences in the 1m x 1m plots.

Species	Habit*	Number of plots occupied		p-value
		2015	2019	
Increased				
Euphorbia stracheyi	Perennial	26	36	<0.005
Phlomis bracteosa	Perennial	3	10	<0.05
Poa alpina	Perennial	21	31	<0.01
Polygonum filicaule	Annual	11	18	<0.01
Decreased				
Gypsophila ceratoides	Perennial	13	2	<0.001
Kobresia nepalensis	Perennial	56	51	<0.05
Pedicularis klotzschii	Perennial	12	0	<0.001
Trachydium roylei	Annual	24	16	<0.05

α = 0.05. * = Pusalkar & Singh, 2012

Table 16. Significant changes in species cover between 2015 survey and 2019 resurvey.

Plant species	Habit*	Vegetation zone	Mean cover (2015)	Mean cover (2019)	Change in cover	p-value
Increased						
Anaphalis contorta	Perennial	a	2.6	5.8	0.84	<0.005
Bistorta affinis	Perennial	a-n	10.6	15.5	1.21	<0.005
Bupleurum falcatum	Perennial	sa-a	1.1	5.7	1.17	<0.0001
Carex setosa	Perennial	a	6.5	19.1	3.16	<0.005
Euphorbia stracheyi	Perennial	a	2.4	4.9	0.61	<0.0001
Parnassia kumaonica	Perennial	a	0.3	1.7	0.37	<0.05
Parnassia nubicola	Annual	a	3.6	6.1	0.63	<0.01
Poa alpina	Perennial	a-sn	2.2	6.5	1.07	<0.0001
Polygonum filicaule	Annual	a-sn	1.1	8.5	1.86	<0.0005
Viola biflora	Perennial	a-sn	5.4	8.1	0.7	<0.01
Decreased						
Corydalis cashmeriana	Perennial	a	0.3	0.5	- 0.11	<0.05

Gypsophila ceratoides	Perennial	sa-a	1.1	0.1	- 0.25	<0.005
Kobresia nepalensis	Perennial	a-sn	53.6	38.1	- 3.83	<0.0005
Ligularia arnecoides	Perennial	sa-n	1.7	0.2	- 0.36	<0.05
Pedicularis pectinata	Perennial	a	3.8	2.7	- 0.28	<0.05
Rumex nepalensis	Perennial	sa-a	7.3	3.8	- 0.85	<0.05
Taraxacum officinale	Annual	sa-a	17.0	11.1	- 1.46	<0.01

α = 0.05; sa-a = sub-alpine to alpine species; a = alpine species; a-sn = alpine to sub-nival species.
* = Pusalkar & Singh, 2012

Annexure XII

1. A twelve-day hands-on training course entitled "Vegetation Assessment, Herbarium Techniques and Statistical Analysis for Long-Term Ecological Monitoring" was organized by Center for Biodiversity Conservation and Management (CBCM) in GBP-NIHE headquarter starting from 24-02-2020 to 6-03-2020 (100 hours). A total of 33 research scholars (M.Sc. and PhD.) affiliated to 9 different institutions participated in the training program. The training program was focused on four major topics: a) Vegetation assessment; b) Herbarium techniques; c) RS and GIS applications in vegetation science; and d) Statistical methods.

Table 1. Details of participants of the 12-day hands-on training course entitled "Vegetation Assessment, Herbarium Techniques and Statistical Analysis for Long-Term Ecological Monitoring".

S. No.	Name	Gender	Qualification	Address	Contact No
1	Akshita Dhapola	Female	M.Sc. (Final semester)	S.S.J. Campus, Almora, KU	9410742474
2	Anchal Rani	Female	M.Sc. (Final semester)	S.S.J. Campus, Almora, KU	7300707479
3	Anjali	Female	M.Sc. (Final semester)	S.S.J. Campus, Almora, KU	9412996771
4	Anjali Tiwari	Female	M. Sc.	I.P.G.G.P.G. College of Commerce, Haldwani	8077305944
5	Ashish Kumar	Male	M.Sc.	D.S.B. Campus, Nainital, KU	9557271565
6	Baby Kanchan	Female	M.Sc. (Final semester)	S.S.J. Campus, Almora, KU	7060636400
7	Bhawna Negi	Female	M.Sc.	D.S.B. Campus, Nainital, KU	8650818748
8	Deepali Kothari	Female	M.Sc.	GBP National Institute of Himalayan Environment (GRC), Srinagar	8979969543
9	Disha Upreti	Female	M.Sc.	D.S.B. Campus, Nainital, KU	7252893287
10	Dixit Kumar Pathak	Male	M.Sc.	D.S.B. Campus, Nainital, KU	9568864827
11	Geetanjali Upadhyay	Female	M.Sc.	D.S.B. Campus, Nainital, KU	9410351431
12	Himani Verma	Female	M. Sc.	D.S.B. Campus, Nainital, KU	8126643099
13	Kanchan Puri	Female	M. Sc.	MoEF&CC, New Delhi	9871813201
14	Kavita Khatri	Female	M.Sc.	D.S.B. Campus, Nainital, KU	8954465311

15	Kusum Joshi	Female	M.Sc.	I.P.G.G.P.G. College of Commerce, Haldwani	9761651285
16	Manisha Bhandari	Female	M.Sc.	I.P.G.G.P.G. College of Commerce, Haldwani	7454885727
17	Mushtaq Ahmed	Male	M.Sc.	K.L.D.A.V.P.G. College, Roorkee, Garhwal University	7889675279
18	Neha Binwal	Female	M.Sc.	I.P.G.G.P.G. College of Commerce, Haldwani	7417839754
19	Neha Joshi	Female	M.Sc.	S.S.J. Campus, Almora, KU	7534037136
20	Neha Kohli	Female	M.Sc.	I.P.G.G.P.G. College of Commerce, Haldwani	7456977479
21	Pooja Joshi	Female	M.Sc.	I.P.GG.P.G. College of Commerce, Haldwani	9410565925
22	Pooja Mehta	Female	M.Sc.	GBP National Institute of Himalayan Environment, Kosi	8954719492
23	Pooranima Rani	Female	M.Sc. (Final semester)	S.S.J. Campus, Almora, KU	7830210044
24	Prabha	Female	M.Sc.	D.S.B. Campus, Nainital, KU	8937039492
25	Pratima Kumari	Female	M.Sc.	Central University of Gujrat, Gandhinagar	8092398395
26	Rashika Mehta	Female	M.Sc. (Final semester)	S.S.J. Campus, Almora, KU	7351225302
27	Sapana Pant	Female	M.Sc.	I.P.GG.P.G. College of Commerce, Haldwani	6396720136
28	Seema Bala	Female	M.Sc. (Final semester)	S.S.J. Campus, Almora, KU	8476896383
29	Shradha Misra	Female	M.Sc.	I.P.G.G.P.G. College of Commerce, Haldwani	7060073939
30	Sunil Joshi	Male	M.Sc.	GBP National Institute of Himalayan Environment, Kosi	9675442890

31	Tanuja Bahuguna	Female	M.Sc. (Final semester)	S.S.J. Campus, Almora, KU	7055054974
32	Vinay Rawat	Male	M.Sc.	HNB Garhwal University, Srinagar	7500357703
33	Zishan Ahmad Wani	Male	M.Sc.	Baba Ghulam Shah Badshah University, Rajouri, J&K	9149493267

1. G.B. Pant National Institute of Himalayan Environment (NIHE), Kosi-Katarmal, Almora, in collaboration with the Department of Botany, Soban Singh Jeena University, Almora and financial assistance of the National Mission on Himalayan Studies (NMHS) organized a three-day field-oriented training course entitled "Plant Taxonomy, Vegetation Assessment and Statistical Analysis" from 25-March-2021 to 27-March-2021. A total of 83 participants (M.Sc./Ph.D. scholars) from the SSJ campus attended the training programme. Major domains covered in the training course included: a) Plant taxonomy: Classification, identification and cataloguing; b) Plant ecology: Methods of field surveys, data collection, analysis and interpretation in ecology and vegetation science; c) Plant conservation approaches, nursery management and plantation techniques; d) Statistical application in the field of plant sciences and ecology.

S. No.	Name of the participant	Designation	Contact no.	
1.	Pankaj Singh Bisht	M.Sc. (III)	7895671044	
2.	Jugmohan Singh Bisht	M.Sc. (III)	8192973561	
3.	Deep Chandra Baswal	M.Sc. (III)	7248267288	
4.	Chanchal Singh Thakardwara	M.Sc. (III)	7900506321	
5.	Babita Pandey	M.Sc. (III)	8954473707	
6.	Ruhita	M.Sc. (III)	9411105800	
7.	Bhawana Khati	M.Sc. (III)	7456973030	
8.	Radha Arya	M.Sc. (III)	7055160534	
9.	Dolly Bisht	M.Sc. (III)	7351498568	
10.	Namrata Papnai	M.Sc. (III)	8279978792	
11.	Pranjali Pandey	M.Sc. (III)	8171014012	
12.	Pooja Negi	M.Sc. (III)	9756484978	
13.	Beena Balodi	M.Sc. (III)	7251832720	
14.	Mukesh Joshi	M.Sc. (III)	9720355987	
15.	Pooja	M.Sc. (III)	7088486667	
16.	Renu Sharma	M.Sc. (III)	7252914469	
17.	Saumya Joshi	M.Sc. (III)	8534091757	

18.	Mamta Kanwal	M.Sc. (III)	9411369450	
19.	Hema Bisht	M.Sc. (III)	8006152513	
20.	Tanuja Sah	M.Sc. (III)	8006269317	
21.	Rashmi Negi	M.Sc. (III)	7251052522	
22.	Anjali Manral	M.Sc. (III)	8650734144	
23.	Meenakshi Kanwal	M.Sc. (III)	9634830471	
24.	Laxman Giri	M.Sc. (I)	7451973250	
25.	Hitesh Pandey	M.Sc. (I)	8650834100	
26.	Neha Bisht	M.Sc. (III)	9568209829	
27.	Saloni Panchpal	M.Sc. (I)	9917632117	
28.	Himani Tiwari	M.Sc. (I)	8171968456	
29.	Neha Giri	M.Sc. (I)	9634072138	
30.	Mamata Pandey	M.Sc. (I)	7409040457	
31.	Jyoti Joshi	M.Sc. (I)	8445472132	
32.	Diksha Tewari	M.Sc. (I)	7252899441	
33.	Priyanka Matela	M.Sc. (I)	6398554419	
34.	Sapna Parihar	M.Sc. (I)	9084510958	
35.	Nidhi Joshi	M.Sc. (I)	8393964350	
36.	Prema Shahi	M.Sc. (I)	7060121338	
37.	Jyoti Lohani	M.Sc. (I)	9105539348	
38.	Jigyasa Upadhyay	M.Sc. (I)	7500946187	
39.	Priyanka Bala	M.Sc. (I)	9068205557	
40.	Ruchika Bisht	M.Sc. (I)	6397722981	
41.	Sapna Mehta	M.Sc. (I)	7248191615	
42.	Manish Mamgai	M.Sc. (I)	8395851763	
43.	Babita Pandey	M.Sc. (I)	9720141125	
44.	Pooja Joshi	M.Sc. (I)	9084487898	
45.	Babita Bora	M.Sc. (I)	7617739468	
46.	Salochana	M.Sc. (I)	7534940286	
47.	Usha	M.Sc. (I)	7500659508	
48.	Ritakshi Manral	M.Sc. (I)	8650486121	
49.	Priyanka Pandey	M.Sc. (I)	9012342884	
50.	Yamini Joshi	M.Sc. (I)	8193092294	

51.	Pooja Ray	M.Sc. (I)	7037154851	
52.	Yogesh Upreti	M.Sc. (III)	7409998913	
53.	Kritika Rani	M.Sc. (I)	8859054849	
54.	Pooja Bhandari	M.Sc. (I)	9837993320	
55.	Muskan Parveen	M.Sc. (I)	8979165176	
56.	Pankaja Pandey	PhD Scholar	9027636621	
57.	Priyanka Joshi	PhD Scholar	9760581769	
58.	Pooja Negi	PhD Scholar	7078826398	
59.	Bhawna Pandey	PhD Scholar	9675951231	
60.	Paras Negi	PhD Scholar	7830594042	
61.	Anubha Mehra	PhD Scholar	9456557378	
62.	Kalpana Rawat	PhD Scholar	9540763867	
63.	Naveen Singh	PhD Scholar	7060635893	
64.	Madhumita Bisht	PhD Scholar	7302207472	
65.	Neeraj Ram	PhD Scholar	8477905963	
66.	Tanuja Joshi	PhD Scholar	7536871337	
67.	Supriya	PhD Scholar	9456129982	
68.	Paras Negi	PhD Scholar	7830594042	
69.	Anubha Mehra	PhD Scholar	9456557378	
70.	Kalpana Rawat	PhD Scholar	9540763867	
71.	Naveen Singh	PhD Scholar	7060635893	
72.	Madhumita Bisht	PhD Scholar	7302207472	
73.	Neeraj Ram	PhD Scholar	8477905963	
74.	Tanuja Joshi	PhD Scholar	7536871337	
75.	Supriya	PhD Scholar	9456129982	
76.	Paras Negi	PhD Scholar	7830594042	
77.	Anubha Mehra	PhD Scholar	9456557378	
78.	Neha Thapliyal	PhD Scholar	9568210078	
79.	Charu Pundir	JPF	9650304940	
80.	Akshita Dhapola	PhD Scholar	9410742474	
81.	Mrs. Zoya Shah	PhD scholar	9012019003	
82.	Dr. Kapil Bisht	Research Associate	9627694404	
83.	Mrs. Poonam Mehta	PhD scholar	9557766417	

Photo plate 1: Field activities and plot design of GLORIA target region in Chaudans valley, Pithoragarh

Photo plate 2: Twelve day hands on training organised by GBP-NIHE on "Vegetation assessment, herbarium techniques and statistical analysis for Long-term Ecological Monitoring".

Photo plate 3: Soil temperature data loggers: Geo-Precision M-Log 5W

Methods

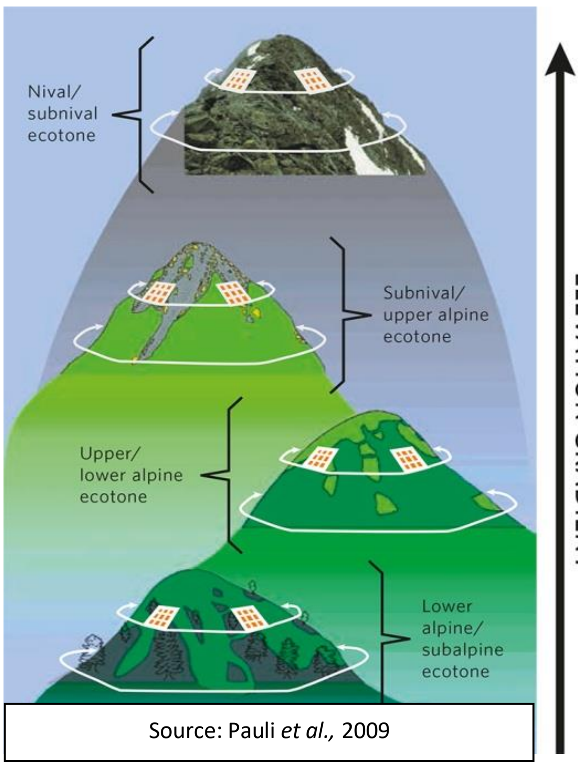
A-Methodology adopted to achieve the objectives of the project activities:

i. Analysing the floristic diversity and its composition pattern along altitude range different alpine landscapes of West Himalaya

Extensive field surveys will be conducted in different alpine areas of Uttarakhand, West Himalaya ranging from 3000-5000 m. Representative alpine regions will be identified on the basis of dominant vegetation and physical attributes along different altitudes. Two alpine landscape (Chaudans / Pindari region in Kumaun and Lata Kharag region in Garhwal) will be identified as intensive study sites. Geo-coordinates (latitude N and longitude E), altitude (m) and aspect of each site will be measured by using the Global Positioning System (GPS) receiver with an accuracy of up to 5 m and compass, respectively. The slope below 20° will be considered gentle; between 20° - 35° moderate and above 35° steep. Species richness will be determined as the total number of species recorded in the sampling plots in each site. The data on presence and absence of plant species in the sampling plots in each site will be analyzed for estimation of frequency whereas numerical strength of species will be computed in terms of density following Misra (1968) and Muller-Doimbois and Ellenberg (1974). Shannon diversity index (*H'*), which is based on the assumption that individuals are randomly sampled from an infinitely large population, Simpson's index of dominance (*D*) and evenness are calculated for each site following Magurran (1988). All the plant samples will be identified with local flora and monograph (as possible) and will be deposited in herbarium of the Institute (GBP) and Botanical Survey of India, Dehradun (BSD, only high value elements). Composite soil samples will be analyzed for selected phyto-chemical properties following standard methods (Tandon, 2001; Gupta, 2002). Correlation of Shannon diversity with soil parameters will be worked out using non-linear regression analysis where *p*-value of less than 0.05 is statistically defined as significant. Information regarding the medicinal uses of plants is collected through interviews and discussions with local people. However, the data on medicinal uses from earlier reports will also explore for comprehensive information. Threatened status of the plants is ascertained according to the IUCN categorization. Climate data will be obtained from nearby metrological stations and compared the diversity of alpine vegetation.

ii. Establishing and strengthening long-term monitoring sites by using Global Observation Research Initiative in Alpine Environments (GLORIA) protocol for analysing impacts of climate change

One alpine site will be targeted for establishing GLORIA sites in alpine regions. Sampling will be followed by the multi-summit approach of the GLORIA (Pauli *et al.*, 2009) with some modifications as per the field conditions in the alpine region of Uttarakhand. In each state four summits (plotting area) will be selected on the basis of following criteria: (1) gentle and round morphology with slopes, with an average steepness between 5 and 25 approx.; (2) co-location along the altitude gradient which includes the nival belts; (3) reduced or absent human disturbance. On this basis, 2-4 summits (areas) will be selected across different altitudinal ranges. The survey area in each summit will be defined as a polygon with four corners at 10 m lower from the summit top where a complete list of plants will be compiled. Within each of these survey areas a smaller one will be defined in a similar manner at 5 m lower from the summit top in order to evaluate the quantitative floristic composition for each principal exposure (N–E–S–W). For that purpose, four 9 m^2 grids (permanent plots), one for each principal exposure will be placed in each summit. The list of plants will be drawn in each grid and the cover value for every species will be determined visually and expressed as a percentage of the total ground cover. Shoot frequency will also be counted for every species by measuring the plant species within the quadrat. The position of every plot will be recorded using a GPS receiver, accompanied by photo-documentation. All the species will be collected as per standard procedures (Jain and Rao, 1977), identified using standard floras and the voucher specimens will be deposited in the Institute herbarium (GBP) and Botanical Survey of India, Dehradun (BSD, high value materials only). In addition, a data logger were installed at a depth of 10 cm into the soil in the center of each grid in order to record the temperature at 1h intervals. From this temperature data,



Source: Pauli *et al.,* 2009

the mean annual temperature and the mean daily temperature for each summit will be calculated, whereas for each exposure the mean year temperature will be considered. Species richness was measured as the total number of species at each altitudinal interval. Shannon–Wiener index was used to express species richness weighted by species evenness (Krebs, 1999). Species turnover (beta diversity), was calculated as the gain and loss of species between altitudes following the method of Wilson and Shmida (1984). The Sorensen similarity coefficient was employed in order to measure floristic similarity between the summits (Kent and Coker, 1992).

iii. Investigation of changes of plant diversity in different alpine sites

For analysing change in plant diversity patterns, the reconnaissance survey methods (Palgrave *et al.*, 2007) will be adopted. The first GLORIA site in India, located in Chaudans Valley, Pithoragarh, Uttarakhand will be utilized for analyzing the changes in alpine composition. Further, emphasis on earlier datasets on alpine region / sites will also be explored. There are different sets of information available in the form of unpublished (i.e. thesis) or published (Kala, 2003; Rawat, 1983, 2005) records. The present investigation will be targeted to compare the floristic composition, pattern, high value elements (threatened, medicinal, endemic, etc.) and invasive with earlier studies. Efforts will be made to accuracy of location / specific sites. Earlier data records available in alpine regions will be revisited for analyzing the change prediction. The climate data sets will be obtained from data-loggers already installed in GLORIA (32 nos. in Chaudans and Byans Valley) as well as nearby metrological stations available in the region (including our own station located in Sri. Narayan Ashram, Pithoragarh district, Uttarakhand). The climate data will be integrated with the climate change impact as per the protocol followed by Gonzalez and Mata (2005).

iv. Soil Variability at GLORIA Sites

The soil samples were collected during the month of August 2019 from the summit sites. On each summit four locations outside the SAS corresponding to each *cardinal direction* were selected for soil sampling. Samples were taken from the depths 0-10 cm and 10-20 cm. The collected samples were stored in polythene bags tagged with suitable codes for identification and then brought to laboratory for analysis. The soil samples were air dried and coarse materials including stones and pieces of roots, leaves and other under decomposed organic residues were removed. Then, the samples were sieved through 2mm mesh sized sieve and used for further analysis.

a- pH

pH of the soil samples was determined in 1:2 soil water suspension with digital pH meter Eutech pH700 **(Gairola *et al.*, 2012)**, using potentiometric method. 20g of soil was weighed and transferred into 100mL beaker. 40mL distilled water was added and stirred well with a glass rod. This was allowed to stand for half an hour with intermittent stirring. To the soil water suspension in the beaker, the electrode was immersed and pH value was determined from the automatic display of pH meter.

b- **Soil Moisture**

About 100 gm. of fresh soil samples (in triplicate) were dried in an oven till constant weight and weighed (**Misra, 1968**). The moisture content was calculated on dry- weight basis, following **(Jackson (1958)**:

$$\textit{Soil Moisture content (\%)} = \frac{Fresh\ weight\ of\ soil - Dry\ weight\ of\ soil}{Fresh\ weight\ of\ soil} \times 100$$

c- Soil texture

The soil texture was determined after removing the gravel or stone pieces from the air-dried soil and then the soil was seived through a series of sieves with different sized holes **(Misra, 1968)** and the proportion of soil particles was calculated by weight. The soil particles over 2.0 mm size were considered as gravel. According to the International Soil Testing Association (ISTA) classification of soil, the texture of the soil was determined. The criteria of soil classification as given by ISTA were followed:

Particle Size Class

Sand 0.02 mm - 2.0 mm

Silt 0.002 mm - 0.02 mm

Clay Smaller than 0.002 mm

d- Soil bulk density

For determining soil bulk density, soil samples were collected by means of a special mental core – sampling cylinder of known volume for different soil depths (0-10 cm, 10-20 cm) without disturbing the natural structure. Sample of soil was brought to the laboratory and oven dried at 60ºC till constant weight following **Misra** (**1968**).

$$\textit{Bulk density}\ (gm/cm^3) = \frac{W(weight)}{V(volume)}$$

Where,

W= oven dried weight of soil

V= volume of the cylinder ($\pi r^2 h$)

e- Organic Carbon

Soil organic carbon was determined following modified **Walkley and Black (1947**) method. For the analysis, 0.5 gm of sieved soil was taken in Erlenmeyer flask and 10ml of 1N Potassium dichromate was added and the flask was swirled for a minute. After that 20ml of concentrated sulphuric acid was added and the mixture was kept for 20-40 minutes. Then 30ml distilled water and 3-4 drops of o-Phenanthroline indicator was added to the solution and it was titrated against 0.5N Ferrous Sulphate solutions till the colour changes to dark green from reddish brown and was recorded as the end point. The organic carbon was then calculated according to following equation.

$$\textit{Soil Organic Carbon}(\%) = \frac{M \times (V1 - V2) \times 0.39}{\textit{Weight of soil sample } (gm)}$$

Where;

M= Molarity of $FeSO_4$ Solution

V1= Volume of $FeSO_4$ required for blank (ml)

V2= Volume of $FeSO_4$ required for sample (ml)

f- Total nitrogen

Soil N was determined by micro-Kjeldhal technique by using Kjel Auto Vs-KTP Nitrogen Analyzer **(Parkinson and Allen, 1975).** For it, 10 ml each of aliquot and sodium hydroxide (40%NaOH) solution were added in reaction chamber of Bremkar and Edward's semi micro nitrogen still assembly. Pass the steam through the reaction chamber. Collect the steam in the beaker containing 5ml of 1% boric acid and drops of mixed indicator up to 20ml. Titrate the collected steam against hydrochloric acid (N/140).

$$\textit{Nitrogen in soil } (g/kg) = \frac{(\textit{HCl used for sample} - \textit{HCl used for blank}) \text{X} 14 \text{X} \textit{Normality}}{\textit{Weight of soil sample } (gm) \text{X} 140}$$

g- Total Phosphorus

For determining phosphorus content in soil, 1ml of wet digested soil sample was pipette out and made up to 10ml using distilled water. Then 1-2 drops of *p*-nitrophenol was added to it.

