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WORKING PAPER

Harmonizing the vegetation classification of Kailash Sacred Landscape

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Executive summary

Data on the distribution and extent of vegetation and land cover types is important for the planning and management of natural ecosystems. In this study, we developed a harmonized vegetation classification scheme and applied it to the preparation of a vegetation map of Kailash Sacred Landscape using satellite data, field data, and inputs from experts and partner institutions in China, India, and Nepal. We also assessed the accuracy of the vegetation map, which was found to be more than 80%, to ensure its usability for other studies. The vegetation map provides information on the geographic extent, area coverage, and species composition of 14 vegetation and six land use/land cover types. The findings from our study could be used to enhance decision making for ecosystem management in the landscape. In addition, the methods used in our study are dynamic and could be easily applied to other landscapes in the Hindu Kush Himalayan region.

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SECTION I

Introduction

The Hindu Kush Himalayan (HKH) region extends over 4.2 million km^2 and covers, wholly or partly, eight countries namely, Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan (Bajracharya and Shrestha, 2011). The region contains 10 of Asia's largest river systems, which provide water and ecosystem services to the more than 240 million people living in mountain areas, as well as nearly 1.9 billion people downstream (Molden and Sharma, 2013). The HKH includes four out of 36 global biodiversity hotspots, and is home to more than 200 species of animals and 35,000 species of plants (Xu et al., 2019). The region exhibits quite a distinct range of high mountains and diverse micro-climatic habitats that lead to varied ecological gradients, which support species evolution. Owing to this, this mountain biome is home to one of the most ecologically unique and diverse ecosystems in the world (Xu et al., 2019).

The rural population of the HKH is highly dependent on natural ecosystems. The region's biodiversity has long been threatened by anthropogenic drivers such as over-extraction of forest resources and land use and land cover dynamics. In recent times, the region has been exposed to drivers that pose direct threats to the ecosystems, which include climatic change and unsustainable development. In such a scenario, mapping and monitoring of ecosystems can support and enhance decision making related to planning and management of natural ecosystems.

Various studies in recent years have focused on mapping and monitoring of vegetation in the HKH regional member countries. Some of the studies were national level efforts such as Roy et al. (2015), FRA-Nepal, and China 1: 1000000 scale vegetation mapping. Others were carried out on a smaller scale, focusing on specific administrative units, e.g., a district, state or province. However, natural ecosystems do not follow administrative boundaries and they can span across different states and countries. Transboundary cooperation plays a crucial role in ensuring effective conservation of ecosystems that span across adjoining countries. This is one of the main objectives of ICIMOD's Regional Programme on Transboundary Landscapes.

The Transboundary Landscapes Programme hosts five initiatives viz., 1) Kailash Sacred Landscape, 2) Kanchenjunga Landscape, 3) Hi-Life Landscape, 4) Hindu-Kush Karakoram Pamir (HKPL) Landscape, and 5) REDD+. These initiatives bring together different countries in the HKH region to work together for natural resource management, ecosystem conservation, and livelihoods development. The Kailash Sacred Landscape (KSL) is a transboundary conservation landscape comprising parts of China, India and Nepal (Zomer et al., 2013). The landscape spans over 31,000 km^2 and accommodates highly diverse terrain including high and remote mountains, the most notable being the sacred Mount Kailash. It is endowed with diverse ecosystems with high levels of natural and agricultural biodiversity. These ecosystems directly provide important ecosystem services to the large population of the KSL and indirectly to the millions more living downstream (Zomer and Oli, 2011; Eriksson et al., 2009). We could find only a few studies that shed light on the impacts of changing climate on the vegetation of Kailash Sacred Landscape (Zomer et al., 2013, 2014). There haven't been any studies that identify and describe the vegetation composition of the landscape. Such studies could greatly support decision making related to conservation of ecosystems of the landscape.

This requires bringing together researchers, practitioners and policy makers to understand the common issues across the landscape while harmonizing the nomenclature and schema of vegetation classes to map the vegetation. In the present study, we attempted to map the vegetation of Kailash Sacred Landscape using a harmonized vegetation classification scheme suited to the whole landscape. The study is an excellent example of how transboundary cooperation can help address issues of ecosystem management.