And the pH of the solution was adjusted to~5 using 4M NaOH and 0.25M H_2SO_4. Then 8ml of the colour developing solution was added to it. After 10 minutes, the absorbance was read at 712 nm using spectrophotometer **(Watanabe and Olsen, 1965)**.

$$\textit{Phosphorus (\%)} = \frac{\textit{Concentration read from the standard curve x 0.25 x Dilution factor}}{\textit{Weight of soil sample (gm)}}$$

For total potassium of soil, 2 ml of the wet digested sample solution was pipette out into a 50 ml volumetric flask and made up to mark with distilled water and mix well. Potassium concentration of sample solutions was measured with flame photometer using potassium filter after necessary setting and calibration of the instrument. It was made to read 100 with 100ppm solution for potassium. Then the readings for standard solutions and soil extracts were taken. The standard curve with the readings for the standard solutions is drawn. Then the concentrations of the extracts from the standard curve are read.

$$\textit{Potassium (\%)} = \frac{C \times 0.125}{W}$$

Where,

C= corrected concentration for sample solution (in ppm K)

W= weight of sample

Data Analysis

All the statistical analyses were conducted in R version 3.5.2 (R Core Team, 2019). Temporal changes in air and soil temperature were analyzed with linear regression. Further, from each temperature logger, we first calculated daily average of hourly values as Tavg = 0.5 _ (Tmin C Tmax), where Tmin and Tmax are the daily minimum and maximum temperatures, respectively. Growing Degree Days (GDD) were then calculated from August2014–July 2015 and August 2017–July 2018 (as data loggers were installed in August 2014) using the following formula: GDD D Tavg □ 5 Threshold value of 5_C was used since it has been reported to be most justified biologically for alpine ecosystems (Scherrer and Körner, 2011). GDD were calculated by considering all the days during which Tavg was above 5_C. Finally differences in GDD among the two years were assessed with ANOVA. To determine how species richness (i.e., the number of species) respond to aspect and summit, a one-way ANOVA test was done with “aspect” (nested within summit) and “summit” as fixed effects, and the number of species per quadrat as responsevariables. Further, a multiple pairwise-comparison between the aspects and summits separately was performed with a Tukey multiple comparison test using multicomp package in R (Torsten et al., 2008) to determine whether the mean difference between the specific pairs of groups is statistically significant. Next, to determine how species richness changed over time, a two-way ANOVA test was performed with “sampling year,” “summit” and their interaction as fixed effects, and the species number per quadrat as response variable. This procedure was repeated for soil temperature, specifying “aspect” and “summit” as fixed effects and soil temperature as response variables. Prior to ANOVA test, data was subjected to Shapiro-Wilk and Levene’s tests for checking the normality and homogeneity of variance, respectively. Levene’s test was performed using leveneTest function in R package car (Fox and Weisberg, 2019). Levene’s test is considered to be more robust in the checking the homogeneity of variance as it is less sensitive to departures from normal distribution.

v. Capacity building on plant assessment and taxonomic identification of students

Attempt will be made to build the capacity on plant assessment including long-term monitoring protocols and essentiality in alpine environment. Further, the taxonomic identification of alpine elements will also be provided to masters’ students and researchers to create scientific interest towards alpine landscape. The importance of alpine landscape, loss of biodiversity, anthropogenic activities *Vs* biodiversity, habitat loss and tool for conservation approaches, etc. will also be focused in this capacity building program. Besides, information booklets, brochure, monograph and posters will also be prepared and distributed for optimal dissemination.

PART B: DETAILED PROJECT REPORT

The Detailed report should include an Executive Summary and it should have separate chapters on (i) Introduction (ii) Methodologies, Strategy and Approach (iii) Key Findings and Results (iv) Overall Achievements (v) Project's Impacts in IHR (vi) Exit Strategy and Sustainability (vii) References and (viii) Acknowledgement (It should have a mention of financial grant from the NMHS, MoEF&CC)

Further, description of Technical Activities, List of Trainings/ Workshops/ Seminars with details of trained resources, list of New Products developed under the project, Manual of Standard Operating Procedures (SOPs) developed, Technology developed/Transferred etc should be enclosed as Appendix.

1 EXECUTIVE SUMMARY

Over the last three decades, climate warming has been a major topic of concern for ecologists and environmentalists with 74% of the observed temperature increase caused by human-induced radiative forcing, and less than 26% by unforced internal variability. Model projections of climate change impacts on floral diversity have suggested that habitats of plants, specifically the alpine life zones, could change drastically causing species range shifts and reshuffling of species composition and abundances. While reports on ecological responses (for example, changes in species range or local extinctions) to the Great Acceleration are multiplying, it is unknown whether such biotic responses are undergoing a similar acceleration over time. Over the last three decades, climate warming has been a major topic of concern for ecologists and environmentalists with 74% of the observed temperature increase caused by human-induced radiative forcing, and less than 26% by unforced internal variability. Furthermore, the Himalaya is reported to be warming at a much higher rate than global average, making it a hotspot for climate change studies. Model projections of climate change impacts on floral diversity suggest that suitable habitats of plants could reduce drastically by the end of 21st century, particularly where climate warming is combined with decreasing precipitation. Even if alpine plants do not disappear rapidly, a growing extinction debt will have to be paid later on, if they are unable to adapt or cope with changing conditions. The severity of such extinction scenarios can only be documented by long term *in situ* monitoring. However, as per IPCC, the region remains data-deficient in terms of long-term climate data specifically on account of compatibility mismatch due to instrumentation and methodology. This calls for an urgent attention of researchers for long-term Ecological Monitoring (LTEM) in the region, following global standard methods. In view of this, a new LTEM site was established in alpine region of Lata valley, Chamoli following the Global Observation Research Initiative in Alpine Environment (GLORIA) protocol and floristic diversity of the

region was analyzed. The site inhabited a total of 124 plant species belonging to 91 genera and 37 families, with 53 species recorded in usage as medicinal herbs by local people and 13 species under threatened categories as per IUCN, CAMP and RDB. There was a significant decrease in species richness with increasing altitude, with maximum species in KHR (88 species), followed by SAI (80 species), DON (67 species) and PUL (40 species). Through review of literature and interview with local inhabitant in the Lata valley, a total of 53 species were recorded in usage by local people for the treatment of various ailments. Resurveys of permanent observation sites was done after 5-years period to analyze changes in floristic diversity and its relation to temperature trends. In this context, previously established observation sites in Chaudans and Byans valley, Pithoragarh (Uttarakhand) were resurveyed in 2019 and 2021, respectively. Temporal trends in soil temperature showed a significant decreasing trend over a four-year period ($p<0.05$; decrease of 0.82 ºC from August 2015 to July 2019) in Chaudans, while in Byans the trend was significantly increasing ($p<0.01$; increase of 0.38ºC from October 2015 to September 2021). Temporal patterns in vegetation were represented by significant increase in plant cover (%) in all sites while species richness increased in KHA, GAN and SKN in Chaudans. While species richness decreased in north and west, in south it increased significantly and remained same in east. However, in Byans, there was significant ($p<0.05$) increase in plant cover, richness and diversity in all summits. Relating vegetation indices with soil temperature across the two surveys exhibited a significant positive correlation between species richness and diversity (r from 0.3 to 0.6, $p< 0.05$) in both valleys. However, plant cover percent showed no significant relationship with temperature trends in Byans valley, while it was positive in Chaudans. Thus, temporal trends in richness and diversity were related to corresponding temperature trends in both valleys, plant cover changes did not show significant relation with temperature trends in Byans valley. Of the total 105 species, a total of ten species (such as *Bistorta affinis*, *Bupleurum falcatum*, *Carex setosa*, *Poa alpina*, *Polygonum filicaule*, etc.) showed significant increase in their plant cover in 2019 as compared to that in 2015, while seven species exhibited a significant decrease (such as *Kobresia nepalensis, Taraxacum officinale, Rumex nepalensis*, etc.) (Table 21). Similarly, seven species exhibited a significant increase in their cover (%) from 2015 to 2021 in observation plots in Byans, among which the most predominant was *Danthonia cachemyriana* which increased in all the summits. We suggest that the observed trend in plant community dynamics responds to short term temperature and precipitation variability and time lags in plant community response. It may take much longer than one decade for the observed trends to become stable and statistically significant. Our study provides an important foundation of documenting profound changes in alpine plant communities, as global climate change continues.

2 INTRODUCTION

2.1 Background of the Project

Mountain ecosystems are regarded as important biodiversity hotspots as well as one of the most ecologically fragile zones. The varying topography, micro and macro-climatic conditions cause variations in habitats as well as among the life-forms which are highly sensitive towards natural and human perturbations. Among the many mountain ecosystems of the world, Himalaya is the youngest globally recognized biodiversity hotspot embracing a rich and complex diversity and ecological peculiarities. As elsewhere in the mountain environments, the high-altitude alpine life zones are considered to be particularly sensitive to climate warming because they are determined by low temperature conditions. A number of studies relating to the climate change and its impact on the high-altitude vegetation has been carried out in the last three decades. Steinbauer *et al.* (2018) also found an increase of species richness on 302 mountain summits across Europe over the past 145 years. Similarly, increase in vascular plant species richness of about 11% per decade in alpine zone of Alps was reported by Holzinger *et al.* (2008). Such an increase in species richness can be attributed to the warming-induced upward shift of species from lower elevations. Carilla *et al.* (2017), using a standardized protocol, surveyed alpine plant communities in permanent plots on four high Andean summits in NW Argentina and reported a significant increase in plant cover in the highest summit, in species richness in the lower summit, and in diversity (Shannon index) in the four summits, over time, together with increase in small herbs and non-tussock grasses. Similarly, the high tropical Andes Mountain host one of the richest alpine floras of the world, with exceptionally high levels of endemism and turnover rates. Cuesta *et al.* (2017) carried out the first continental-scale comparative study of plant community diversity on summits of the tropical Andes. Precipitation, maximum temperature and rock cover were reported to be the strongest predictors of community similarity across all summits. Generalized linear model (GLM) quasi-Poisson regression indicated that across all summits' species richness increased with maximum air temperature and above-ground necro mass and decreased on summits where scree was the dominant substrate. Furthermore, different climatic drivers were considered as key factors for explaining both vertical and latitudinal species turnover and species richness patterns in high Andean summits.

2.2 Overview of the Major Issues to be Addressed

Mountains are particularly sensitive to ecological change and are experiencing some of the highest rates of warming under anthropogenic climate change. Numerous reports of species redistribution towards summits and warming-induced changes in biodiversity on summits suggest that mountain biota are highly sensitive to increasing temperatures. The current accelerating trend in temperature increase should therefore also affect the velocity of changes observed for mountain biota. Appropriate empirical assessments of the rate of change in the velocity of ecological responses (biodiversity and ecosystem trajectories) to accelerated global warming require long-term resurveys (for example, time series) of species communities, but these are scarce and localized. Mountain summits are especially suited for long-term studies of biotic responses to environmental changes because they represent natural permanent study sites that are easy to re-locate over time thus making it possible to record reliable time series. Globally accelerating trends in societal development and human environmental impacts since the mid-twentieth century are known as the Great Acceleration and have been discussed as a key indicator of the onset of the Anthropocene epoch. While reports on ecological responses (for example, changes in species range or local extinctions) to the Great Acceleration are multiplying, it is unknown whether such biotic responses are undergoing a similar acceleration over time. Over the last three decades, climate warming has been a major topic of concern for ecologists and environmentalists with 74% of the observed temperature increase caused by human-induced radiative forcing, and less than 26% by unforced internal variability. Model projections of climate change impacts on floral diversity have suggested that habitats of plants, specifically the alpine life zones, could change drastically causing species range shifts and reshuffling of species composition and abundances. Furthermore, the Himalaya is reported to be warming at a much higher rate than global average, making it a hotspot for climate change studies. However, as per IPCC, the region remains data-deficient in terms of long-term climate data specifically on account of compatibility mismatch due to instrumentation and methodology. This calls for an urgent attention of researchers for long-term Ecological Monitoring (LTEM) in the region, following global standard methods. Very little is known about the alpine vegetation responses to recent climate change in the rapidly warming Himalaya. A study conducted by Hamid *et al.* (2020) alpine summits in Kashmir Himalaya showed that species richness increased on the lower three summits but decreased on the highest summit (nival zone) and also revealed a substantial increase in the cover of dominant shrubs, graminoids, and forbs. The nestedness-resultant dissimilarity, rather than species turnover, contributed more to the magnitude of beta-diversity among the summits. High temporal species turnover was found on south and east aspects, while high nestedness was recorded along north and west aspects. Thermophilization was more pronounced on the lower two summits and along the northern aspects. While the accumulated scientific knowledge on alpine environments is growing fast, there are still substantial knowledge gaps across the world. Though some ambitious research efforts have been made in studying boreal and temperate alpine ecosystems, mainly in the northern hemisphere, some important alpine areas of the world, such as the Himalaya, have received little research attention. The Himalaya, sustaining the world's highest mountain peaks, undoubtedly is one of the most sensitive areas to climate warming (Immerzeel *et al.*, 2010). The Himalaya, being one of the global biodiversity hotspots, harbors diverse alpine flora (Myers *et al.*, 2000). Under the contemporary climate change, this region is believed to be warming at a much higher rate than the global average (Kumar *et al.*, 2006).

2.3 Baseline Data and Project Scope

As elsewhere in the mountain environments, the high-altitude alpine life zones are particularly sensitive to climate warming because they are determined by low temperature conditions. Model projections of climate change impacts on floral diversity suggest that suitable habitats of plants could reduce drastically by the end of 21st century, particularly where climate warming is combined with decreasing precipitation. Even if alpine plants do not disappear rapidly, a growing extinction debt will have to be paid later on, if they are unable to adapt or cope with changing conditions. The severity of such extinction scenarios can only be documented by long term *in situ* monitoring. Towards addressing this data gap in the Indian Himalayan Region (IHR), especially in alpine areas, the G.B. Pant Institute of Himalayan Environment & Development (GBPIHED) under its Biodiversity Conservation and Management Programme and in collaboration with Kailash Sacred Landscape Conservation and Development Initiative (KSLCDI) has initiated establishing Long-term Ecological Monitoring (LTEM) sites in Chaudans Valley of Pithoragarh, Uttarakhand, following the Global Observation Research Initiative in Alpine Environments (GLORIA) procedure. The project, therefore, attempts to address these gaps and aims to address the issues of data-deficiency and compatibility of datasets to with global datasets. The study targets climate change impacts on floristic diversity in selected alpine areas of Uttarakhand, West Himalaya.

2.4 Project Objectives and Target Deliverables (as per the NMHS Sanction Order)

(a) To analyse the floristic diversity and its composition patterns along altitude range in different alpine landscapes of West Himalaya

(b) To establish and strengthen Long-Term monitoring sites by using Global Observation Research Initiative in Alpine Environments (GLORIA) protocol for analysing impacts of climate change

(c) To investigate the change of plant diversity in relation to climate change in different alpine sites.

(d) To build plant assessment and taxonomic identification capacity of master's students and researchers.

3. METHODOLOGIES, STARTEGY AND APPROACH

i. Analyzing the floristic diversity and its composition pattern along altitude range different alpine landscapes of West Himalaya

The present study was conducted in the alpine regions (>3200m) of Uttarakhand (30° 10' N to 31° 19' N and 78° 56' E to 80° 59' E), west Himalaya average elevation ranging from 3200-5000 m asl. Several intensive survey trips (10-15 days each) were conducted to analyse species distribution along altitude gradient. The plant specimens were collected as per methods of Jain and Rao (1977) and housed in the herbarium of G.B. Pant National Institute of Himalayan Environment and Sustainable Development, Kosi-Katarmal, Almora (Acronym: GBP). The collected specimens were identified using local and regional Floras (Osmaston 1927, Naithani 1984, Deva & Naithani 1986, Gaur 1999, Pusalkar & Singh 2012) and earlier herbarium/literature records (i.e., Botanical Survey of India, Dehradun, Kolkata; Forest Research Institute – Dehradun, etc. For categorization of threatened plants, the Red data books published by Botanical Survey of India and global threat categorization accredited by International Union for Conservation of Nature were used (Nayar & Sastry 1987, 1988, 1990, Ved *et al.* 2003, IUCN 2017).

ii. To establish and strengthen Long-Term monitoring sites by using Global Observation Research Initiative in Alpine Environments (GLORIA) protocol for analysing impacts of climate change.

Representative alpine regions were identified based on dominant vegetation and physical attributes along different altitudes. Three alpine landscapes (Chaudans and Byans in Pithoragrah and Lata Kharak in Chamoli district of Uttarakhand) were selected as intensive study sites called as *target regions* and sampling was done by following the multi-summit approach of the GLORIA (Pauli *et al.*, 2009) with some modifications as per the field conditions. In each of the target region four mountain summits (plotting area) were selected representing an elevation gradient from natural treeline ecotone upto uppermost sub-nival or nival vegetation zone **(Figure 1)**. All summits of a *target region* must be exposed to the same regional climate, where climatic differences are caused by elevation rather than by topographically determined weather divide effects. Furthermore, summits should be of: (1) gentle and round morphology with slopes, with an average steepness between 5 & 25º; (2) "moderate" geomorphologic shape (very steep summits as well as flat tops are unsuitable); (3) reduced or absent human disturbance. For GLORIA target regions, sampling design for each summit consists of a) *1-m² quadrats*, arranged as the four corner quadrats of *3 m × 3 m quadrat clusters* in all four main *compass directions* (= 16 quadrats); b) *Summit area sections* (SAS), with four sections in the upper

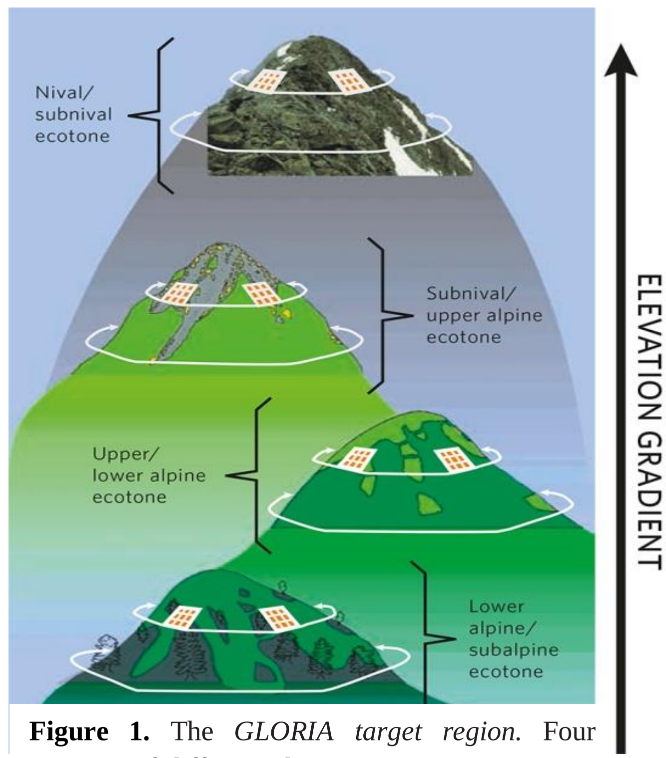


Figure 1. The *GLORIA target region.* Four summits of different elevations represent a *target region* (for vegetation zonation compare). The white lines indicate the lower boundaries of the *5-m* and the *10-m summit area*, respectively

summit area (*5-m summit area*) and four sections in the lower *summit area* (*10-m summit area*) **(Figure 2 & 3)**. In each of the cardinal directions (*i.e.*, true geographic N, S, E, W), 3m x 3m quadrat clusters is positioned at 5m altitudinal distance from HSP. Each quadrat cluster consists of nine 1m^2, delineated by a grid of flexible measuring tape. The lower boundary of each quadrat cluster should lie at 5m contour line below HSP.

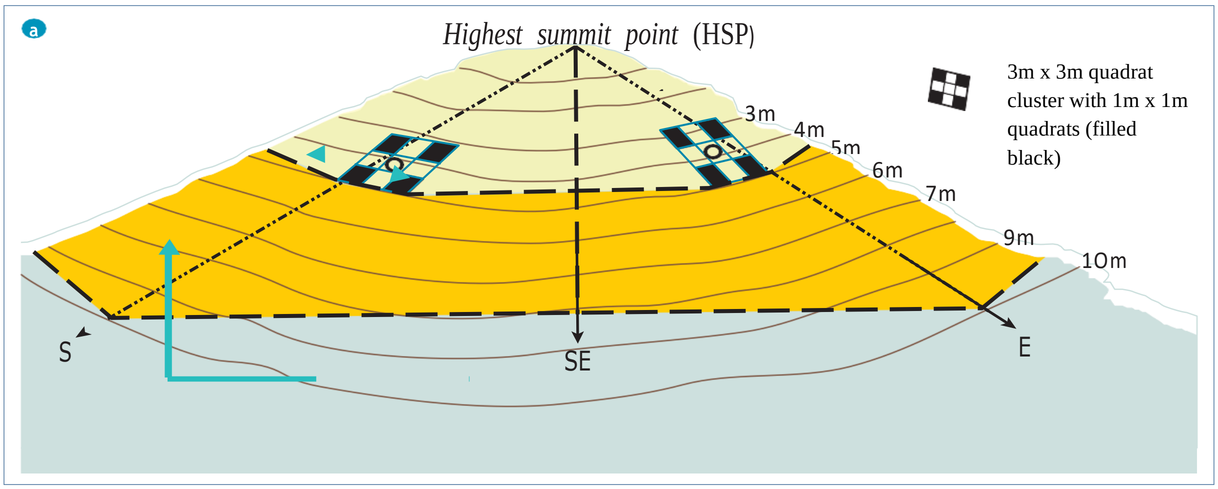
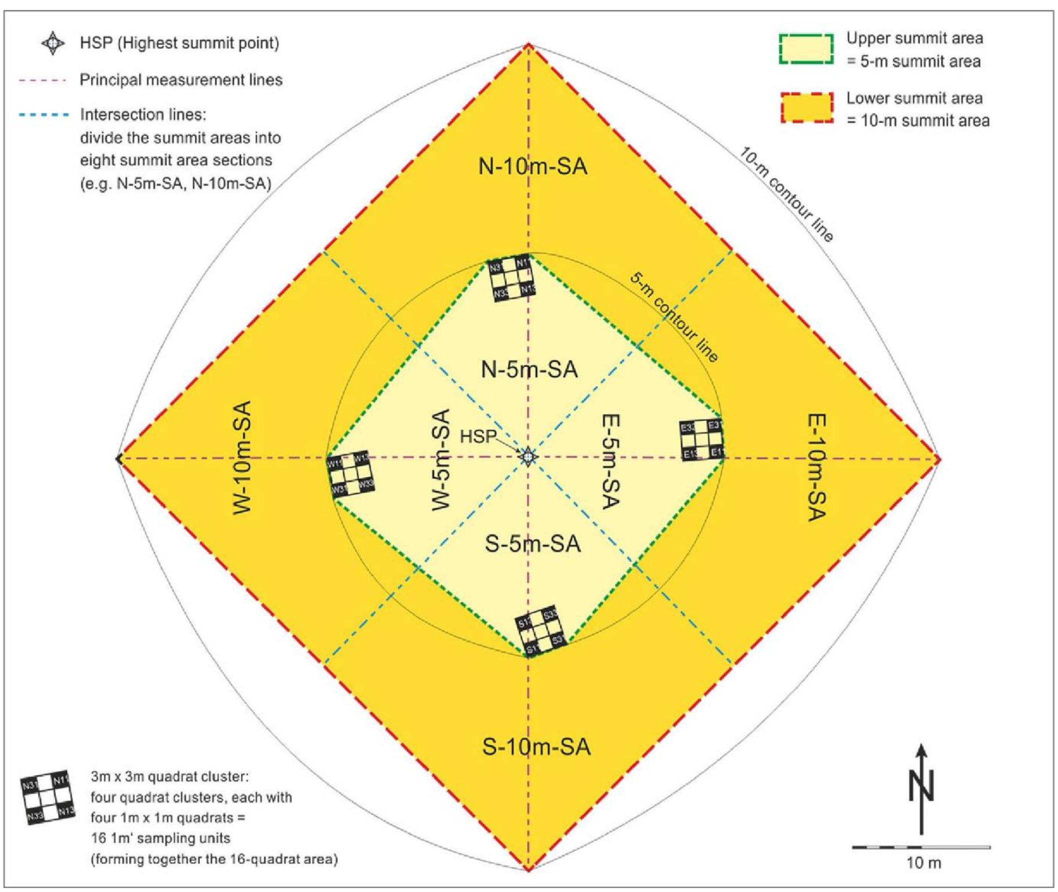


Figure 2. Oblique view of a summit design showing 10m and 5m summit area sections and positioning of 3mx3m quadrat cluster



p5m-N11, p5m-E31, p5m-E11, p5m-S31, p5m-S11, p5m-W31, p5m-W11, p5m-N31 : 8 lower corner points of the 3m x 3m quadrat clusters at the 5-m level	p-N13, p-E13, p-S13, p-W13, p-N33, p-E33, p-S33, p-W33 : the 8 upper corner points of the quadrat clusters at the 5-m level
p10m-N, p10m-E, p10m-S, p10m-W: the 4 corner points at the 10-m level; they determine the lower limit of the 10-m summit area	pNE-5, pNE-10, pSE-5, pSE-10, pSW-5, pSW-10, pNW-5, pNW-10 : the 8 corner points at the intersection lines (these points usually lie above the 5-m level and the 10-m level, respectively)

Figure 3: Scheme of the GLORIA sampling design. The standard sampling design comprises 16 *1-m² quadrats* and eight *summit area sections (SASs)*.

For ecological assessment of target regions basic sets of field sampling procedures as described in GLORIA protocol will be followed.

a) Recording in the 1m² quadrats

The vegetation of each 1m x 1m quadrat in the four corners of each 3m x 3m quadrat clusters will be assessed, yielding vegetation data for 16 quadrats per summit. For each sample quadrat, the top cover surface types (vascular plant cover, solid rock, scree, etc.) and cover of each vascular plant will be recorded. The aim is to provide baseline for detecting changes in species composition and in vegetation cover. Furthermore, species richness will be determined as the total number of species recorded in the sampling plots in each site.The structural aspect of vegetation such as density, frequency, abundance, and dominance were determined following Misra (1968) and Muller-Doimbois & Ellenberg (1974). The diversity index (H') was computed by using Shannon- Wiener's index (Shannon and Weaver (1949) and concentration of dominance by Simpson's index (Simpson 1949).

b) Recording in the Summit area sections

The four sections of 5-m summit area together with four sections of 10-m summit area form as set of eight sampling areas covering total summit area. As per standard methods, sampling in SASs will include: a) complete listing plus estimation of abundance of each species along an ordinal scale in five abundance categories (very rare, rare, scattered, common, dominant); b) visual estimation of percentage top cover of surface types. The main focus lies on data of the species pool of a summit site and in detecting changes in species richness. Cover records on top cover surface types characterise the habitat situation and vegetation coverage within summit area. Complete lists of vascular plants are crucial for assessing species invasions and disappearances from summit area sections.

In addition, data loggers were installed at a depth of 10 cm into the soil in the center of each grid in order to record the temperature at 2h intervals. Four T-loggers will be positioned on each summit, one in each 3m x 3m quadrat cluster at a depth of 10cm below soil surface. Soil temperature still is buffered but influenced by solar radiation and conduction through soil, which varies with soil texture and moisture. In the GLORIA programme the data will be used (a) to compare summits along the altitudinal gradient within and between target regions according to their temperature and snow regimes and (b) to detect mid- to long-term climate changes. Soil samples were also collected during surveys to document the soil variability and patterns along altitude as well as aspects and its relation with plant diversity. On each summit four locations outside the SAS corresponding to each *cardinal direction* were selected for soil sampling. Samples were taken from the depths 0-10 cm and 10-20 cm. The collected samples were stored in polythene bags tagged with suitable codes for identification and then brought to laboratory for analysis. The soil samples were air dried and coarse materials including stones and pieces of roots, leaves and other under decomposed organic residues were removed. Then, the samples were sieved through 2mm mesh sized sieve and used for further analysis as per various procedures: pH- Gairola *et al.,* 2012; moisture, texture, bulk density-Misra (1968); organic carbon- Walkley and Black (1947); total nitrogen- Parkinson and Allen (1975); total phosphorus- Watanabe and Olsen (1965).

iii. Investigation of changes of plant diversity in different alpine sites

For analysing change in plant diversity patterns, the reconnaissance survey methods (Palgrave *et al.,* 2007) were adopted. The established target sites in alpine region were resurveyed after a period of five years and compared with earlier survey datasets for analysing changes in diversity, composition. The present investigation was targeted to compare the floristic composition and pattern with earlier studies. To determine how species richness (i.e., the number of species) respond to aspect and summit, a one-way ANOVA test was done with “aspect” (nested within summit) and “summit” as fixed effects, and the number of species per quadrat as response variables. Further, a multiple pairwise-comparison between the aspects and summits separately was performed with a Tukey multiple comparison test using multicomp package in R (Hothorn et al., 2008) to determine whether the mean difference between the specific pairs of groups is statistically significant. Next, to determine how species richness changed over time, a two-way ANOVA test was performed with “sampling year,” “summit” and their interaction as fixed effects, and the species number per quadrat as response variable. This procedure was repeated for soil temperature, specifying “aspect” and “summit” as fixed effects and soil temperature as response variables. Prior to ANOVA test, data was subjected to Shapiro-Wilk and Levene’s tests for checking the normality and homogeneity of variance, respectively. Levene’s test was performed using leveneTest function in R package car (Fox and Weisberg, 2019).

Levene’s test is considered to be more robust in the checking the homogeneity of variance as it is less sensitive to departures from normal distribution. Temporal changes in air and soil temperature were analyzed with linear regression. Further, from each temperature logger, we first calculated daily average of hourly values as Tavg = 0.5 _ (Tmin C Tmax), where Tmin and Tmax are the daily minimum and maximum temperatures, respectively. The climate data was integrated with the plant diversity for analysing impact of climate change on vegetation as per the protocol followed by Liu *et al.* (2019). The relationship between species richness, diversity and environmental factors was analysed by linear correlation, polynomial regression and regression trees. Correlation of Shannon diversity with soil parameters was worked out using non-linear regression analysis where *p*-value of less than 0.05 is statistically defined as significant. All the statistical analyses were conducted in R version 3.5.2 (R Core Team, 2019).

3 KEY FINDINGS AND RESULTS

3.1 Major Research Findings

- ✓ Temporal analysis of plant diversity showed a significant increase in vegetation cover and richness in west Himalaya.
- ✓ A significant decreasing trend was recorded in soil temperature, with a decrease of 0.85ºC in Chauadans and increase of 0.32ºC in Byans valleys of alpine regions of Uttarakhand, west Himalaya.
- ✓ Correlation analysis revealed a strong positive relation between plant diversity & temperature in alpine regions.

3.2 Key Result:

- ✓ A total of 137 plant species distributed in 90 genera and 42 families were documented from target regions. The most represented families in summits were Asteraceae, Rosaceae, Scrophulariaceae, Ranunculaceae, Polygonaceae and Gentianaceae comprising 44% of total species pool. *Potentilla* L. was the dominant genus with six species, followed by *Pedicularis* L. and *Swertia* L.
- ✓ Of the total reported taxa, 44 are used in various therapeutic and medicinal practices and 11 are reported under different threat categories. Among these, *Nardostachys jatamansi* and *Picrorhiza kurroa* were critically endangered (CR), *Malaxis musifera* and *Allium stracheyi* were vulnerable (VU), *Polygonatum multiflorum* was data deficient and *Rhododendron anthopogon*, *R. campanulatum* and *R. lepidotum* were near threatened (NT).
- ✓ The summit flora exhibited an apparent decrease in species richness (S) and diversity (H') in Chaudans with increasing summit altitude, *i.e.*, highest in lowest summit.
- ✓ The mean species richness per $1m^2$ did not show a significant change during the five-year period at 95% confidence level (t= 1.99, p= 0.06) in CHU-TR. However, summit-wise analysis revealed a significant increase in species number from 9.8 to 11.2 in sub-nival vegetation zone only (t= 4.38,

$p<0.001$) which corresponds to ~2 species per plot. In BYN-TR, mean species richness per $1m^2$ significantly increased from 6.5 to 7.6 during the six-year period; this corresponds to an increase of ~1 species (16%) per quadrat at 95% confidence level ($t= 1.67$, $p< 0.01$). The gain in species numbers was significant in all summits, with maximum increase in lower alpine zone (~2 species per quadrat).

- ✓ Comparing the mean species diversity (calculated as Shannon index or *H'*) in baseline and resurvey datasets, a significant increase was observed in the study, *i.e.*, 2.32 to 2.42 (4.3%) Chaudans (*wr*; $p<0.01$) and 1.63 to 1.76 (8.4%) in Byans (*wr*; $p<0.001$). The relative change in vascular plant diversity was maximum in sub-nival zone (13%) in Chaudans, while in Byans lpine vegetation zone exhibited higher diversity change (21%) as compared to sub-nival/nival zones.

- ✓ The relative change in vegetation cover in the Chaudans target region over the years exhibited an increase in vascular (~6.1%; $p< 0.001$) and non-vascular (~0.1%; $p= 0.45$) plant cover, and a subsequent decrease in cover of substrate types (bare ground/rock/scree) (~6.2%; $p<0.001$). While, increase in vascular plant cover was significant in all summits, only the sub-nival zone showed significant increase in bryophytes and lichen cover percent (~1.4%; $p<0.05$). Similarly, in Byans target region, the relative change in vegetation cover exhibited an increase in vascular (~11.64%; $p< 0.001$) and non-vascular (~0.55%; $p= 0.26$) plant cover, and a subsequent decrease in cover of substrate types (bare ground/rock/scree) (~12.9%; $p<0.001$). While, increase in vascular plant cover was significant in all summits, only the sub-nival zone showed significant increase in bryophytes and lichen cover percent (~3.34%; $p<0.05$).

- ✓ Overall, soil temperature data showed a significant decreasing trend over four years (slope= -7.54, df=1459, p=0.001) in Chaudans, with decrease in both maximum and minimum temperatures. Contrary to this, an increasing trend was observed in Byans over six years (slope=0.01, df= 2180, $p<0.001$), with higher increase in minimum temperatures compared to maximum. However, summit wise analysis of temperature trends showed a negative trend in lower summits (BHT, KHA, GAN), whereas a positive trend in highest summit (SKN). Furthermore, average soil temperature change in Chaudans was -0.21ºC per year and in Byans was 0.06ºC per year. One-ANOVA results also reveal significant effect of altitude on rate of temperature change ($p<0.001$). Change in mean temperature (per year) is significantly higher in summits at higher altitude vegetative zones, *i.e.*, sub-nival-nival (>4000m).

- ✓ Results of linear regression models showed that there was a statistically significant relation of magnitude of change in species richness and diversity with change in mean, minimum and maximum soil temperature. However, rate of change in plant cover showed a significant positive trend with change in mean temperature only and was not significant with minimum and maximum. Kendall rank correlation analysis between the explanatory and dependent variables also corroborates the results of regression model. A significant positive correlation between change in species richness, Shannon diversity and plant cover with mean and minimum temperature change (correlation coesaafficient from 0.21 to 0.58). However, change in maximum temperature showed positive correlation with species richness, while it was not significant for diversity and cover.

3.3 Conclusion of the study: We studied vegetation dynamics on the alpine summits of west, Himalaya using standard multi-summit approach to assess the transformation of plant communities and its relation with temperature trends in the region. At the scale of individual mountain summits the change is not that apparent, but at larger scale, we observed a significant increase in species richness (4.3%) and cover (8.9%), with more rate of change in the sub-nival and nival summits. Transformation of plant communities to a warmer habitat was assessed using thermophilization indicator (D), which was significantly positive *i.e.*, *D*= 0.037. Correlation analysis of detected changes in richness and cover revealed a significant relation with the mean and minimum soil temperature. Thus, in view of the projected climate warming, the observed signals in the Himalayan mountain suggest an initiation of community transformation in high-altitudes which may lead to extinction of high-value floras.

4 OVERALL ACHIEVEMENTS

4.1 Achievement on Project Objectives

Objective 1- To analyze the floristic diversity and plant community composition along altitude range in alpine landscapes of Uttarakhand, west Himalaya.

Floristic diversity patterns along altitude gradients in the alpine regions of Darma and Byans valley of Pithoragarh district, Uttarakhand west Himalaya were compiled. In Darma valley, a total of 286 taxa (283 species and 3 varieties) belonging to 161 genera and 55 families were documented. Among them, the angiosperms were distributed in 279 taxa (276 species and 3 varieties) under 55 families and 161 genera, whereas the Gymnosperms were distributed in 7 species under 03 families and 05 genera (Table 1). Asteraceae (17 genera and 30 species) was reported as the most dominant family, followed by Ranunculaceae (13 genera and 29 species), Rosaceae (6 genera and 16 species), Poaceae (8 genera and 15 species), and Polygonaceae (7 genera and 13 species) (Figure 1). Herbaceous taxa were the most dominant with 240 plant taxa, followed by 36 shrubs, 8 trees and 2 climbers (Figure 2).

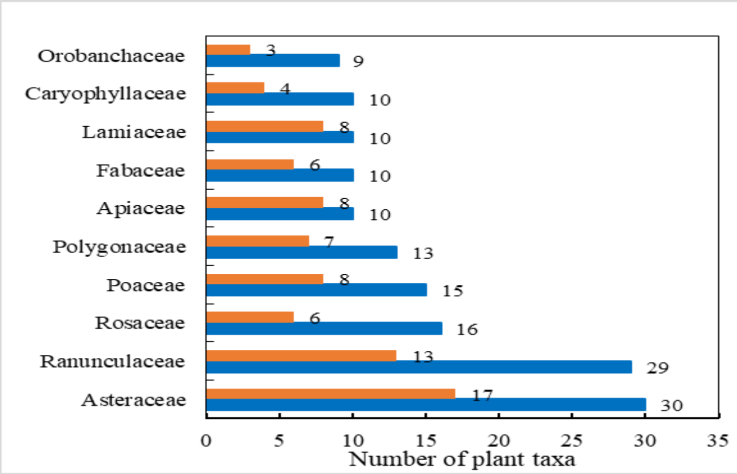


Figure 1: Top ten plant families represented by highest number of plant species in Darma valley

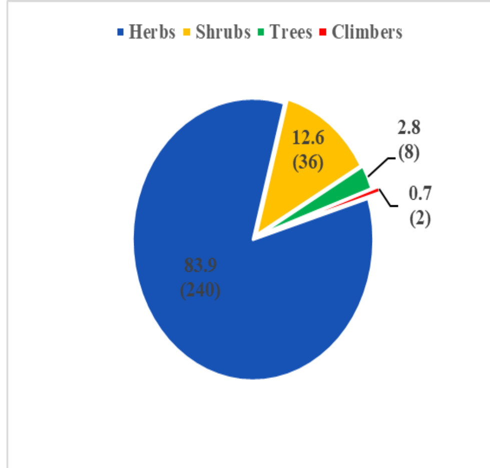


Figure 2: Percent share of various plant growth habit forms in Darma valley.

In Byans valley, a total of 371 taxa (364 species and 7 varieties) belonging to 197 genera and 63 families inhabited the alpine zone. Among them, the angiosperms were distributed in 364 taxa (357 species and 7 varieties) under 60 families and 192 genera, whereas the Gymnosperms were distributed in 7 species under 03 families and 05 genera. Asteraceae (18 genera and 33 species) was reported as the most dominant family, followed by Ranunculaceae (13 genera and 30 species), Poaceae (13 genera and 24 species), Rosaceae (7 genera and 25 species) and Fabaceae (7 genera and 17 species) (Figure 3). Herbaceous taxa were the most dominant with 303 plant taxa, followed by 55 shrubs, 22 trees and 6 climbers (Figure 4).

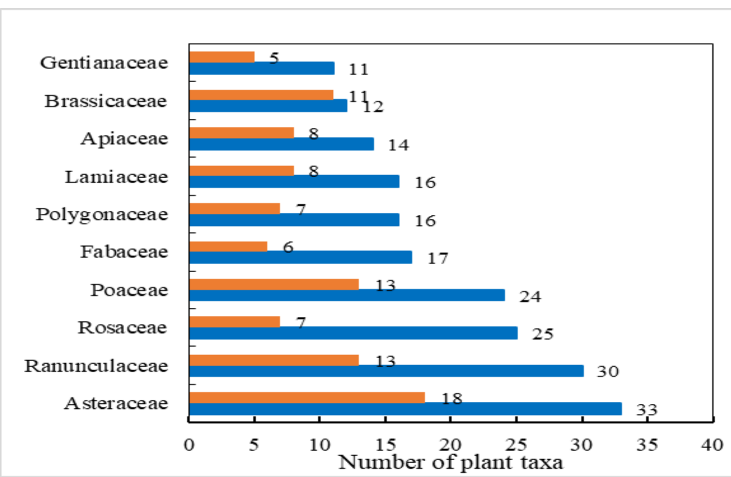


Figure 3: Top ten plant families represented by highest number of plant species in Byans valley

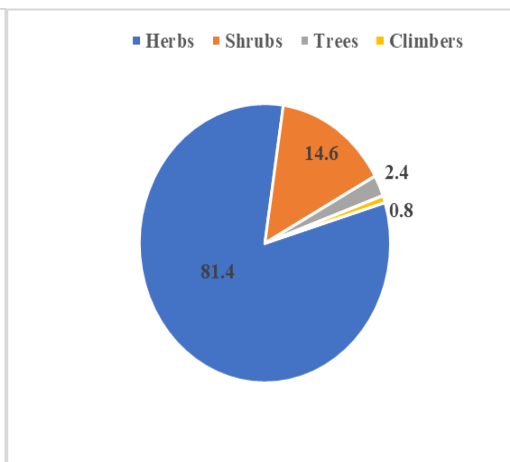


Figure 4: Percent share of various plant growth habit forms in Byans valley.

When species distribution is seen in relation to four altitude zones, lowest altitude zone exhibited maximum number of plants (254 species) with a continuous decrease in plant species number (trees, shrubs & herbs) going up the altitude zones in both valleys (Table 2 & 3). While considering diversity distribution of higher level of taxa (i.e., genera and family), more rapid decline with altitude is apparent as compared to the species. Across the altitude zones, S/G values remained same for trees, while it decreased continuously for shrubs and sporadically for herbs from lower to higher zone (Table 2).