1.1 Objectives

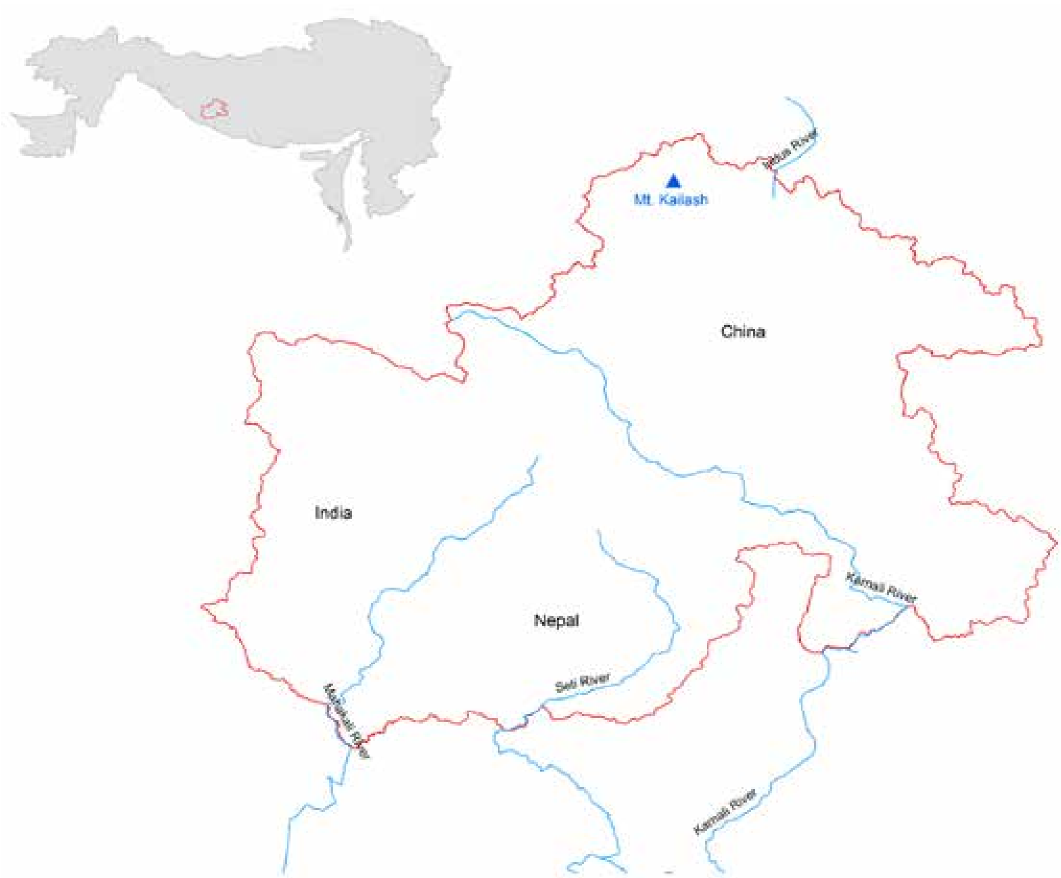
The main objectives of the study are as follows:

1) Assess and report the vegetation composition in different vegetation types in Kailash Sacred Landscape
2) Develop the vegetation classification scheme for parts of the three countries based on existing literature and experts' knowledge from each country
3) Harmonize the vegetation classification and the map for the whole landscape through consultation with national and local experts in the field

1.2 Why is mapping vegetation important?

Vegetation forms the main component of any natural landscape. It can serve as an indicator of the effects of changes in environmental conditions. Data and information on natural ecosystems are key input in structural and functional characterization of the landscape (Roy et al., 2015). Identifying and classifying vegetation communities is important for managing natural resources (Xiao et al., 2004). Effective mapping and classification of various natural vegetation types has also become crucial for planning and management of natural ecosystems (Leverington et al., 2010) and sustainable development (Foody, 2003) at a regional and global scale (De Groot et al., 2010). In addition, mapping of vegetation types helps us understand the distribution of natural and semi-natural landscapes as mapping entails measuring vegetation at various geographic scales (Roy et al., 2015). This information on distribution patterns could be key in decision making and planning at sub-national, national, and regional scales for effective sustainable natural resource management (Roy et al., 2012).

LOCATION MAP OF THE KAILASH SACRED LANDSCAPE



Vegetation mapping in inaccessible and remote mountainous terrain of the Himalaya has always been a great challenge to forest and natural resource managers. During the last few decades, scientists have explored the possibility of using geospatial technology such as remote sensing (RS) and geographic information systems (GIS) for the assessment of vegetation distribution and occurrence of resources on a large scale with minimum ground data, time and cost. Satellite remote sensing, due to its synoptic coverage, provides a cost-effective and time-saving option for mapping and monitoring vegetation over a continuous time scale (Navalgund et al., 2007).

Various vegetation and land cover classification schemes exist around the world; however only a few meet international standards and are widely accepted. Harmonization of vegetation classification schemes is important as it is the first step towards preparation of reliable data and information on vegetation distribution. During the past two decades, researchers have focused on harmonization of different vegetation and land cover classification schemes (Fritz et al., 2003). Standardization and harmonization of vegetation and land cover classification schemes aids the efforts to combine already existing heterogeneous land cover datasets to support data analysis at a global scale. It may introduce several challenges resulting from inconsistencies in terminology, semantic content and cartographic factors. Maintaining consistency among vegetation types is crucial while conducting land cover assessment and monitoring. This paper presents the detailed methodology and approach used for mapping the vegetation and land cover of KSL, and describes our efforts to build transboundary collaboration.