Table 2. Species richness among three growth forms in four altitude zones in Darma valley of Uttarakhand.

	Trees			Shrubs			Herbs		
Altitude	S	G	S/G	S	G	S/G	S	G	S/G
3000-3500	8	8	1.0	32	16	2.0	214	132	1.6
3501-4000	3	3	1.0	29	16	1.8	194	121	1.6
4001-4500	2	2	1.0	15	11	1.4	129	84	1.5
4501-5000	-	-	-	6	5	1.2	62	44	1.4

Table 3: Species richness among three growth forms in four altitude zones in Byans valley of Uttarakhand.

	Trees			Shrubs			Herbs		
Altitude	S	G	S/G	S	G	S/G	S	G	S/G
3000-3500	9	8	1.0	49	24	2.0	254	146	1.6
3501-4000	3	3	1.0	40	23	1.8	247	136	1.6
4001-4500	2	2	1.0	21	14	1.4	173	99	1.5
4501-5000	-	-	-	8	6	1.2	77	52	1.4

Across altitude zones, the ratio decreased for all growth habits. Recognizing that the S/G ratio have been frequently used to describe the biogeographic patterns and taxonomic structure of clades and biotas (Krug *et al.*, 2008), we interpret the patterns of S/G at local scale in the light of the hypothesis that describes spatial variations of S/G as part of evolutionary dynamics wherein these ratios are related to speciation or diversification rates (Floeter *et al.*, 2004). The altitudinal decrease of S/G in case of shrubs & herbs in study area would imply their phylogenetic over dispersion towards highest altitudes. No such trend was observed for trees.

Objective 2- To establish and strengthen Long-Term Ecological Monitoring site(s) following the Global Observation Research Initiative in Alpine Environments (GLORIA) protocol for continuous monitoring of floristic diversity patterns in alpine environment.

A Long-term monitoring site was established in Lata valley, Chamoli in 2020, following the standard GLORIA protocol consisting of four summits namely Kharak (KHR), Sainikharak (SAI), Donidhar (DON) and Pulan (PUL) along an altitude gradient above natural treeline (Figure 5).

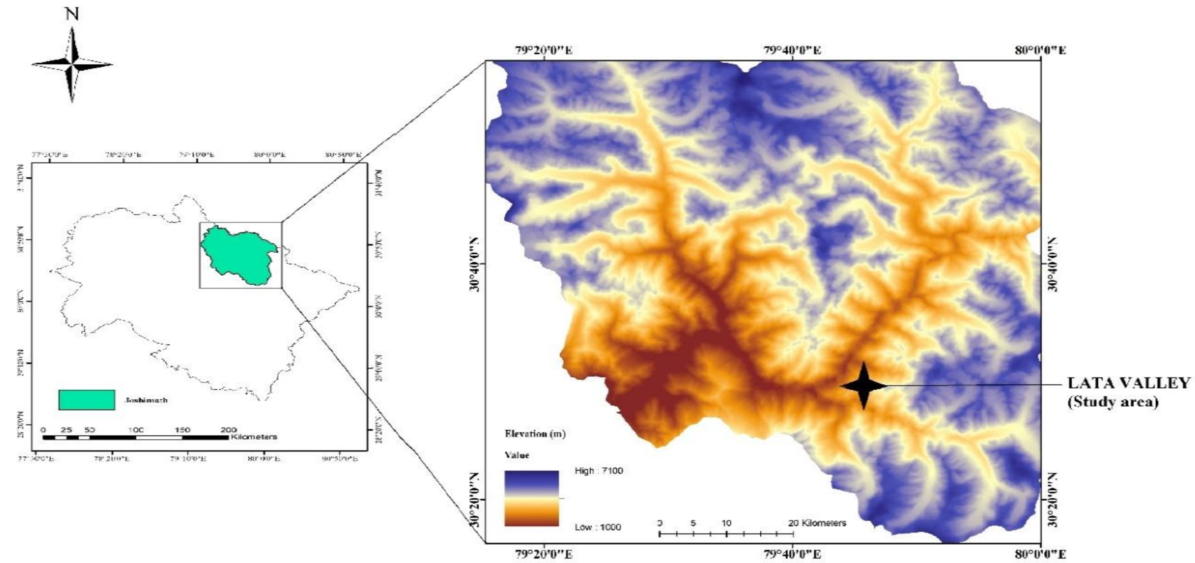


Figure 5: GLORIA observation site-3 in Lata valley, Chamoli, Uttarakhand, India.

Baseline floristic data of the observation site was documented intensive several field surveys. The site inhabited a total of 124 plant species belonging to 91 genera and 37 families (Table 4). The most represented families were Asteraceae (16 species) and Rosaceae (13 species) (Figure 6).

Table 4: Floristic diversity of the GLORIA observation site in Lata valley

Plant Taxa	**Family**	**KHR**	**SAI**	**DON**	**PUL**
Aletris pauciflora (Klotzsch) Hand. - Mazz.	Melanthiaceae		+		
Allium stracheyi Baker	Liliaceae	+		+	
Anaphalis contorta (D. Don) Hook. f.	Asteraceae	+	+	+	+
Anemone obtusiloba D. Don	Ranunculaceae	+	+	+	+
Anemone polyanthes D. Don	Ranunculaceae		+		
Anemone rupicola Cambess.	Ranunculaceae	+	+		
Arabis auriculata Lam.	Brassicaceae	+	+		
Arenaria bryophylla Fernald	Caryophyllaceae		+		
Arenaria festucoides Benth.	Caryophyllaceae	+			
Arenaria serpyllifolia L.	Caryophyllaceae	+			
Arnebia benthamii (Wall. *ex* G. Don) I.M. Johnst.	Boraginaceae	+	+	+	
Aster diplostephioides (DC.) Benth. *ex* C.B. Clarke	Asteraceae	+	+	+	+
Astragalus himalensis Jacquem. *ex* Baker	Fabaceae		+		

Bergenia stracheyi (Hook. f. & Thomson) Engl.	Saxifragaceae	+	+	+	+
Bistorta affinis (D. Don) Greene	Polygonaceae	+	+	+	+
Bistorta amplexicaulis (D. Don) Greene	Polygonaceae		+		
Bistorta vacciniifolia (Wall. *ex* Meisn.) Greene	Polygonaceae		+		+
Bistorta vivipara (L.) Gray	Polygonaceae	+	+	+	+
Bromus japonicus Houtt.	Poaceae		+		
Bupleurum falcatum L.	Apiaceae	+	+	+	+
Caltha palustris L.	Ranunculaceae	+			
Carex infuscata Nees	Cyperaceae	+	+		
Carex setosa Boott	Cyperaceae	+	+	+	+
Cassiope fastigiata (Wall.) D. Don	Ericaceae	+	+	+	
Cicerbita macrorhiza (Royle) Beauverd	Asteraceae		+	+	
Corydalis cashmeriana Royle	Fumariaceae	+	+		
Corydalis flabellata Edgew.	Fumariaceae				+
Cotoneaster microphyllus Wall. *ex* Lindl.	Rosaceae	+	+	+	
Cremanthodium ellisii (Hook. f.) Kitam.	Asteraceae	+	+	+	+
Cyananthus lobatus Wall. *ex* Benth.	Campanulaceae	+	+	+	+
Danthonia cachemyriana Jaub. & Spach	Poaceae	+	+	+	+
Delphinium brunonianum Royle	Ranunculaceae		+		
Dryopteris barbigera (T. Moore ex Hook.) Kuntze	Dryopteridacea	+	+	+	
Elsholtzia eriostachya (Benth.) Benth.	Lamiaceae	+		+	
Epilobium royleanum Hausskn.	Onagraceae			+	+
Erigeron semibarbatus DC.	Asteraceae		+		
Eritrichium villosum (Ledeb.) Bunge	Boraginaceae	+	+		
Euphorbia stracheyi Boiss.	Euphorbiaceae	+		+	
Euphrasia himalayica Wettst.	Scrophulariaceae			+	+
Sanguisorba diandra (Wall.) Nordborg	Rosaceae	+			
Falconeria himalaica Hook. f.	Scrophulariaceae		+		
Fragaria nubicola Lindl. *ex* Lacaita	Rosaceae		+		+
Galium aparine L.	Rubiaceae	+			

Gentiana venusta (G. Don) Griseb.	Gentianaceae		+		+
Geranium collinum Steph. *ex* Willd.	Geraniaceae	+	+	+	
Geranium nepalense Sweet	Geraniaceae	+	+	+	+
Geranium wallichianum D. Don *ex* Sweet	Geraniaceae	+	+	+	
Geum elatum Wall. *ex* G. Don	Rosaceae	+		+	+
Gypsophila cerastioides D. Don	Caryophyllaceae	+	+	+	
Heracleum candicans Wall. *ex* DC.	Apiaceae	+			
Hippolytia dolicophylla (Kitam.) K. Bremer & Humphries	Asteraceae				+
Impatiens leggei Pusalkar & D.K. Singh	Balsaminaceae	+	+		
Impatiens scabrida DC.	Balsaminaceae	+			
Juncus concinnus D. Don	Juncaceae	+		+	+
Juncus membranaceus Royle	Juncaceae	+	+	+	
Juniperus communis L.	Cupressaceae	+		+	
Dolomiaea macrocephala DC.	Asteraceae	+		+	
Kobresia laxa Nees	Cyperaceae	+		+	
Kobresia nepalensis (Nees) Kük.	Cyperaceae	+		+	+
Lactuca dubyaea C.B. Clarke	Asteraceae	+	+	+	
Lamium album L.	Lamiaceae		+		
Leibnitzia pusilla (DC.) S. Gould	Asteraceae	+	+		
Leontopodium jacotianum Beauverd	Asteraceae			+	+
Ligularia arnicoides DC. *ex* Royle	Asteraceae	+		+	
Lloydia longiscapa Hook.	Liliaceae	+			
Lomatogonium carinthiacum (Wulfen) Rchb.	Gentianaceae			+	
Malaxis muscifera (Lindl.) Grubov	Orchidaceae		+		
Morina longifolia Wall. *ex* DC.	Caprifoliaceae	+	+	+	
Nardostachys grandiflora DC.	Caprifoliaceae		+		
Oxygraphis polypetala (D. Don) Hook. f. & Thomson	Ranunculaceae		+		
Parochetus communis Buch.-Ham. *ex* D. Don	Fabaceae	+			
Parnassia kumaonica Nekrass.	Parnassiaceae	+	+		

Parnassia nubicola Wall. *ex* Royle	Parnassiaceae	+	+	+	+
Pedicularis gracilis Wall. *ex* Benth.	Scrophulariaceae	+	+	+	
Pedicularis pectinata Wall. *ex* Benth.	Scrophulariaceae	+	+	+	
Pedicularis punctata Decne.	Scrophulariaceae	+	+	+	
Pedicularis trichoglossa Hook. f.	Scrophulariaceae	+	+		
Phlomis bracteosa Royle *ex* Benth.	Lamiaceae	+	+		
Picrorhiza kurrooa Royle	Scrophulariaceae		+		+
Plantago depressa Willd.	Plantaginaceae		+		
Pleurospermum brunonis (DC.) C.B. Clarke	Apiaceae	+			
Poa alpina L.	Poaceae	+	+	+	+
Poa annua L.	Poaceae	+	+		
Polygonatum multiflorum (L.) All.	Liliaceae	+		+	
Polygonum filicaule Wall. *ex* Meisn.	Polygonaceae		+		
Polygonum polystachyum Wall. *ex* Meisn.	Polygonaceae	+		+	
Polystichum thomsonii (Hook. f.) Bedd.	Dryopteridaceae			+	
Ponerorchis chusua (D. Don) Soo	Orchidaceae	+			
Potentilla argyrophylla Wall. *ex* Lehm.	Rosaceae	+	+	+	+
Potentilla atrosanguinea G. Lodd. *ex* D. Don	Rosaceae			+	+
Potentilla biflora D.F.K. Schltdl.	Rosaceae	+	+		
Potentilla cuneata Wall. ex Lehm.	Rosaceae	+	+	+	
Potentilla cuneifolia Bertol.	Rosaceae	+	+	+	
Potentilla microphylla D. Don	Rosaceae				+
Primula denticulata Sm.	Primulaceae	+	+	+	
Ranunculus hirtellus Royle	Ranunculaceae	+	+		
Rheum moorcroftianum Royle	Polygonaceae			+	
Rhodiola bupleuroides (Wall. *ex* Hook. f. & Thomson) S.H. Fu	Crassulaceae	+		+	+
Rhododendron anthopogon D. Don	Ericaceae			+	+
Rhododendron campanulatum D. Don	Ericaceae	+		+	
Rhododendron lepidotum Wall. *ex* G. Don	Ericaceae	+	+		

Rosa macrophylla Lindl.	Rosaceae	+			
Rumex nepalensis Spreng.	Polygonaceae	+		+	
Salix sp.	Salicaceae	+	+	+	
Saussurea obvallata (DC.) Sch. Bip.	Asteraceae				+
Saussurea taraxifolia (Lindl.) DC.	Asteraceae	+			+
Saxifraga flagellaris Willd. *ex* Sternb.	Saxifragaceae		+	+	+
Saxifraga sp.	Saxifragaceae	+	+	+	+
Sedum multicaule Wall. *ex* Lindl.	Crassulaceae		+		
Selinum elatum M. Hiroe	Apiaceae	+			
Selinum wallichianum (DC.) Raizada & H.O. Saxena	Apiaceae	+	+	+	
Senecio chrysanthemoides DC.	Asteraceae	+		+	
Sibbaldia cuneata Hornem. *ex* Kuntze	Rosaceae	+	+		+
Sibbaldia parviflora Willd.	Rosaceae	+	+	+	
Silene vulgaris (Moench) Garcke	Caryophyllaceae	+		+	
Stellaria media (L.) Vill.	Caryophyllaceae		+		+
Swertia chirata Buch.-Ham. *ex* C.B. Clarke	Gentianaceae		+	+	+
Swertia ciliata (D. Don *ex* G. Don) B.L. Burtt	Gentianaceae	+		+	
Swertia cuneata Wall. *ex* D. Don	Gentianaceae	+			
Swertia petiolata D. Don	Gentianaceae		+		
Swertia speciosa Wall.	Gentianaceae		+		
Taraxacum officinale F.H. Wigg.	Asteraceae	+		+	
Thalictrum alpinum L.	Ranunculaceae	+	+		
Trachydium roylei Lindl.	Apiaceae	+	+	+	+
Valeriana hardwickii Wall.	Valerianaceae		+		
Veronica biloba L.	Scrophulariaceae	+			
Viola biflora L.	Violaceae	+	+	+	+

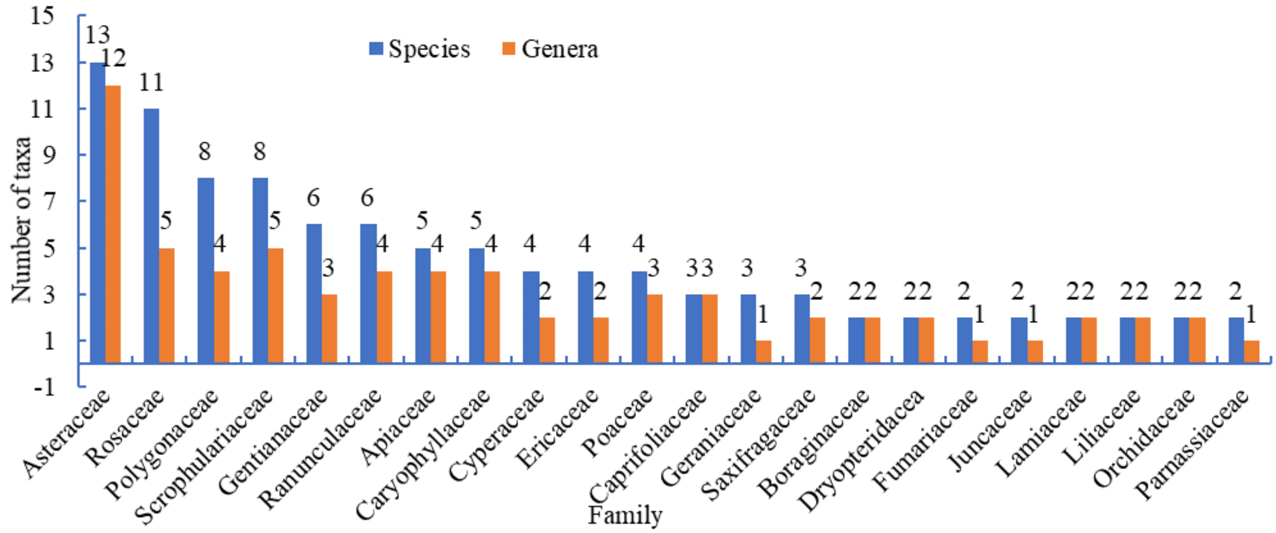


Figure 6: Plant families represented by number of plant species and genera in Lata valley.

Vegetation composition trends in individual summits was also documented. There was a significant decrease in species richness with increasing altitude, with maximum species in KHR (88 species), followed by SAI (80 species), DON (67 species) and PUL (40 species) (Table 5). Phytosociological analysis also exhibited variation in species composition along altitude gradient, *i.e.*, KHR with 93% of vegetation cover was dominated by *Bistorta affinis* (IVI-29) and *Danthonia cachemyriana* (IVI-20; SAI with 81% cover was dominated by *D. cachemyriana* (IVI-21) and *Anaphalis contorta* (IVI-20); DON with 92% cover was dominated by *B. affinis* (IVI-22) and *D. cachemyriana* (IVI-18); and PHU with 78% cover was dominated *B. affinis* (IVI-45) and *Nardostachys grandiflora* (IVI-21) (Table 5).

Table 5. Summit details and vegetation composition patterns in GLORIA Observation site in Lata Valley.

Locality (Summit code)	Altitude & location	Vegetation zone	Plant species richness; Dominant species (IVI)
Kharak (KHR)	3820 m 30º29'41.47" N 79º45'12.20" E	Lower alpine- above treeline	88 species; *Bistorta affinis* (29) and *Danthonia cachemyriana* (20)
Sainikharak (SAI)	3923 m 30º29'28.79" N 79º45'14.97" E	Transition between the lower and upper alpine	80 species; *D. cachemyriana* (21) and *Anaphalis contorta* (20)
Donidhar (DON)	4030 m 30º29'35.14" N 79º45'20.16" E	Upper alpine- the top region	67 species; *B. affinis* (22) and *D. cachemyriana* (18)

Pulang(PUL)	4269 m 30º29'39.01" N 79º45'42.63" E	Transition between the upper alpine and nival	40 species; *B. affinis* (45) and *Nardostachys grandiflora* (21)

Among the total recorded species, a total of 13 species were considered threatened as per IUCN, CAMP and RDB among which three are Critically Endangered, 1 is Endangered, 3 are Vulnerable and 6 are Least Concern (Table 6). In review of literature and interview with local inhabitant in the Lata valley, a total of 53 species were recorded in usage by local people for the treatment of various ailments.

Table 6: Distribution of threatened plants of the GLORIA Target Region in Lata valley.

Species name	**Threat Status**	**Species cover (%)**			
		KHR	SAI	DON	PUL
Arnebia benthamii	CR	4.5	3.8	2.5	
Nardostachys grandiflora	CR			11	57
Picrorhiza kurrooa	CR		1		5
Saussurea obvallata	EN				5
Allium stracheyi	VU	5.5		3	
Bergenia stracheyi	VU		9.2		16
Malaxis muscifera	VU	1.2			
Juniperus communis	LC			50	
Silene vulgaris	LC	2.5	4.5		
Rhododendron anthopogon	NT	66.4	25	171	381
Rhododendron campanulatum	NT	1.5		3	
Rhododendron lepidotum	NT			4.2	6.2

CR- Critically Endangered; EN- Endangered; VU- Vulnerable; LC- Least Concern; NT- Near Threatened

Furthermore, analysis of various physico-chemical parameters of soil in the target region was done in order to document soil ecological processes under global change scenarios. Soil moisture content (%) significantly varied ranging from 28.60 ± 0.17 (KHR-East 5m:10-20cm) to 62.88 ± 0.20 (PUL-East 5m:0-10cm) (Table 7). However, depth wise analysis revealed exhibited significantly higher moisture content at 0-10cm as compared to 10-20cm. Along altitude gradient, it followed an increasing trend with maximum value in PUL (47.37%) and minimum in KHR (39.67%) (7i). Furthermore, North aspect exhibited the highest moisture content of 45.15 % and East aspect exhibited the lowest, *i.e.*, 39.80% (Figure 7ii).

Table 7. Soil moisture content (%) in GLORIA Target Region in Lata valley along four aspects at depths 0-10 cm and 10-20 cm.

Aspect	Contour line (m)	Depth (cm)	Soil moisture (%)			
			KHR	SAI	DON	PUL
HSP		0-10	43.27 ± 0.07	43.53 ± 0.07	54.90 ± 0.20	46.83 ± 0.23
		10 20	38.17 ± 0.13	37.69 ± 0.26	53.90 ± 0.13	40.26 ± 0.07
North	5m	0-10	43.48 ± 0.20	48.66 ± 0.07	44.51 ± 0.07	47.99 ± 0.07
		10 20	40.23 ± 0.17	39.23 ± 0.11	47.39 ± 0.07	46.10 ± 0.13
	10m	0-10	57.49 ± 0.37	49.74 ± 0.07	57.83 ± 0.07	40.01 ± 0.13
		10 20	49.82 ± 0.07	41.83 ± 0.07	28.43 ± 0.07	39.63 ± 0.20
South	5m	0-10	36.69 ± 0.07	35.12 ± 0.11	43.68 ± 0.07	54.01 ± 0.20
		10 20	38.35 ± 0.07	30.39 ± 0.24	41.51 ± 0.13	43.55 ± 0.33
	10m	0-10	42.00 ± 0.07	35.46 ± 0.27	38.20 ± 0.07	56.76 ± 0.20
		10 20	38.27 ± 0.07	33.73 ± 0.35	32.54 ± 0.07	43.07 ± 0.13
East	5m	0-10	33.33 ± 0.39	35.03 ± 0.13	43.21 ± 0.07	62.88 ± 0.20
		10 20	28.60 ± 0.17	34.78 ± 0.17	34.28 ± 0.07	51.12 ± 0.13
	10m	0-10	34.92 ± 0.24	32.14 ± 0.30	43.63 ± 0.20	52.72 ± 0.07
		10 20	28.77 ± 0.33	32.20 ± 0.33	41.87 ± 0.20	43.30 ± 0.13
West	5m	0-10	36.91 ± 0.07	54.83 ± 0.17	50.58 ± 0.07	52.37 ± 0.20
		10 20	32.15 ± 0.07	51.71 ± 0.13	37.45 ± 0.07	45.29 ± 0.07
	10m	0-10	44.69 ± 0.12	44.82 ± 0.20	38.82 ± 0.07	45.56 ± 0.07
		10-20	46.95 ± 0.07	38.98 ± 0.07	35.11 ± 0.13	41.20 ± 0.17

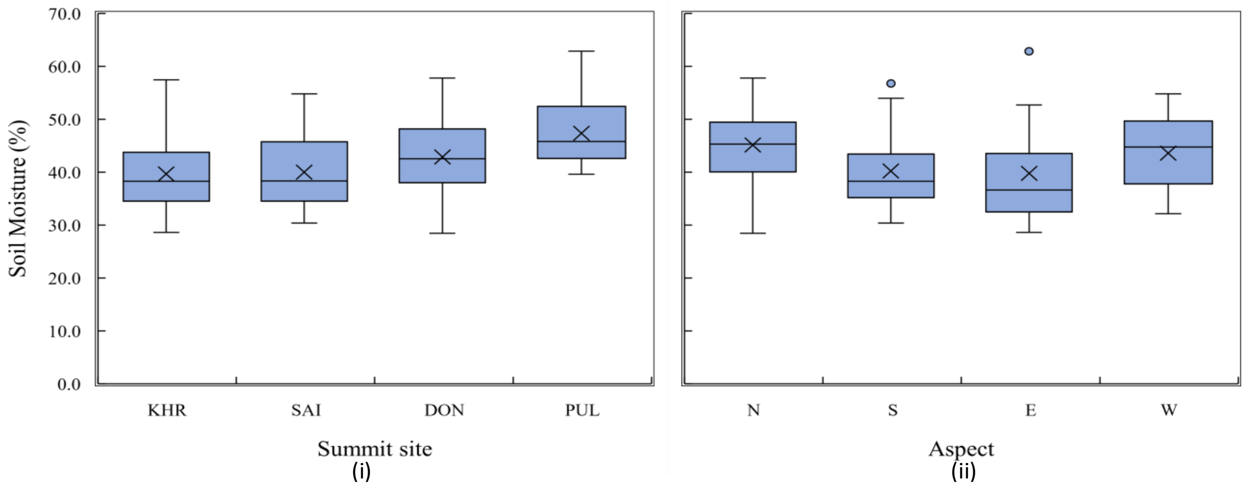


Figure 7. Soil moisture (%) variation with respect to (i) Altitude and (ii) Aspect in the GLORIA Target Region in Lata valley.

The bulk density values (g/cm3) measured for the soil samples varied between 0.42 ± 0.002 (SAI-South 10m:0-10cm) and 1.26 ± 0.001 (PUL-West 10m:10-20cm) (Table 8). It was observed that the bulk density was significantly higher at 10-20cm depth than that at 0-10cm. Moving along the altitude gradient, bulk density decreased from KHR (0.81 g/cm3) to SAI (0.74 g/cm3) and then exhibited a significant increase with increasing altitude, *i.e.*, DON (0.85 g/cm3) and PUL (1.00 g/cm3) (Figure 8i*). Among aspect, bulk density was maximum in west (0.94 g/cm3), followed by south (0.86 g/cm3), north (0.81 g/cm3) and east (0.79 g/cm3) (Figure 8ii*).

Table 8. Bulk density (g/cm^3) in GLORIA Target Region in Lata valley along fouraspects at depths 0-10cm and 10-20cm.

Aspect	Contour line (m)	Depth (cm)	KHR	SAI	DON	PUL
HSP		0-10	0.93 ± 0.007	0.80 ± 0.001	0.51 ± 0.015	1.00 ± 0.002
		10 20	1.07 ± 0.003	0.87 ± 0.001	0.55 ± 0.015	1.13 ± 0.001
North	5m	0-10	0.81 ± 0.005	0.69 ± 0.013	0.67 ± 0.007	0.88 ± 0.001
		10 20	0.67 ± 0.002	1.10 ± 0.011	0.78 ± 0.003	1.02 ± 0.001
	10m	0-10	0.54 ± 0.007	0.66 ± 0.015	0.52 ± 0.010	1.11 ± 0.001
		10 20	0.51 ± 0.003	0.94 ± 0.004	0.97 ± 0.001	1.12 ± 0.003
South	5m	0-10	0.78 ± 0.005	0.96 ± 0.001	0.68 ± 0.003	0.94 ± 0.001
		10 20	1.11 ± 0.001	0.79 ± 0.004	1.00 ± 0.001	1.22 ± 0.001
	10m	0-10	0.75 ± 0.002	0.42 ± 0.002	0.83 ± 0.001	0.79 ± 0.007
		10 20	0.90 ± 0.001	0.45 ± 0.002	1.05 ± 0.001	1.02 ± 0.001

East	5m	0-10	0.63 ± 0.001	0.51 ± 0.001	0.70 ± 0.002	0.64 ± 0.005
		10 20	0.86 ± 0.001	0.92 ± 0.001	1.13 ± 0.001	0.76 ± 0.001
	10m	0-10	0.80 ± 0.001	0.56 ± 0.004	0.98 ± 0.001	0.85 ± 0.001
		10 20	0.67 ± 0.001	0.58 ± 0.002	0.99 ± 0.001	1.11 ± 0.001
West	5m	0-10	0.81 ± 0.001	0.60 ± 0.013	0.71 ± 0.006	1.09 ± 0.001
		10 20	1.07 ± 0.001	0.94 ± 0.001	1.04 ± 0.002	1.01 ± 0.001
	10m	0-10	0.81 ± 0.001	0.59 ± 0.003	0.93 ± 0.002	1.11 ± 0.001
		10 20	0.93 ± 0.001	0.99 ± 0.001	1.18 ± 0.002	1.26 ± 0.001

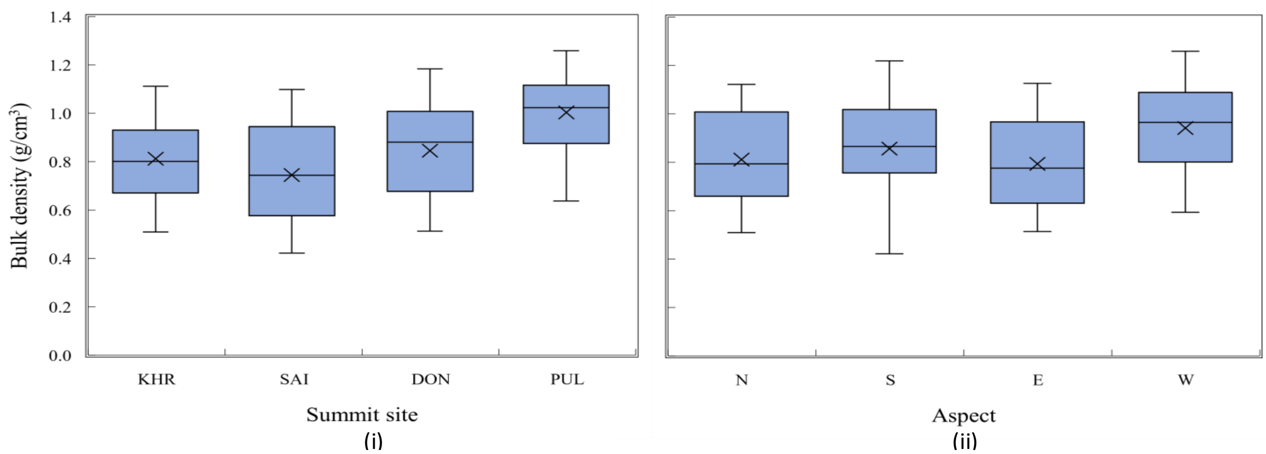


Figure 8. Bulk density (g/cm^3) variation with respect to (i) Altitude and (ii) Aspect in theGLORIA Target Region in Lata valley.

The soil samples of the summit sites exhibited acidic to mild acidic nature ranging from 3.22±0.12 in KHR-North 10m-0-10cm to 6.46±0.17 in DON-West 5m-10-20cm (Table 9*). Depth-wise analysis revealed significant variations in soil pH values at two different depths, *i.e.*, 0-10cm and 10-20cm, however there was no significant trend between the depths. pH value increased with altitude significantly from KHR to DON and decreased further to PUL (Figure 9i*). Among aspects pH was maximum in West aspect (5.36) and minimum in North aspect (5.05), while East and South aspect did not show significant difference (Figure 9ii*).

Table 9. pH of soil sampled along altitude gradient in the different aspects at depths0-10cm and 10-20cm in GLORIA Target Region in Lata valley.

Aspect	Contour line (m)	Depth (cm)	KHR	SAI	DON	PUL

HSP		0-10	4.76 ± 0.05	5.16 ± 0.06	5.55 ± 0.05	5.34 ± 0.02
		10 20	5.19 ± 0.11	5.38 ± 0.10	5.25 ± 0.06	5.35 ± 0.01
North	5m	0-10	5.94 ± 0.11	5.46 ± 0.07	5.27 ± 0.19	5.57 ± 0.02
		10 20	5.39 ± 0.02	5.64 ± 0.09	4.94 ± 0.01	4.72 ± 0.03
	10m	0-10	3.22 ± 0.12	4.53 ± 0.22	5.04 ± 0.04	5.60 ± 0.05
		10 20	3.64 ± 0.13	4.99 ± 0.22	5.83 ± 0.04	4.99 ± 0.10
South	5m	0-10	5.73 ± 0.09	5.37 ± 0.05	5.01 ± 0.02	5.44 ± 0.03
		10 20	4.18 ± 0.08	5.81 ± 0.15	4.96 ± 0.04	5.56 ± 0.16
	10m	0-10	4.14 ± 0.11	5.48 ± 0.12	4.80 ± 0.29	5.40 ± 0.20
		10 20	5.05 ± 0.18	5.12 ± 0.05	5.71 ± 0.14	4.09 ± 0.02
East	5m	0-10	4.21 ± 0.05	4.79 ± 0.02	5.44 ± 0.01	5.56 ± 0.05
		10 20	3.35 ± 0.04	5.01 ± 0.03	5.46 ± 0.21	5.03 ± 0.04
	10m	0-10	5.97 ± 0.03	4.61 ± 0.16	5.48 ± 0.12	5.06 ± 0.31
		10 20	3.95 ± 0.27	4.55 ± 0.16	5.43 ± 0.17	5.26± 0.03
West	5m	0-10	4.64 ± 0.02	4.13 ± 0.10	6.16 ± 0.11	4.64 ± 0.13
		10 20	4.16 ± 0.04	5.46 ± 0.08	6.46 ± 0.17	5.90 ± 0.16
	10m	0-10	5.68 ± 0.18	5.13 ± 0.07	5.77 ± 0.09	5.51 ± 0.07
		10 20	5.20 ± 0.07	5.66 ± 0.07	5.34 ± 0.09	5.89 ± 0.19

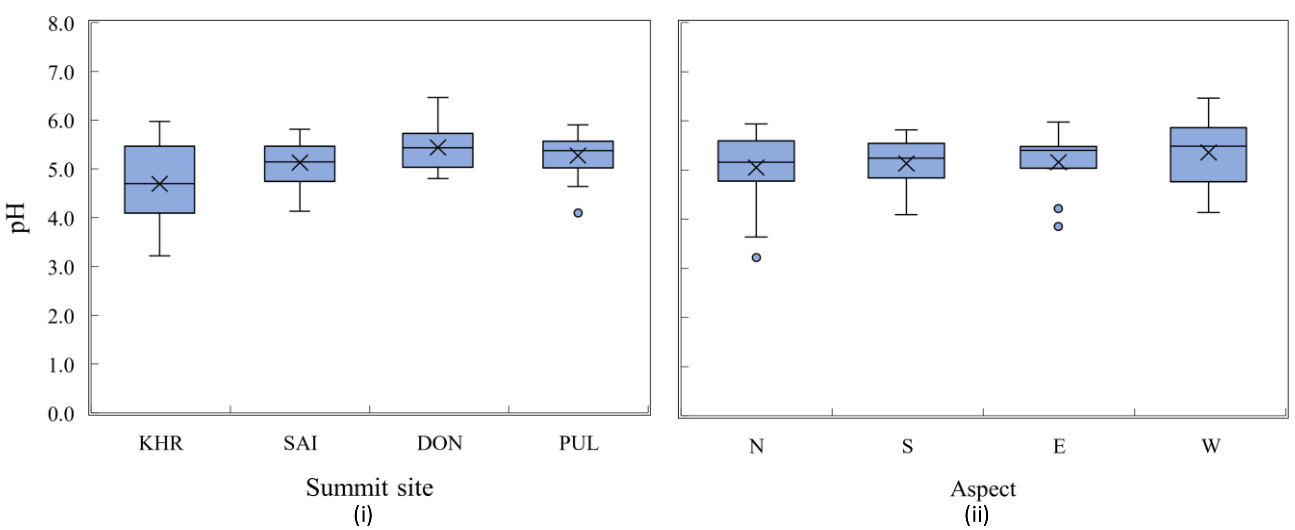


Figure 9. Soil pH variation with respect to (i) Altitude and (ii) Aspect in the GLORIATarget Region in Lata valley.

Organic carbon content (%) ranged from 0.34±0.01 (in SAI-West 5m) to 1.82±0.04 (in PUL-East 5m) and significantly decreased with increasing soil depth (Table 10). Analysis of soil organic carbon (%) in the target region showed that organic carbon content ranged from 0.77% (in SAI) to 1.08% (in DON and PUL) Figure 10i*). Among aspects, organic carbon was highest in East (1.09%), followed by South (1.04%), North (0.90%) and West (0.86%) (Figure 10ii*).

Table 10. Soil organic carbon content (%) along altitude gradient in the differentaspects at depths 0-10cm and 10-20cm in GLORIA Target Region in Lata valley.

Aspect	Contour line (m)	Depth (cm)	KHR	SAI	DON	PUL
HSP		0-10	0.36 ± 0.01	0.79 ± 0.02	1.19 ± 0.09	1.36 ± 0.02
		10 20	0.76 ± 0.08	0.37 ± 0.01	0.90 ± 0.13	0.72 ± 0.01
North	5m	0-10	0.45 ± 0.03	0.99 ± 0.01	1.14 ± 0.09	1.17 ± 0.03
		10 20	0.75 ± 0.05	0.58 ± 0.02	0.95 ± 0.08	1.06 ± 0.03
	10m	0-10	0.99 ± 0.02	1.18 ± 0.03	0.90 ± 0.08	1.30 ± 0.02
		10 20	0.92 ± 0.06	0.69 ± 0.02	0.54 ± 0.08	0.80 ± 0.01
South	5m	0-10	1.54 ± 0.09	1.07 ± 0.03	1.44 ± 0.02	1.13 ± 0.04
		10 20	0.79 ± 0.03	0.97 ± 0.02	1.24 ± 0.03	1.00 ± 0.01
	10m	0-10	0.84 ± 0.05	0.60 ± 0.01	1.34 ± 0.02	1.21 ± 0.02
		10 20	0.73 ± 0.04	0.54 ± 0.01	1.20 ± 0.06	1.10 ± 0.02
East	5m	0-10	0.80 ± 0.02	1.16 ± 0.02	1.05 ± 0.07	1.82 ± 0.04
		10 20	0.69 ± 0.03	1.10 ± 0.01	1.10 ± 0.14	1.36 ± 0.04
	10m	0-10	1.33 ± 0.09	0.60 ± 0.02	1.04 ± 0.11	1.73 ± 0.03
		10 20	1.48 ± 0.08	0.41 ± 0.01	0.73 ± 0.15	1.00 ± 0.02
West	5m	0-10	1.46 ± 0.07	1.16 ± 0.02	1.20 ± 0.20	0.76 ± 0.01
		10 20	0.39 ± 0.03	0.34 ± 0.01	1.13 ± 0.03	0.70 ± 0.01
	10m	0-10	0.84 ± 0.05	0.80 ± 0.02	1.25 ± 0.03	0.63 ± 0.01
		10 20	0.95 ± 0.05	0.51 ± 0.01	1.05 ± 0.14	0.53 ± 0.02

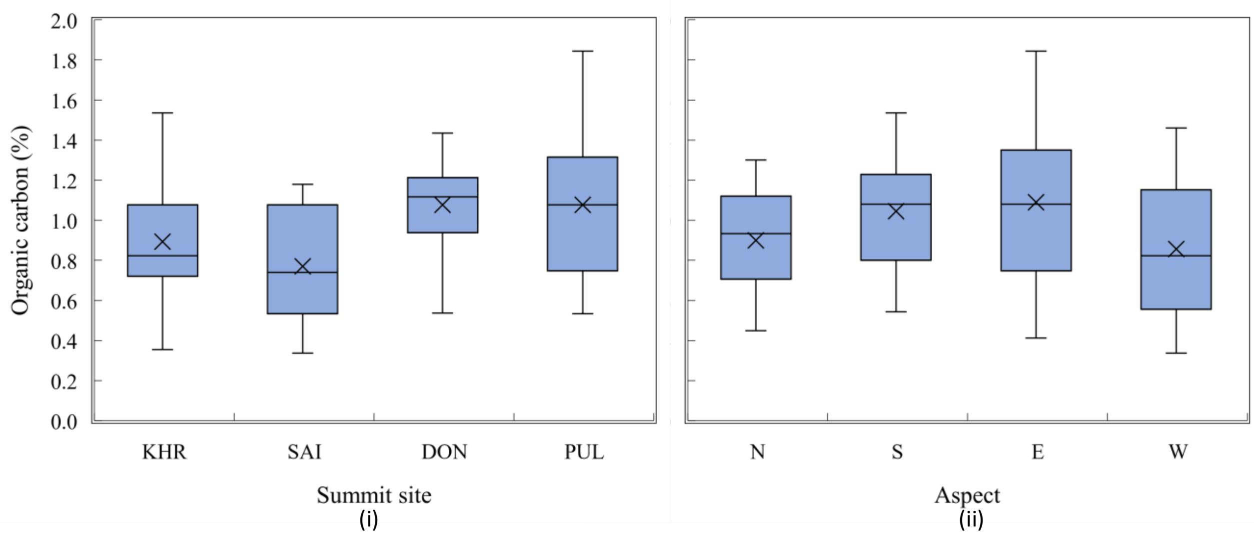


Figure 10. Soil organic carbon content (%) variation with respect to (i) Altitude and (i)Aspect in the GLORIA Target Region in Lata valley

Climatic data (temperature and precipitation) for Lata target region was taken from www.worldclim.org. Annual temperature (ºC) showed significant decreasing trend along altitude gradient ($p < 0.001$; R^2= 0.98) and annual precipitation (mm) also decreased with increasing altitude of summit sites (R^2= 0.97) (Figure 11).

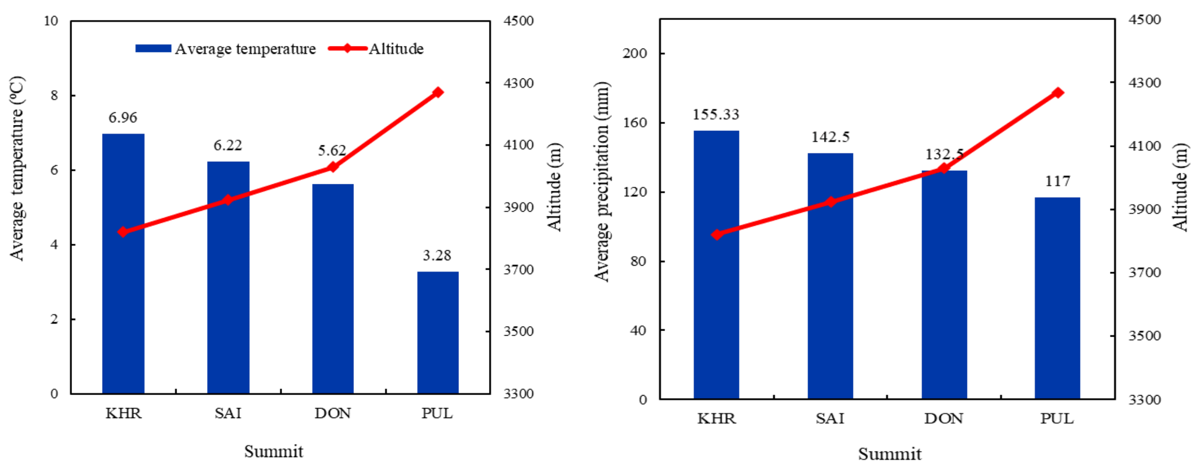


Figure 11. Spatial variation in mean annual temperature (ºC) & precipitation (mm) in Lata valley Target region.

Correlation analysis between different environmental variables (*i.e.*, climate & soil parameters) revealed that temperature exhibited significant positive correlation with precipitation & OC and negative correlation with soil moisture & pH (Table 11). Increase in temperature influences decomposition of organic matter causing increase in accumulation of acids which decrease soil pH. Furthermore, correlation analysis between species richness & the environmental variables revealed that only temperature and precipitation exhibited significant positive correlation ($p<0.01$) with floristic diversity, while it was insignificant ($p>0.01$) with soil parameters (Figure 12).

Table 12: Correlation between different environmental variables ($p<0.01$*; $p<0.001$**) in Lata valley Target region.

	Temperature	Precipitation	Moisture	Bulk density	pH	OC
Temperature	1	**	**		*	*
Precipitation	0.68	1	*	*		
Moisture	-0.78	-0.65	1			
Bulk density	-0.44	-0.60	0.33	1	*	
pH	-0.55	-0.42	0.24	0.51	1	*
OC	0.73	-0.27	0.13	0.22	0.61	1

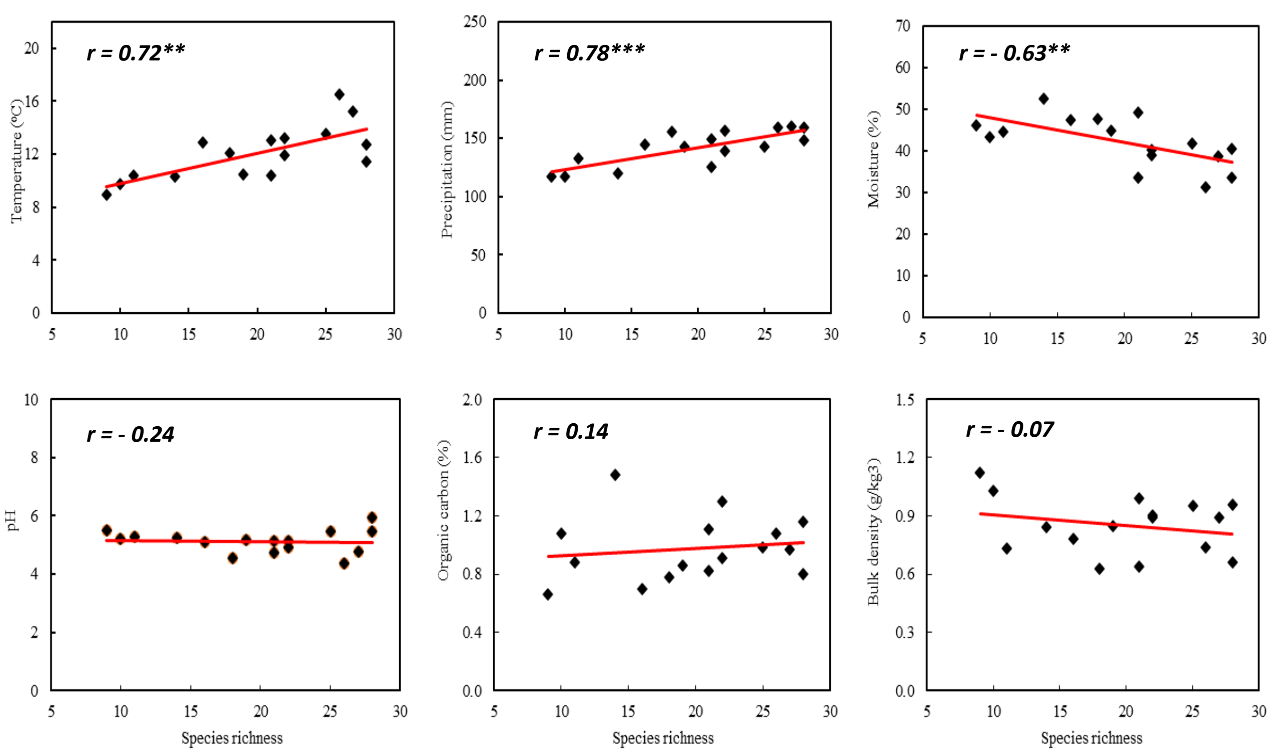


Figure 12. Correlation analysis between species richness and different environment variables in Lata valley.

- Resurvey of previously established Chaudans Valley Target Region (TR) was carried out in August 2019 after 5 years. A total of 107 vascular plants belonging to 72 genera and 35 families were documented in 64 observation plots, with a gradual decrease in species richness with increasing altitude of summits

(Table 13). The most represented families were Asteraceae and Scrophulariaceae with 14 and 12 species, respectively (Figure 13). The most abundant species overall in terms of Important Value index were were *Bistorta affinis* (19.50) and *Anaphalis contorta* (16.72) in BHT, *Geum elatum* (21.62) and *Bistorta affinis* (21.04) in KHA, *Carex setosa* (31.61) and *Hippolytia dolicophylla* (27.90) in GAN and *Bistorta vaccinifolia* (56.63) and *Kobresia nepalensis* (48.83) in SKN (Table 13).

Table 13. Vegetation composition pattern of the summit sites of GLORIA Target Region in Chaudans Valley.

Locality (Summit code)	Altitude and location	Vegetation zone (IVI)	Plant species richness
Bhairav Ghati (BHT)	3773 m Lat: 30º02.782' N Long: 80º39.122'E	Lower alpine- above treeline; *Bistorta affinis* (19.50) and *Anaphalis contorta* (16.72)	75 plant taxa (59 genera and 28 families)
Kharangdhang (KHA)	3881 m Lat: 30º02.927'N Long: 80º39.320'E	Transition between the lower and upper alpine; *Geum elatum* (21.62) and *Bistorta affinis* (21.04)	51 plant taxa (42 genera and 27 families)
Ganglakhan (GAN)	4060 m Lat: 30º03.113'N Long: 80º39.575'E	Upper alpine; the top region; *Carex setosa* (31.61) and *Hippolytia dolicophylla* (27.90)	38 plant taxa (29 genera and 18 families)
Sekhuakhan (SKN)	4266 m Lat: 30º03.783'N Long: 80º39.927'E	Transition between the upper alpine and nival; *Bistorta vaccinifolia* (56.63) and *Kobresia nepalensis* (48.83)	32 plant taxa (27 genera and 19 families)

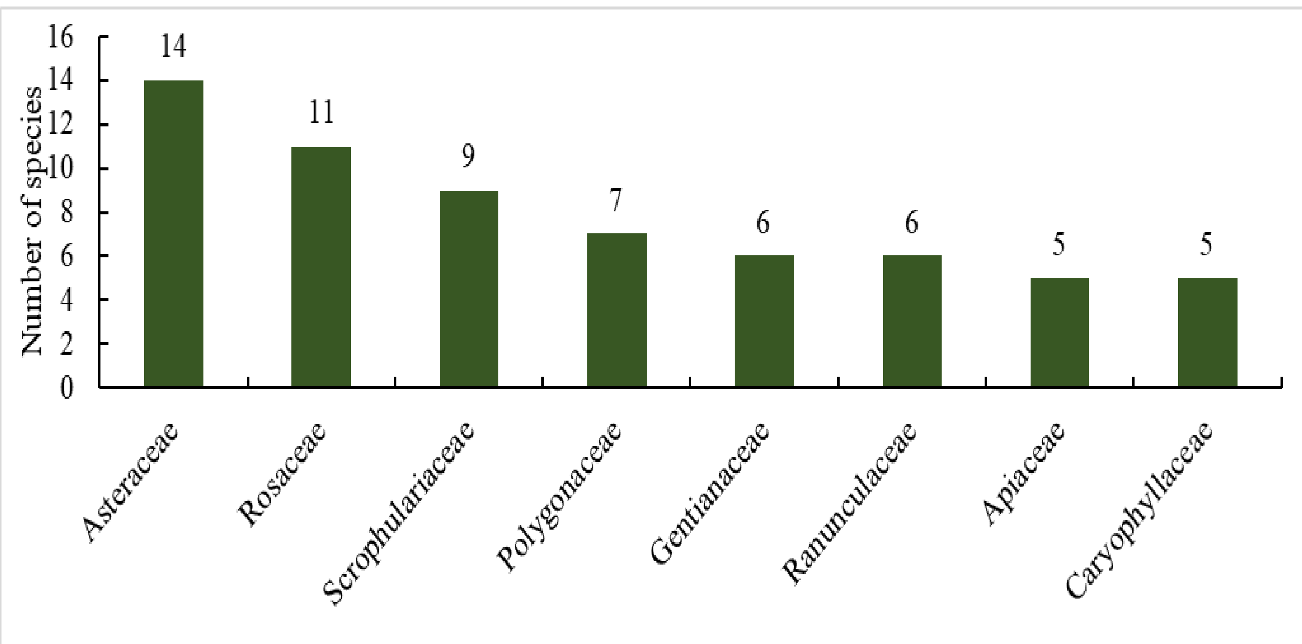
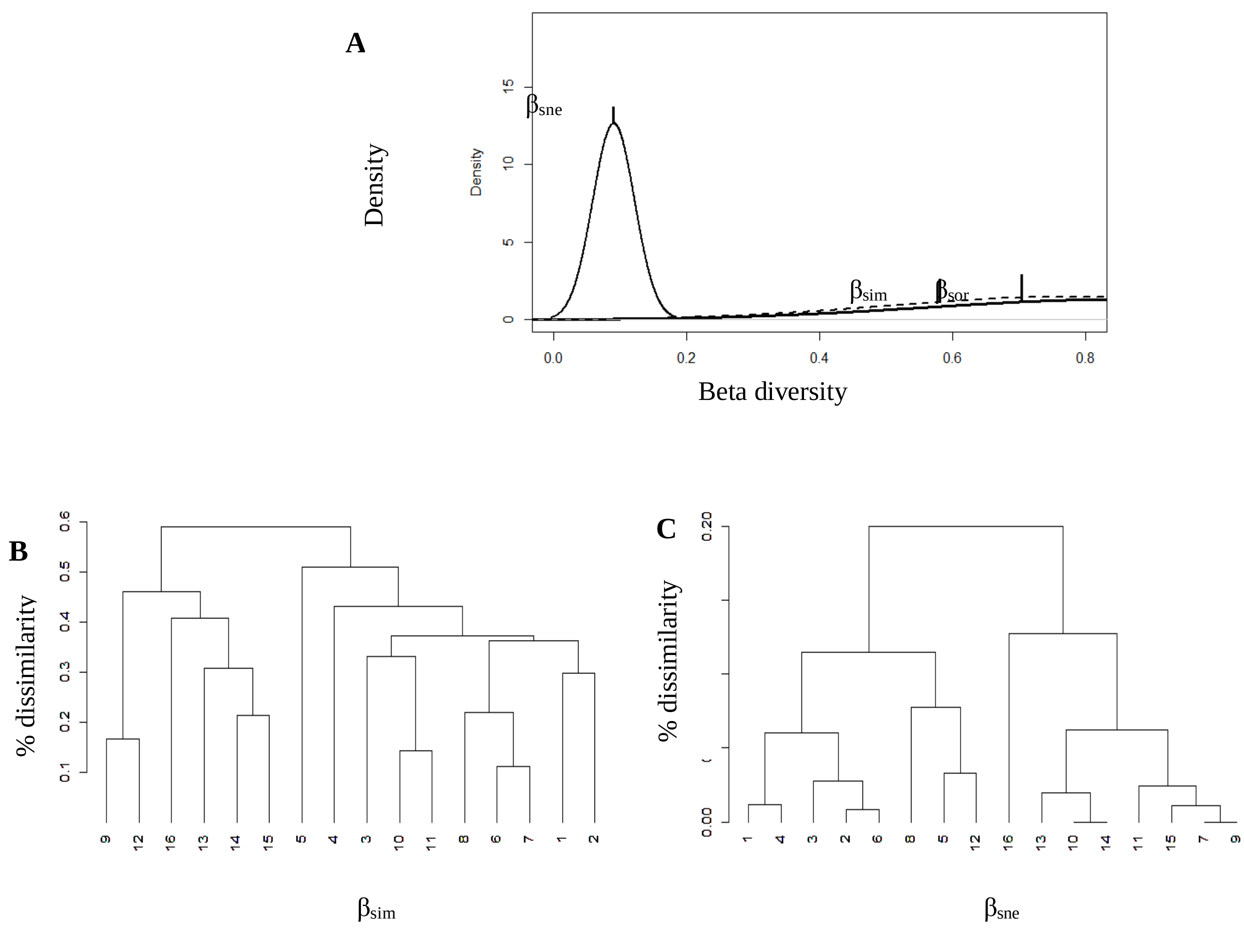


Figure 13. Plant families represented by number of plant species and genera in Chaudans valley.

Spatial patterns in beta diversity at multiple sites revealed very low Sørensen dissimilarity among all the studied summits (Figure 14). The nestedness component (β_{sne}) was found to be the largest contributor to the overall dissimilarity (Figure 14A). Cluster analysis from the dissimilarity matrices of turnover revealed that east and west aspect of BHT is highly dissimilar from rest of the aspects, followed by west aspect of SKN (Figure 14B). Cluster analysis obtained from dissimilarity matrices of nestedness showed that west aspects of KHA and GAN and north aspect of KHA are quite dissimilar from the rest of summit aspects. Also, west aspect of SKN which falls in the sub-nival zone, was highly dissimilar from the other aspects of the four summits (Figure 14C).



1-BHTN; 2-BHTS; 3-BHTE; 4-BHTW; 5-KHAN; 6-KHAS; 7-KHAE; 8-KHAW; 9-GANN; 10-GANS; 11-GANE; 12-GANW; 13-SKNN; 14-SKNS; 15-SKNE; 16-SKNW

Figure 14. Multiple-site dissimilarities across the four studied summits and four aspects north (N), south (S), east (E) and west (W) on each summit. A- Partitioning of β_{sor} (total dissimilarity) into β_{sim} (turnover) and β_{sne} (nestedness). Average clustering of C- β_{sim} and D- β_{sne} among summits and aspects.

Analysis of various physico-chemical parameters of soil was done in order to document and monitor characteristics of soil under changing climate and its influence on vegetation. In KHA and GAN soil was mainly sandy while in BHT and SKN it was a mixed proportion of sand and silt (Figure 15). The soil exhibited mild acidic nature in all the sites (Table 14).

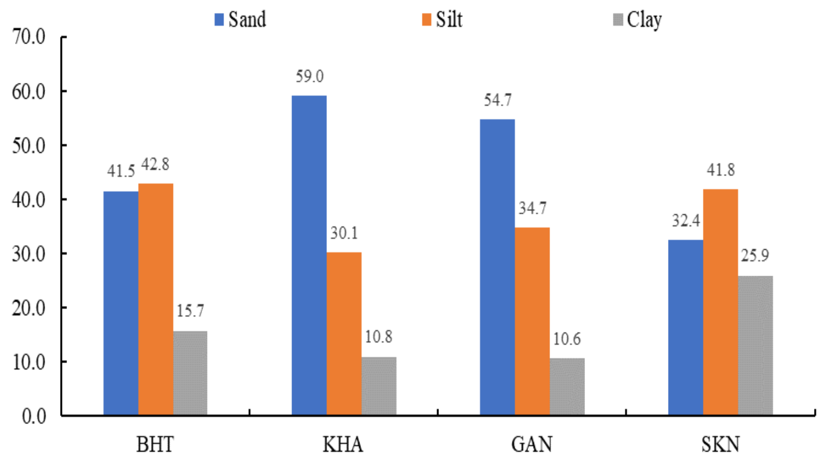


Figure 15. Texture of soil sampled from four summit sites in Chaudans valley.

Depth wise analysis revealed a decrease in moisture, organic carbon and phosphorus content, while an increase in bulk density from 0-10 cm to 10-20 cm in all summits. pH ranged from 5.58 (KHA) to 6.53 (SKN), moisture content from 31.24 % (SKN) to 36.24 % (GAN), bulk density from 0.62 gm/cm^3 (KHA) to 0.98 gm/cm^3 (BHT) (Table 14 & 15). Apart from this, organic carbon and potassium content (9.78 % and 0.66 %, respectively) was maximum in GAN, while nitrogen and phosphorus (2.20 g/kg and 9.97 ppm, respectively) was maximum in KHA (Table 15).

Table 14. Soil characteristics in four summit areas of Chaudans GLORIA Target Region.

Sites	Aspect	Depth	pH	Moisture (%)	Bulk Density
BHT	N	0-10	6.56±0.03	39.43±0.16	0.96±0.06
		10-20	6.45±0.09	34.36±1.08	1.00±0.08
	S	0-10	6.60±0.07	34.92±0.51	0.86±0.05
		10-20	5.65±0.02	23.66±0.34	1.08±0.14
	E	0-10	6.46±0.04	31.65±1.45	0.96±0.15
		10-20	5.93±0.03	29.44±1.15	1.03±0.05
	W	0-10	6.09±0.03	31.22±0.79	0.89±0.09
		10-20	6.04±0.04	30.12±1.01	0.93±0.01

KHA	N	0-10	5.19±0.04	40.69±0.76	0.67±0.16
		10-20	6.37±0.09	29.19±0.40	0.69±0.03
	S	0-10	4.41±0.08	39.86±0.45	0.55±0.12
		10-20	6.35±0.11	15.37±0.52	0.57±0.02
	E	0-10	5.24±0.15	38.73±0.47	0.61±0.07
		10-20	5.44±0.13	29.77±1.03	0.63±0.03
	W	0-10	6.80±0.06	53.53±1.11	0.59±0.11
		10-20	6.99±0.01	36.23±1.09	0.62±0.09
GAN	N	0-10	6.20±0.04	33.18±0.29	0.83±0.19
		10-20	6.33±0.18	24.35±0.28	0.84±0.08
	S	0-10	6.93±0.01	35.07±0.41	0.94±0.07
		10-20	6.61±0.17	33.97±0.12	0.97±0.12
	E	0-10	6.35±0.03	41.32±0.44	0.88±0.04
		10-20	6.86±0.04	35.31±0.38	0.88±0.08
	W	0-10	6.45±0.08	45.77±0.37	0.81±0.07
		10-20	5.83±0.02	32.88±0.22	0.89±0.02
SKN	N	0-10	6.57±0.02	37.27±0.69	0.86±0.09
		10-20	6.33±0.02	26.87±0.07	1.20±0.07
	S	0-10	6.51±0.01	42.16±0.83	0.94±0.03
		10-20	5.96±0.02	32.94±0.70	1.21±0.08
	E	0-10	6.45±0.04	45.32±0.51	0.79±0.11
		10-20	6.65±0.28	33.34±0.42	0.87±0.12
	W	0-10	6.85±0.05	40.11±0.23	0.93±0.03
		10-20	5.92±0.06	31.91±0.52	0.97±0.02

N- North; S- South; E- East; W= West.

Table 15. Chemical characteristics of soil in the four summit areas of Chaudans GLORIA Target Region.

Sites	Aspect	Depth (cm)	Organic carbon (%)	Nitrogen (gm/kg)	Phosphorus (ppm)	Potassium (%)
BHT	N	0-10	9.75±0.04	1.36±0.12	6.31±0.28	0.54±0.05
		10-20	9.13±0.04	0.46±0.11	3.59±0.96	0.35±0.05
	S	0-10	9.86±0.23	1.24±0.02	9.25±0.07	0.55±0.05
		10-20	9.68±0.04	1.23±0.05	3.60±1.32	0.54±0.07

	E	0-10	9.79±0.30	1.80±0.26	7.27±0.83	0.76±0.10
		10-20	9.62±0.38	0.92±0.44	3.17±1.06	0.48±0.13
	W	0-10	9.83±0.28	1.71±0.15	7.17±0.16	0.56±0.07
		10-20	9.36±0.08	1.38±0.11	5.43±0.97	0.59±0.06
KHA	N	0-10	9.89±0.05	2.53±0.03	18.52±0.65	0.52±0.03
		10-20	9.37±0.15	1.96±0.05	12.53±2.90	0.50±0.07
	S	0-10	9.44±0.66	2.03±0.19	7.60±0.16	0.54±0.06
		10-20	8.33±0.07	1.86±0.03	7.15±0.06	0.60±0.02
	E	0-10	9.46±0.08	2.51±0.07	9.95±0.87	0.71±0.07
		10-20	9.02±0.04	1.99±0.31	9.52±1.19	0.70±0.10
	W	0-10	9.82±0.12	2.73±0.09	10.48±0.99	0.67±0.04
		10-20	9.51±0.03	2.01±0.22	4.77±1.00	0.57±0.09
GAN	N	0-10	9.77±0.25	2.35±0.21	9.02±0.43	0.59±0.02
		10-20	9.55±0.04	1.84±0.02	6.13±0.18	0.63±0.03
	S	0-10	9.94±0.17	2.23±0.01	7.90±0.56	0.75±0.04
		10-20	9.26±0.04	1.76±0.03	7.76±1.74	0.74±0.09
	E	0-10	9.87±0.19	2.08±0.12	8.69±0.31	0.72±0.01
		10-20	9.14±0.05	1.87±0.12	5.47±1.69	0.73±0.02
	W	0-10	9.90±0.07	1.53±0.01	6.41±1.22	0.56±0.03
		10-20	9.54±0.02	1.12±0.02	5.28±1.85	0.55±0.03
SKN	N	0-10	8.91±0.07	0.24±0.04	7.88±0.91	0.57±0.03
		10-20	7.25±0.10	0.40±0.08	7.03±0.86	0.65±0.1
	S	0-10	8.11±0.13	0.54±0.36	5.58±0.09	0.39±0.11
		10-20	7.41±0.24	1.03±0.54	8.54±0.18	0.52±0.02
	E	0-10	9.63±0.10	1.08±0.16	8.58±1.29	0.56±0.03
		10-20	8.58±0.04	1.12±0.01	7.72±0.47	0.48±0.04
	W	0-10	7.33±0.12	0.66±0.41	4.64±1.12	0.36±0.12
		10-20	7.23±0.07	0.73±0.15	7.19±0.72	0.47±0.02

N- North; S- South; E- East; W= West.

Soil temperature data obtained from the soil data loggers exhibited a significant decrease in temperature with increasing altitude of summits (highest in BHT- 7.41ºC and lowest in SKN- 2.52ºC). However, among aspects east direction exhibited highest temperature (7.43ºC) while it was lowest in north (4.42ºC) (Table 16).

Table 16: Soil temperature (mean ± standard deviation) across four summits and four cardinal directions in Chaudans Target Redion depicted obtained from 2015-2019 period.

Summit code	Temperature (ºC)		
	Min	Mean	Max
BHT	0.59±4.30	7.41±4.30	13.40±5.99
KHA	-0.85±4.82	5.54±4.82	12.82±7.28
GAN	-0.29±4.85	5.93±4.85	13.63±7.70
SKN	-6.09±5.31	2.52±5.31	12.02±9.50
N	-3.28±5.43	4.42±5.43	13.09±5.43
S	0.21±4.01	6.31±4.01	12.56±4.01
E	0.88±4.31	7.43±4.31	13.35±4.31
W	-3.18±5.22	4.46±5.22	12.97±5.22

BHT- Bhairav Ghati; KHA- Kharangdhang; GAN- Ganglakhan; SKN- Sekuakhan.
N- North; S- South; E- East; W= West.

Plant species richness exhibited a significant positive correlation with mean soil temperature and organic carbon. Furthermore, there was highly significant correlation between soil temperature, potassium and organic carbon content, potassium and nitrogen content (Figure 16).

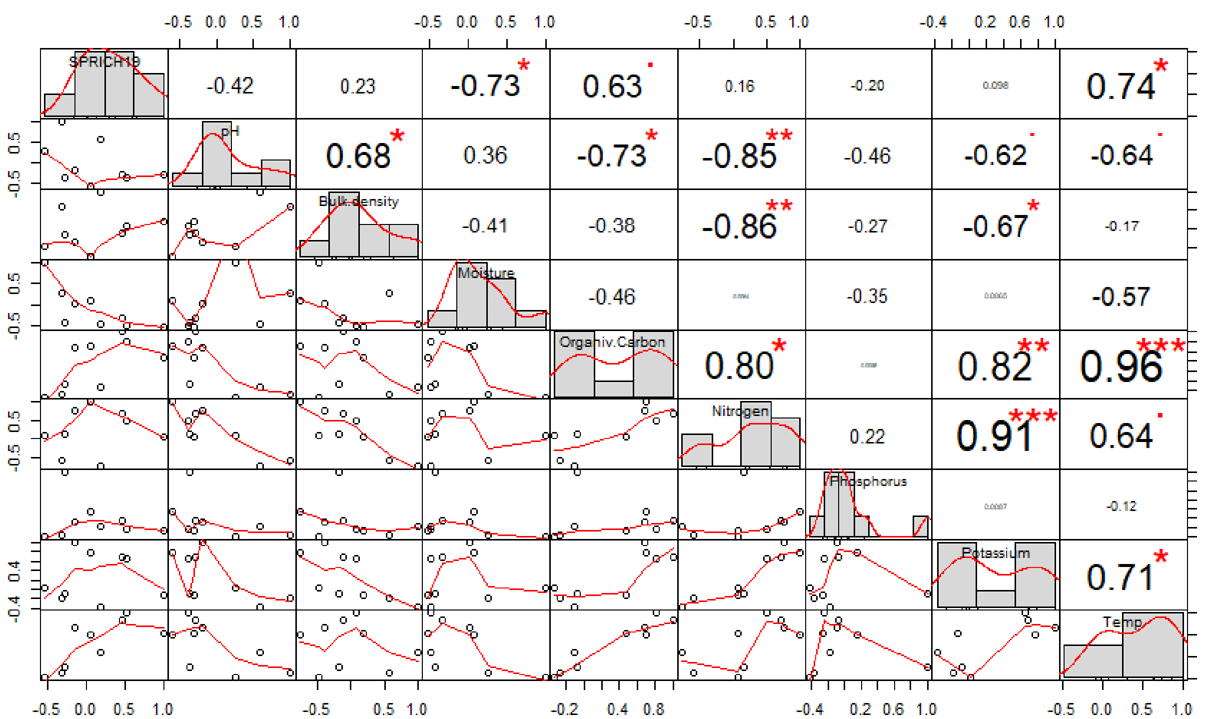


Figure 16. Pearson's Correlation between soil parameters and species richness. (Significant differences are indicated as '***'for P < 0.001, '**' P < 0.01, '*' P < 0.05, and '.' for P < 0.1

- Resurvey of previously established Byans Valley Target Region (TR) was carried out in September 2021 after 6 years. A total of 41 vascular plants belonging to 29 genera and 20 families were documented in 64 observation plots. Among these, 38 were angiosperms and only three species are gymnosperms namely *Ephedra intermedia*, *Juniperus communis* and *Juniperus indica*. Of the total summit flora, 31 were herbs, and 10 shrubs namely *Berberis jaeschkeana*, *Cassiope fastigiata*, *Ephedra intermedia, Juniperus communis, Juniperus indica, Lonicera spinosa, Potentilla arbuscula* and *Salix flabellaris* etc. The most represented families were Asteraceae (5 species), Rosaceae (5 species) and Fabaceae (4 species). Maximum species richness was found in Kuti (16) followed by Syang (12), Chaga (11) and Eurong (11) (Table 17). Analysis of various physico-chemical parameters of soil was done in order to document and monitor characteristics of soil under changing climate and its influence on vegetation (Table 18).

Table 17. Vegetation composition pattern of the summit sites in GLORIA observation site in Byans valley.

Locality (Summit code)	**Altitude & location**	**Vegetation zone**	**Plant species and dominant taxa**
Shyang (SHY)	3999 m Lat: 30°18.573' N Long: 80°45.830' E	Lower alpine; above the tree line.	12 species; *Danthonia cachemyriana* dominated
Kuti (KUT)	4038 m Lat: 30°18.336' N Long: 80°45.528' E	Transition between the lower and upper alpine.	16 species; *Danthonia cachemyriana* and *Juniperus indica* dominated
Chaga (CHA)	4062 m Lat: 30°18.615' N Long: 80°45.951' E	Upper alpine; the top region.	11 species; *Juniperus*, *Danthonia* and *Potentilla* dominated
Eurong (EUR)	4154 m Lat: 30°18.645' N Long: 80°46.165' E	Transition between upper alpine and nival.	11 species; *Danthonia cachemyriana* and *Juniperus indica* dominated

Table 18. Some physico-chemical parameters of soil in Byans valley target region.

Summit	Depth (cm)	pH	N (kg/h)	P (%)	K (%)
SHY-N	0-10	6.57	0.83	0.16	0.29
	10-20	6.59	0.37	0.11	0.24
SHY-S	0-10	6.26	0.40	0.15	0.32

	10-20	6.33	0.13	0.11	0.34
	0-10	6.26	0.27	0.13	0.29
SHY-E	10-20	6.33	0.37	0.10	0.35
	0-10	7.29	0.80	0.18	0.30
SHY-W	10-20	7.27	0.43	0.10	0.27
	0-10	5.74	0.53	0.19	0.32
KUT-N	10-20	5.96	0.10	0.10	0.28
	0-10	5.94	0.60	0.23	0.30
KUT-S	10-20	5.83	0.20	0.25	0.31
	0-10	6.29	0.63	0.24	0.30
KUT-E	10-20	6.35	0.50	0.18	0.26
	0-10	5.43	0.10	0.26	0.18
KUT-W	10-20	6.03	0.17	0.05	0.30
	0-10	5.45	0.37	0.16	0.31
CHA-N	10-20	4.98	0.10	0.03	0.20
	0-10	5.26	0.07	0.02	0.19
CHA-S	10-20	5.89	0.07	0.22	0.20
	0-10	5.08	0.13	0.26	0.25
CHA-E	10-20	5.48	0.07	0.22	0.22
	0-10	5.54	0.13	0.21	0.34
CHA-W	10-20	5.52	0.37	0.39	0.31
	0-10	5.59	0.23	0.10	0.22
EUR-N	10-20	5.97	-0.07	0.15	0.24
	0-10	5.74	-0.07	0.05	0.25
EUR-S	10-20	6.50	0.20	0.11	0.24
	0-10	7.14	0.53	0.22	0.20
EUR-E	10-20	7.04	0.57	0.17	0.25
	0-10	5.94	0.53	0.17	0.27
EUR-W	Oct-20	6.12	-0.07	0.17	0.27

Soil temperature data obtained from the soil data loggers for the period of six years exhibited significant variation among summits as well as aspects. Among all summit Kuti had the highest soil temperature (7.1ºC), followed by Chaga (6.8ºC), Shyang (6.2ºC) and Eurong (5.4ºC) (Figure 5). Correlation analysis (calculated as Pearson's correlation) exhibited a significant relation between plant diversity indices (richness & H index) with altitude (r= - 0.89* to -0.85**), air temperature (r = 0.77* to 0.90**), precipitation (r = 0.80* to 0.92**), pH (r= -0.78* to -0.89**) (Table 19).

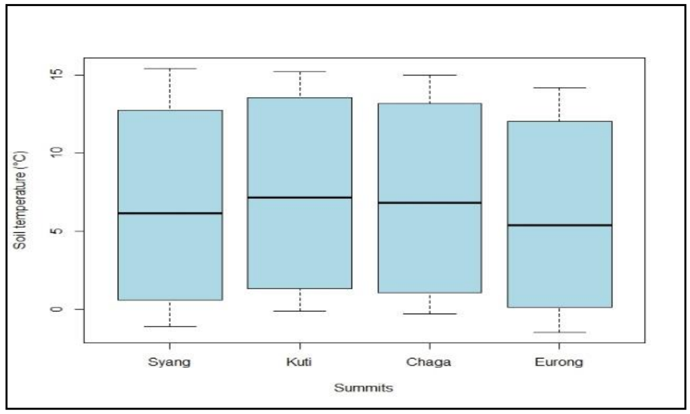


Figure 17. Spatial variability in soil temperature among summits in Byans valley observation site.

Table 19. Correlation analysis between different plant and environmental variables ($p<0.05$:*; $p<0.01$: **)

	Species richness	Diversity	Plant cover (%)
Altitude	-0.85**	-0.89**	-0.67*
Air temperature	0.77*	0.90**	0.076
Precipitation(mm)	0.80*	0.92**	0.08
Moisture (%)	0.31	0.52	0.09
pH	-0.78*	-0.89**	0.07
N (kg/h)	0.05	-0.1	0.86
P (%)	-0.29	-0.56	0.32
K (%)	-0.09	-0.16	0.75

Objective 3- To investigate the change in plant diversity patterns under the influence of climate change in different alpine sites.

- Temporal trends in soil temperature were obtained from previously installed loggers during the resurvey of the observation sites in Chaudans and Byans valley in 2019 and 2022, respectively. While in Chaudans valley soil temperature averaged across the 15 data loggers showed a significant decreasing trend over for four-year period (Linear regression, F= 0.32, df= 1, P= 0.05; August 2015 to July 2019), in Byans valley the trend was significantly increasing (Linear regression, F= 6.31, df= 1, P= 0.01; October 2015 to September 2021) (Figure 18). Overall, annual mean soil temperature of Chaudans significantly decreased by 0.82 ºC from 2014 to 2019, while in Byans it increased by 0.38 ºC from 2015 to 2021.

- Comparative analysis of species richness, diversity and cover between the surveys in 2014 and 2019 of the Chaudans target region and 2015 and 2021 of Byans target region was done. In the revisit, temporal patterns in community changes were represented by significant increase in plant cover (%) in all sites while species richness increased in KHA, GAN and SKN (Figure 19a) in Chaudans. While species richness decreased in north and west, in south it increased significantly and remained same in east. However, in Byans, there was significant (p<0.05) increase in plant cover, richness and diversity in all summits (Figure 19b).

(a) (b)

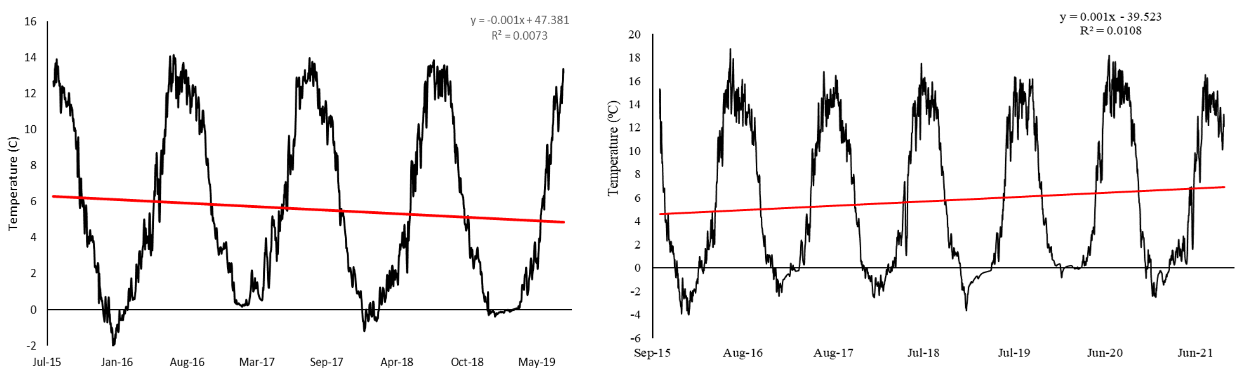
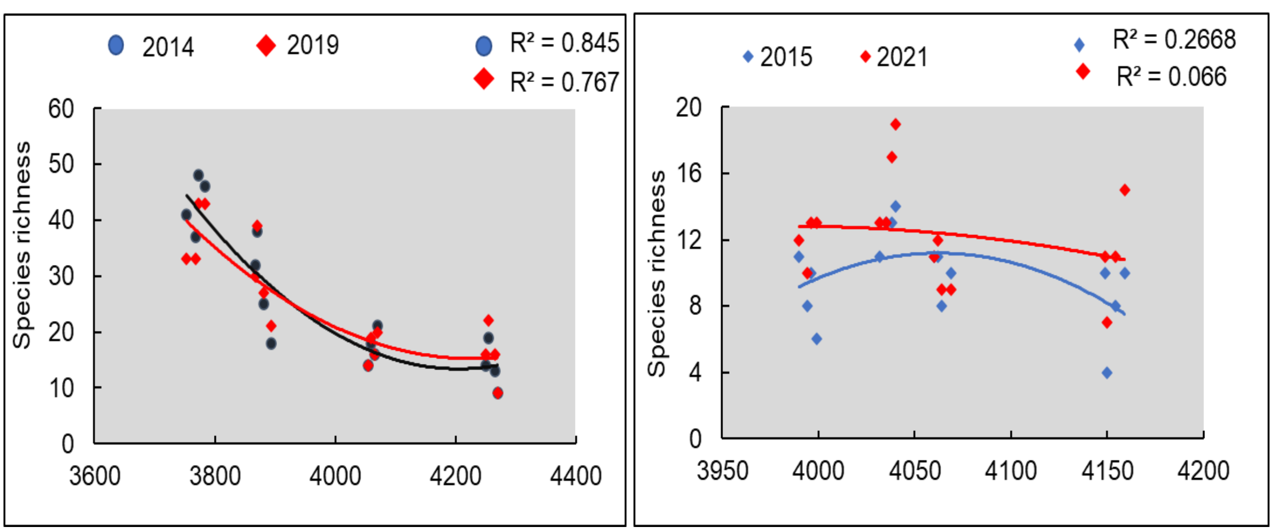


Figure 18. Soil temperature trends over years in (a) Chaudans and (b) Byans observation sites (*p<0.05*).

(a) **(b)**



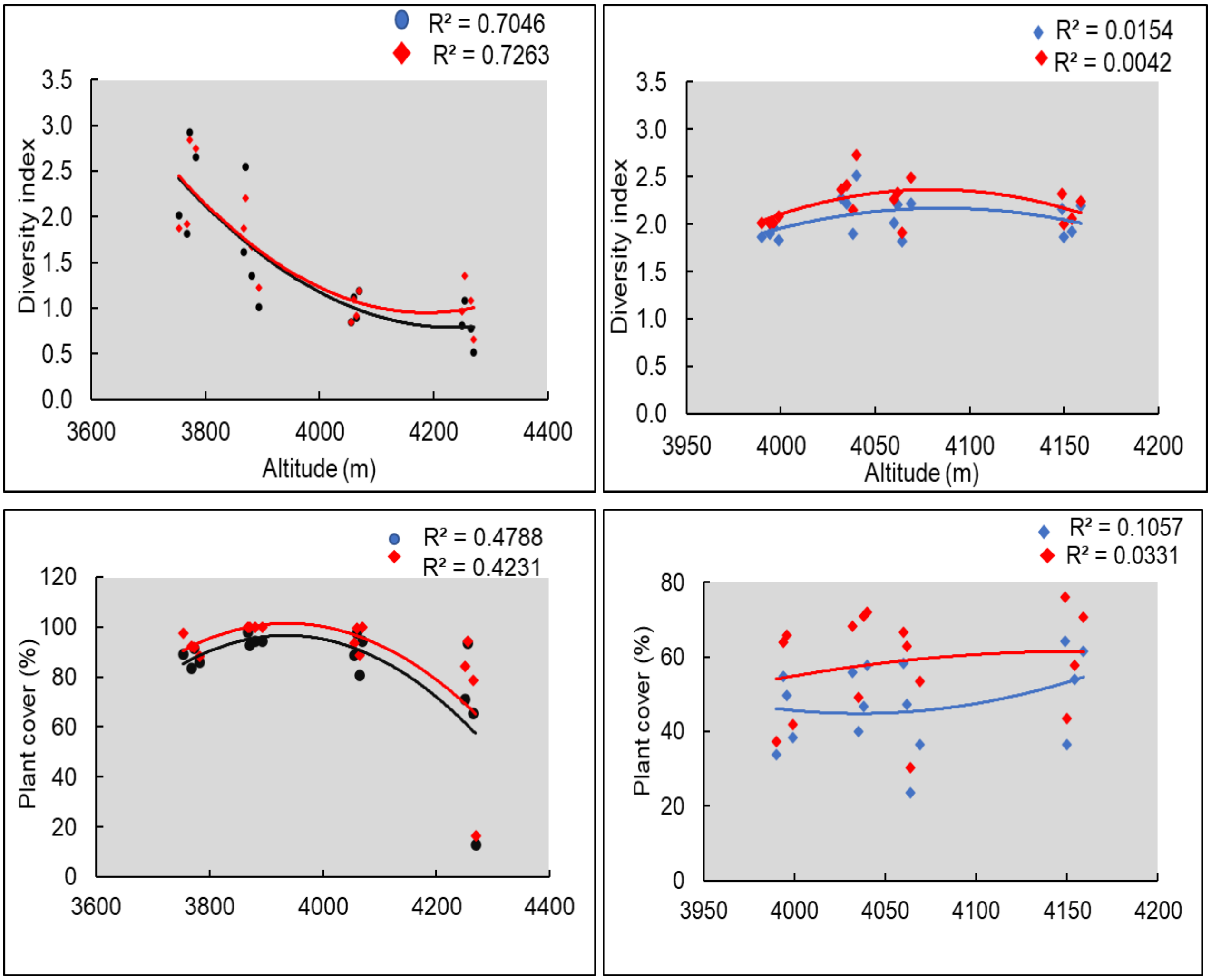


Figure 19. Temporal changes in species richness, diversity and plant cover in (a) Chaudans and (b) Byans observation sites.

Relating vegetation indices with soil temperature across the two surveys exhibited a significant positive correlation between species richness and diversity (*r* from 0.3 to 0.6, $p < 0.05$) in both valleys. However, plant cover percent showed no significant relationship with temperature trends in Byans valley, while it was positive in Chaudans (Figure 20). Thus, temporal trends in richness and diversity were related to corresponding temperature trends in both valleys, plant cover changes did not show significant relation with temperature trends in Byans valley.

Of the total 105 species, recorded in 2015 in Chaudas valley, only four species showed a significant expansion ($p < 0.05$) to new plots namely *Euphorbia stracheyi*, *Phlomis bracteosa*, *Poa alpina*, *Polygonum filicaule*, while four reduced their plot occupancy, namely *Gypsophila ceratoides*, *Kobresia nepalensis*, *Pedicularis klotzschii*, *Trachydicum roylei* (Table 20). Furthermore, a total of ten species (such as *Bistorta affinis*, *Bupleurum falcatum*, *Carex setosa*, *Poa alpina*, *Polygonum filicaule*, etc.) showed significant

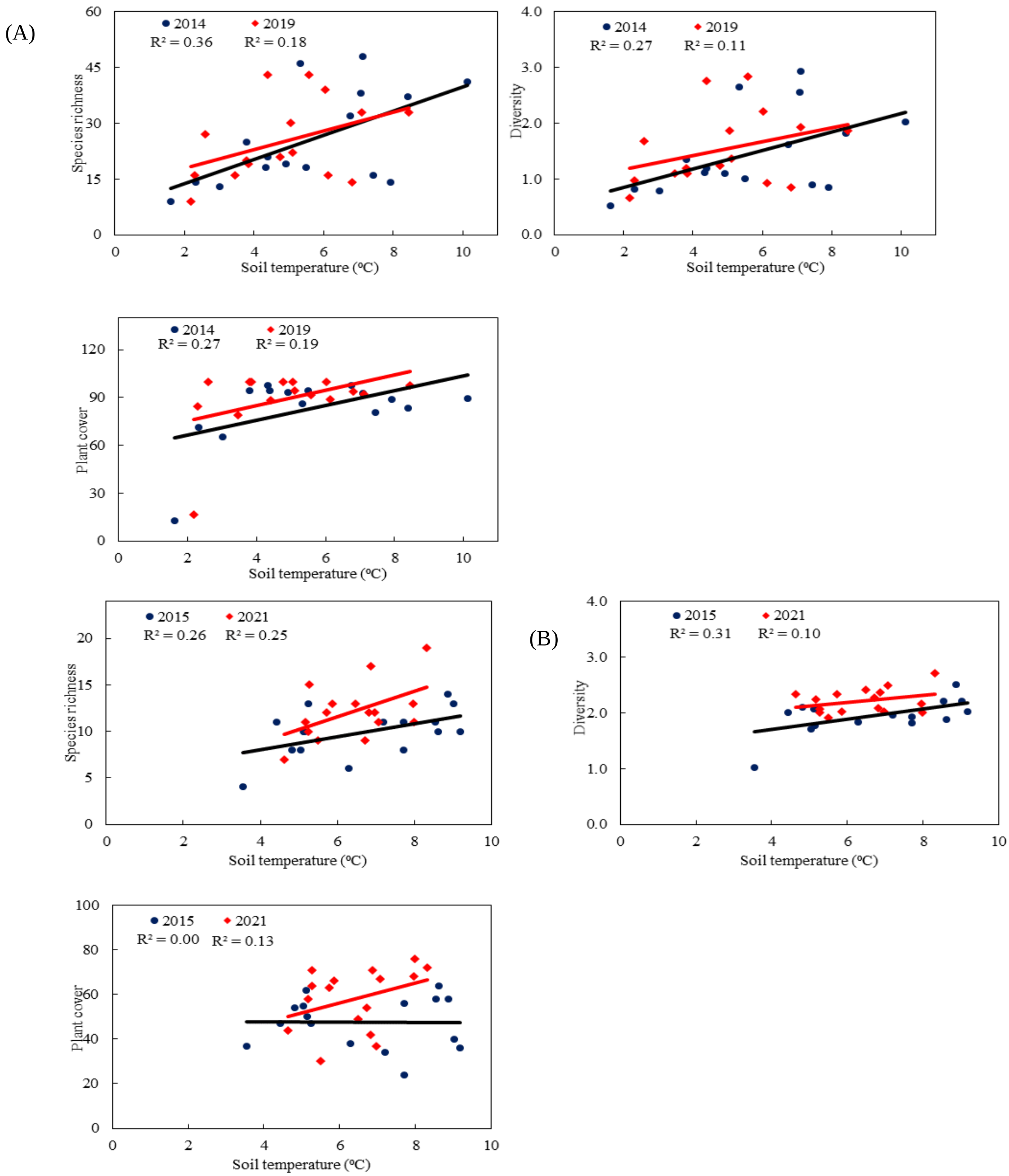


Figure 20. Correlation of species richness, diversity and plant cover in relation to mean soil temperature for baseline (S1) and resurvey (S2) in (A) Chaudans and (B) Byans valley. ***$p < 0.001$, **$p < 0.01$.

increase in their plant cover in 2019 as compared to that in 2015, while seven exhibited a significant decrease (such as *Kobresia nepalensis*, *Taraxacum officinale*, *Rumex nepalensis*, etc.) (Table 21).

Similarly, 12 species were newly recorded from observation plots in resurvey of Byans target region in 2021, such as *Anemone*, *Aconogonon*, *Aster*, *Viola*, etc. (Table 22). A total of seven species exhibited a significant increase in their cover (%) from 2015 to 2021 in observation plots in Byans (Table 22), among which the most predominant was *Danthonia cachemyriana* which increased in all the summits.

Table 20. Significant changes in species occurrences in the 1m x 1m plots in Chaudans.

Species	**Habit***	**2015**	**2019**	***p*-value**
Increased				
Euphorbia stracheyi	Perennial	26	36	<0.005
Phlomis bracteosa	Perennial	3	10	<0.05
Poa alpina	Perennial	21	31	<0.01
Polygonum filicaule	Annual	11	18	<0.01
Decreased				
Gypsophila ceratoides	Perennial	13+	2	<0.001
Kobresia nepalensis	Perennial	56	51	<0.05
Pedicularis klotzschii	Perennial	12	0	<0.001
Trachydium roylei	Annual	24	16	<0.05

α = 0.05. * = Pusalkar & Singh, 2012

Table 21. Significant changes in species cover between 2015 survey and 2019 resurvey in Chaudans.

Plant species	**Habit***	**Vegetation zone**	**Mean cover (2015)**	**Mean cover (2019)**	**Change in cover**	***p*-value**
Increased						
Anaphalis contorta	Perennial	a	2.6	5.8	0.84	<0.005
Bistorta affinis	Perennial	a-n	10.6	15.5	1.21	<0.005
Bupleurum falcatum	Perennial	sa-a	1.1	5.7	1.17	<0.0001
Carex setosa	Perennial	a	6.5	19.1	3.16	<0.005

Euphorbia stracheyi	Perennial	a	2.4	4.9	0.61	<0.0001
Parnassia kumaonica	Perennial	a	0.3	1.7	0.37	<0.05
Parnassia nubicola	Annual	a	3.6	6.1	0.63	<0.01
Poa alpina	Perennial	a-sn	2.2	6.5	1.07	<0.0001
Polygonum filicaule	Annual	a-sn	1.1	8.5	1.86	<0.0005
Viola biflora	Perennial	a-sn	5.4	8.1	0.7	<0.01
Decreased						
Corydalis cashmeriana	Perennial	a	0.3	0.5	- 0.11	<0.05
Gypsophila ceratoides	Perennial	sa-a	1.1	0.1	- 0.25	<0.005
Kobresia nepalensis	Perennial	a-sn	53.6	38.1	- 3.83	<0.0005
Ligularia arnecoides	Perennial	sa-n	1.7	0.2	- 0.36	<0.05
Pedicularis pectinata	Perennial	a	3.8	2.7	- 0.28	<0.05
Rumex nepalensis	Perennial	sa-a	7.3	3.8	- 0.85	<0.05
Taraxacum officinale	Annual	sa-a	17.0	11.1	- 1.46	<0.01

α = 0.05; sa-a = sub-alpine to alpine species; a = alpine species; a-sn = alpine to sub-nival species.

* = Pusalkar & Singh, 2012

Table 22. New species occurrences in 1m^2 x 1m^2 observation plots in Byans

Summits	**Species Name**	**2015**	**2021**
Syang	*Anemone rivularis*	-	+
	Aconogonon kuttiense	-	+
	Euphrasia himalayica	-	+
Kuti	*Trigonella emodi*	-	+
	Leontopodium sp.	-	+
	Ephedra intermedia	-	+
	Euphorbia stracheyi	-	+
Chaga	*Euphorbia stracheyi*	-	+
	Viola biflora	-	+
Eurong	*Euphorbia stracheyi*	-	+
	Viola biflora	-	+
	Aster flaccidus	-	+

Table 23. Significant changes of species cover between 2015 and 2021 in different summits in Byans valley.

	Name of Species	Change in species cover (%)	P-value
	Increased		
Summit-I	*Danthonia cachemyriana*	5.01	0.03
Summit-II	*Danthonia cachemyriana*	2.84	0.05
	Astragalus candolleanus	2.10	0.05
	Anemone sp.	4.69	0.02
Summit-III	*Danthonia cachemyriana*	1.96	0.06
	Anaphalis contorta	0.37	0.05
	Cyananthus microphyllus	2.56	0.00
	Cassiope fastigiata	1.84	0.05
Summit-IV	*Danthonia cachemyriana*	7.05	0.03
	Potentilla argyrophylla	1.63	0.02

Objective 4- To build plant assessment and taxonomic identification capacity of master's students and researchers.

1. A twelve-day hands-on training course entitled "Vegetation Assessment, Herbarium Techniques and Statistical Analysis for Long-Term Ecological Monitoring" was organized by Center for Biodiversity Conservation and Management (CBCM) in GBP-NIHE headquarter starting from 24-02-2020 to 6-03-2020 (100 hours). A total of 33 research scholars (M.Sc. and PhD.) affiliated to 9 different institutions participated in the training program. The training program was focused on four major topics: a) Vegetation assessment; b) Herbarium techniques; c) RS and GIS applications in vegetation science; and d) Statistical methods.

Details of participants of the 12-day hands-on training course entitled "Vegetation Assessment, Herbarium Techniques and Statistical Analysis for Long-Term Ecological Monitoring".

S. No.	Name	Gender	Qualification	Address	Contact No
1	Akshita Dhapola	Female	M.Sc. (Final semester)	S.S.J. Campus, Almora, KU	9410742474
2	Anchal Rani	Female	M.Sc. (Final semester)	S.S.J. Campus, Almora, KU	7300707479

3	Anjali	Female	M.Sc. (Final semester)	S.S.J. Campus, Almora, KU	9412996771
4	Anjali Tiwari	Female	M. Sc.	I.P.G.G.P.G. College of Commerce, Haldwani	8077305944
5	Ashish Kumar	Male	M.Sc.	D.S.B. Campus, Nainital, KU	9557271565
6	Baby Kanchan	Female	M.Sc. (Final semester)	S.S.J. Campus, Almora, KU	7060636400
7	Bhawna Negi	Female	M.Sc.	D.S.B. Campus, Nainital, KU	8650818748
8	Deepali Kothari	Female	M.Sc.	GBP National Institute of Himalayan Environment (GRC), Srinagar	8979969543
9	Disha Upreti	Female	M.Sc.	D.S.B. Campus, Nainital, KU	7252893287
10	Dixit Kumar Pathak	Male	M.Sc.	D.S.B. Campus, Nainital, KU	9568864827
11	Geetanjali Upadhyay	Female	M.Sc.	D.S.B. Campus, Nainital, KU	9410351431
12	Himani Verma	Female	M. Sc.	D.S.B. Campus, Nainital, KU	8126643099
13	Kanchan Puri	Female	M. Sc.	MoEF&CC, New Delhi	9871813201
14	Kavita Khatri	Female	M.Sc.	D.S.B. Campus, Nainital, KU	8954465311
15	Kusum Joshi	Female	M.Sc.	I.P.G.G.P.G. College of Commerce, Haldwani	9761651285
16	Manisha Bhandari	Female	M.Sc.	I.P.G.G.P.G. College of Commerce, Haldwani	7454885727
17	Mushtaq Ahmed	Male	M.Sc.	K.L.D.A.V.P.G. College, Roorkee, Garhwal University	7889675279
18	Neha Binwal	Female	M.Sc.	I.P.G.G.P.G. College of Commerce, Haldwani	7417839754
19	Neha Joshi	Female	M.Sc.	S.S.J. Campus, Almora, KU	7534037136
20	Neha Kohli	Female	M.Sc.	I.P.G.G.P.G. College of Commerce, Haldwani	7456977479
21	Pooja Joshi	Female	M.Sc.	I.P.G.G.P.G. College of Commerce, Haldwani	9410565925
22	Pooja Mehta	Female	M.Sc.	GBP National Institute of Himalayan Environment, Kosi	8954719492
23	Pooranima Rani	Female	M.Sc. (Final semester)	S.S.J. Campus, Almora, KU	7830210044
24	Prabha	Female	M.Sc.	D.S.B. Campus, Nainital, KU	8937039492
25	Pratima Kumari	Female	M.Sc.	Central University of Gujrat, Gandhinagar	8092398395

26	Rashika Mehta	Female	M.Sc. (Final semester)	S.S.J. Campus, Almora, KU	7351225302
27	Sapana Pant	Female	M.Sc.	I.P.G.G.P.G. College of Commerce, Haldwani	6396720136
28	Seema Bala	Female	M.Sc. (Final semester)	S.S.J. Campus, Almora, KU	8476896383
29	Shradha Misra	Female	M.Sc.	I.P.G.G.P.G. College of Commerce, Haldwani	7060073939
30	Sunil Joshi	Male	M.Sc.	GBP National Institute of Himalayan Environment, Kosi	9675442890
31	Tanuja Bahuguna	Female	M.Sc. (Final semester)	S.S.J. Campus, Almora, KU	7055054974
32	Vinay Rawat	Male	M.Sc.	HNB Garhwal University, Srinagar	7500357703
33	Zishan Ahmad Wani	Male	M.Sc.	Baba Ghulam Shah Badshah University, Rajouri, J&K	9149493267

2. G.B. Pant National Institute of Himalayan Environment (NIHE), Kosi-Katarmal, Almora, in collaboration with the Department of Botany, Soban Singh Jeena University, Almora and financial assistance of the National Mission on Himalayan Studies (NMHS) organized a three-day field-oriented training course entitled "Plant Taxonomy, Vegetation Assessment and Statistical Analysis" from 25-March-2021 to 27-March-2021. A total of 83 participants (M.Sc./Ph.D. scholars) from the SSJ campus attended the training programme. Major domains covered in the training course included: a) Plant taxonomy: Classification, identification and cataloguing; b) Plant ecology: Methods of field surveys, data collection, analysis and interpretation in ecology and vegetation science; c) Plant conservation approaches, nursery management and plantation techniques; d) Statistical application in the field of plant sciences and ecology.

Details of participants of the 3-day training course entitled "Plant Taxonomy, Vegetation Assessment and Statistical Analysis".

S. No.	**Name of the participant**	**Designation**	**Contact no.**	**Adhaar no.**
1.	Pankaj Singh Bisht	M.Sc. (III)	7895671044	
2.	Jugmohan Singh Bisht	M.Sc. (III)	8192973561	
3.	Deep Chandra Baswal	M.Sc. (III)	7248267288	
4.	Chanchal Singh Thakardwara	M.Sc. (III)	7900506321	
5.	Babita Pandey	M.Sc. (III)	8954473707	
6.	Ruhita	M.Sc. (III)	9411105800	

7.	Bhawana Khati	M.Sc. (III)	7456973030	
8.	Radha Arya	M.Sc. (III)	7055160534	
9.	Dolly Bisht	M.Sc. (III)	7351498568	
10.	Namrata Papnai	M.Sc. (III)	8279978792	
11.	Pranjali Pandey	M.Sc. (III)	8171014012	
12.	Pooja Negi	M.Sc. (III)	9756484978	
13.	Beena Balodi	M.Sc. (III)	7251832720	
14.	Mukesh Joshi	M.Sc. (III)	9720355987	
15.	Pooja	M.Sc. (III)	7088486667	
16.	Renu Sharma	M.Sc. (III)	7252914469	
17.	Saumya Joshi	M.Sc. (III)	8534091757	
18.	Mamta Kanwal	M.Sc. (III)	9411369450	
19.	Hema Bisht	M.Sc. (III)	8006152513	
20.	Tanuja Sah	M.Sc. (III)	8006269317	
21.	Rashmi Negi	M.Sc. (III)	7251052522	
22.	Anjali Manral	M.Sc. (III)	8650734144	
23.	Meenakshi Kanwal	M.Sc. (III)	9634830471	
24.	Laxman Giri	M.Sc. (I)	7451973250	
25.	Hitesh Pandey	M.Sc. (I)	8650834100	
26.	Neha Bisht	M.Sc. (III)	9568209829	
27.	Saloni Panchpal	M.Sc. (I)	9917632117	
28.	Himani Tiwari	M.Sc. (I)	8171968456	
29.	Neha Giri	M.Sc. (I)	9634072138	
30.	Mamata Pandey	M.Sc. (I)	7409040457	
31.	Jyoti Joshi	M.Sc. (I)	8445472132	
32.	Diksha Tewari	M.Sc. (I)	7252899441	
33.	Priyanka Matela	M.Sc. (I)	6398554419	
34.	Sapna Parihar	M.Sc. (I)	9084510958	
35.	Nidhi Joshi	M.Sc. (I)	8393964350	
36.	Prema Shahi	M.Sc. (I)	7060121338	
37.	Jyoti Lohani	M.Sc. (I)	9105539348	
38.	Jigyasa Upadhyay	M.Sc. (I)	7500946187	
39.	Priyanka Bala	M.Sc. (I)	9068205557	

40.	Ruchika Bisht	M.Sc. (I)	6397722981	
41.	Sapna Mehta	M.Sc. (I)	7248191615	
42.	Manish Mamgai	M.Sc. (I)	8395851763	
43.	Babita Pandey	M.Sc. (I)	9720141125	
44.	Pooja Joshi	M.Sc. (I)	9084487898	
45.	Babita Bora	M.Sc. (I)	7617739468	
46.	Salochana	M.Sc. (I)	7534940286	
47.	Usha	M.Sc. (I)	7500659508	
48.	Ritakshi Manral	M.Sc. (I)	8650486121	
49.	Priyanka Pandey	M.Sc. (I)	9012342884	
50.	Yamini Joshi	M.Sc. (I)	8193092294	
51.	Pooja Ray	M.Sc. (I)	7037154851	
52.	Yogesh Upreti	M.Sc. (III)	7409998913	
53.	Kritika Rani	M.Sc. (I)	8859054849	
54.	Pooja Bhandari	M.Sc. (I)	9837993320	
55.	Muskan Parveen	M.Sc. (I)	8979165176	
56.	Pankaja Pandey	PhD Scholar	9027636621	
57.	Priyanka Joshi	PhD Scholar	9760581769	
58.	Pooja Negi	PhD Scholar	7078826398	
59.	Bhawna Pandey	PhD Scholar	9675951231	
60.	Paras Negi	PhD Scholar	7830594042	
61.	Anubha Mehra	PhD Scholar	9456557378	
62.	Kalpana Rawat	PhD Scholar	9540763867	
63.	Naveen Singh	PhD Scholar	7060635893	
64.	Madhumita Bisht	PhD Scholar	7302207472	
65.	Neeraj Ram	PhD Scholar	8477905963	
66.	Tanuja Joshi	PhD Scholar	7536871337	
67.	Supriya	PhD Scholar	9456129982	
68.	Paras Negi	PhD Scholar	7830594042	
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76.	Paras Negi	PhD Scholar	7830594042	
77.	Anubha Mehra	PhD Scholar	9456557378	
78.	Neha Thapliyal	PhD Scholar	9568210078	
79.	Charu Pundir	Junior Project Fellow	9650304940	
80.	Akshita Dhapola	PhD Scholar	9410742474	
81.	Mrs. Zoya Shah	PhD scholar	9012019003	
82.	Dr. Kapil Bisht	Research Associate	9627694404	
83.	Mrs. Poonam Mehta	PhD scholar	9557766417	

4.1 Establishing New Database/Appending new data over the Baseline Data: Several studied sites were explored for vegetation data on ecological perspectives. This baseline information will provide primary database for further long-term monitoring of the alpine sites in order to assess their dynamics under the climate change scenario. Database on floristic diversity patterns along altitude gradients in the alpine regions of Darma and Byans valley of Pithoragarh district, Uttarakhand west Himalaya was compiled. In Darma valley, a total of 286 taxa (283 species and 3 varieties) belonging to 161 genera and 55 families were documented. In Byans valley, a total of 371 taxa (364 species and 7 varieties) belonging to 197 genera and 63 families inhabited the alpine zone. In both alpine landscapes, the plant species richness exhibited an apparent decrease with increasing altitude, with highest number of taxa in lower altitudes. 15 plant species were documented as threatened as per IUCN, and 53 species were recorded in usage by local people for the treatment of various ailments. This documentation is a significant addition to the population status of threatened plants in Indian Himalayan Region. The information on threatened and medicinal plants can be used by conservation policy makers for prioritization of species at higher risk of extinction and regulation sustainable extraction of valuable plants. Studied sites were explored for soil properties for the first time. This baseline database will provide primary datasets to investigate the relationship between vegetation composition and soil parameters as well as for long-term monitoring of the alpine sites in order to assess their dynamics under the climate change scenario.

4.2 Generating Model Predictions for different variables-NIL

4.3 Technological Intervention-NIL

4.4 On field Demonstration and Value-addition of Products- NIL

4.5 Promoting Entrepreneurship in IHR-NIL

4.6 Developing Green Skills in IHR- A twelve-day hands-on training course entitled "Vegetation Assessment, Herbarium Techniques and Statistical Analysis for Long-Term Ecological Monitoring" was organized by Center for Biodiversity Conservation and Management (CBCM) in GBP-NIHE headquarter starting from 24-02-2020 to 6-03-2020 (100 hours). A total of 33 research scholars (M.Sc. and PhD.) affiliated to 9 different institutions participated in the training program. The training program was focused on four major topics: a) Vegetation assessment; b) Herbarium techniques; c) RS and GIS applications in vegetation science; and d) Statistical methods.

A three-day field-oriented training course entitled "Plant Taxonomy, Vegetation Assessment and Statistical Analysis" from 25-March-2021 to 27-March-2021. A total of 83 participants (M.Sc./Ph.D. scholars) from the SSJ campus attended the training programme. Major domains covered in the training course included: a) Plant taxonomy: Classification, identification and cataloguing; b) Plant ecology: Methods of field surveys, data collection, analysis and interpretation in ecology and vegetation science; c) Plant conservation approaches, nursery management and plantation techniques; d) Statistical application in the field of plant sciences and ecology.

4.7 Addressing Cross-cutting Issues: Under the current global climate warming scenario, mountain ecosystems are experiencing some of the highest rates of warming, which may lead to degradation of their biodiversity. Numerous reports of species redistribution towards summits, and warming-induced range shifts of species suggest that mountain biota are highly sensitive to increasing temperatures. However, such corroborations are lesser known for the Himalayas, the youngest globally recognized biodiversity hotspot. Hence, to address the issue of climate warming and its impact on plant diversity in Himalaya the present project was designed as per standard protocols to generate globally comparable datasets.

5. PROJECT'S IMPACTS IN IHR

5.1 Socio-Economic Development- NIL

5.2 Scientific Management of Natural Resources In IHR-NIL

5.3 Conservation of Biodiversity in IHR: The present study empirically explored the vegetation dynamics on alpine mountain summits in Uttarakhand Himalaya in order to fill the knowledge gaps that stem from the limited research data on warming-induced biodiversity changes in rapidly warming Himalaya. Further, the study provides long-term climate data of the region compatible and comparable with global climate datasets in terms of instrumentation and methodology. Although an increase in species richness might sound positive as species enrichment, it is an equally alarming signal because as new thermophilic species become established at higher summits, local species extinctions will likely result from competitive displacement of cold climate specialists by potentially more vigorous lower elevation generalists that benefit from warming, rather than from habitat loss directly through warming. Therefore, increase in species richness is expected to be a transient phenomenon that hides the accumulation of extinction debt. This not only gives way for policy makers to consider climate warming as a threat.

5.4 Protection of Environment: NIL

5.5 Developing Mountain Infrastructures: NIL

5.6 Strengthening Networking in IHR: Mountain ecosystems are regarded as important biodiversity hotspots as well as one of the most ecologically fragile zones. Among the many mountain ecosystems of the world, Himalaya is the youngest globally recognized biodiversity hotspot embracing a rich and complex diversity and ecological peculiarities. However, under the changing climate scenario especially in the last three decades, the region has become a focal point for ecologists, environmentalists and natural resource managers from research as well as conservation point of view. A report of the Intergovernmental Panel on Climate Change (IPCC) described the Himalayan Region as data deficient in terms of climate monitoring. Apart from this, there is lack of standard methodology as well as basic and comparable climate data sets over a long period of time.

6. **EXIT STRATEGY AND SUSTAINABILITY**

6.1 **How effectively the project findings could be utilized for the sustainable development of IHR:** The present study empirically explored the vegetation dynamics on alpine mountain summits in Uttarakhand Himalaya in order to fill the knowledge gaps that stem from the limited research data on warming-induced biodiversity changes in rapidly warming Himalaya. Further, the study provides long-term climate data of the region compatible and comparable with global climate datasets in terms of instrumentation and methodology. Although an increase in species richness might sound positive as species enrichment, it is an equally alarming signal because as new thermophilic species become established at higher summits, local species extinctions will likely result from competitive displacement of cold climate specialists by potentially more vigorous lower elevation generalists that benefit from warming, rather than from habitat loss directly through warming. Therefore, increase in species richness is expected to be a transient phenomenon that hides the accumulation of extinction debt.

6.2 Efficient ways to replicate the outcomes of the project in other parts of IHR: The current biodiversity change in the alpine summits in Himalayan Mountain ecosystems can have rapid and widespread consequences for ecosystem functioning, which merits detailed investigation in near future.

The novel research insights will provide crucial baseline data to undertake qualitative/quantitative analyses of vegetation-climate dynamics in the Himalaya. More importantly, re-sampling of the summits in near future will furnish robust results on the impacts of climate change on alpine plant diversity in this ecologically fragile Himalayan region.

6.3 Identify other important areas not covered under this study needs further attention: While the present study assess the impacts of soil temperature trends on the diversity and vegetation composition of alpine plant communities, dynamics of phenological characteristics of plant species (flowering/fruiting time period) is an important aspect while assessing responses of plant species to climate change.

6.4 Major recommendations for sustaining the outcome of the projects in future: We suggest that the observed trend in plant community dynamics responds to short term temperature and precipitation variability and time lags in plant community response. It may take much longer than one decade for the observed trends to become stable and statistically significant. While the study provides an important foundation of documenting profound changes in alpine plant communities under global climate change, continuous monitoring is suggested for important policy making. The suggestions and recommendations could be used by the government officials by taking feedback from the experts and the local people. Some collaborative efforts of scientific institutions and government officials could make a strong hypothesis for the conservation and management of natural resources. It would be helpful for the policy making.

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