SECTION II

Methodology

2.1 Classification approach and criteria

The approach and criteria used to harmonize the vegetation classification in KSL were as follows:

- Classify existing vegetation and land cover at a broader scale using the satellite data, based on the floristic composition and vegetation structure, documented at a specific time and location, preferably during the growing season.
- Design and develop a scientific, standardized classification system with practical use for planning and management of natural ecosystems for each country in the landscape.
- Follow the basic criteria for the types based on ecologically meaningful relationships to organize the vegetation into different types and levels.
- Describe types based on field data and country specific dominant class using authentic data wherever possible.
- Harmonize the classification for the whole landscape covering parts of all three countries, through expert consultations and a structured peer review process. The classification standard shall be dynamic, allowing for refinement as additional information becomes available.
- Refine the satellite data based vegetation map using the harmonized classification scheme.
- Field validation and accuracy assessment need to be conducted and documented.

2.2 Conceptual framework

Mapping vegetation and land cover is a method of demarcating the distribution, extent and patterns of a landscape, depicting the types of vegetation and structural characteristics. For consistent mapping of vegetation and land cover types it is imperative to follow a classification scheme that covers all types of vegetation and land cover (Tart et al., 2005a). Mapping and field validation of vegetation types helps improve the classification scheme and the statistics. The conceptual framework of vegetation and land cover mapping is presented in Figure 1.

The steps followed for mapping vegetation type and land cover units included a literature review, collection and analysis of historical data, selection of multi-season Landsat TM data, digital enhancement, reconnaissance survey, on-screen visual interpretation, field validation, accuracy assessment and area statistics calculation. A GPS device was used for collecting geographic coordinates of field plots, gathering location data of different plant species and vegetation communities and providing field-points for assessing the classification accuracy of the vegetation type map. Cloud-free Landsat TM/ ETM/ ETM+ images for two seasons (March-April and September-October) from year 2014-15 were downloaded from https://earthexplorer.usgs.gov/.

Besides satellite images, we also used NASA SRTM Digital Elevation Model to understand the relation of elevation, slope and aspect gradient to the distribution of different vegetation classes (Rabu et al., 2003). We followed a stratified random sampling approach with geo-located sample points from each of the vegetation type using handheld GPS. These field points were used for mapping vegetation types and for validation of the map through accuracy assessment. We prepared a remote sensing-based hierarchic classification scheme for vegetation and land cover mapping using a climatologically driven distribution of forest ecosystems for the Chinese part of the landscape (Chinese vegetation atlas, 2007) (Table 1), Champion and Seth (1968) for the Indian part of the landscape (Table 2), and Stainton (1972) and Tree improvement and Silviculture component (TISC, 2000) for the Nepalese part of the landscape (Table 3). We then further divided these groups into sub-groups based on the dominant species composition and location-specific formations, which are controlled by edaphic and disturbance conditions. In addition to knowledge and data-driven digital classification methods, we used an onscreen visual interpretation technique to understand the context, association and texture of the field-based information so as to effectively delineate different classes of vegetation. We initially classified the dominant vegetation and land cover types using the different characteristics of the satellite data such as texture, tone, pattern and association using the False Colour Composites imagery of Landsat satellite. We found the on-screen visual image interpretation technique to be useful for two main reasons: 1) digital classification of forest types can provide more repeatable results; nevertheless it needs human inputs to ensure acceptance of the results, 2) vegetation heterogeneity is high in KSL and the different vegetation classes may cause confusion, so we need to understand the spectral response patterns of key elements for visual interpretation of forest types (Reddy et al., 2015). We used the geophysical zones as a broad stratum for classifying vegetation communities at the first level, in view of the unique geophysical conditions, floristic uniqueness and distinct geological origins in KSL. We then separately classified the layer in each zone by deriving the Normalized Difference Vegetation Index (NDVI) and unsupervised maximum likelihood classification based on the False Colour Composite image-using hybrid per pixel approach for vegetation and land cover classes based on the phenological variations (i.e., peak growth and leaf fall). We further applied a 3 x 3 majority filter in Erdas Imagine Software for smoothening the image. Additionally, we also used the inputs from field surveys and open access high-resolution imagery such as from Google Earth in post-classification refinement of vegetation and land cover map.

2.3 Classification scheme

Initially, in this study we delineated 25 vegetation and 6 land use and land cover types. During the harmonization process, some vegetation types were merged and the total number of vegetation classes were reduced to 14. The primary classification is intended to separate natural vegetation cover (e.g., forests, grasslands) from cultivated and managed systems (e.g., croplands and orchards), rock/barren land, water bodies, snow and glaciers and human settlements. We developed a vegetation classification scheme to distinctly classify natural and semi-natural systems into forests, scrub lands, grasslands, meadows and steppes on the basis of the extent of green cover. In the classification of natural forest vegetation, we used the following four criteria: (1) life form, (2) forest cover, (3) leaf types, and (4) leaf longevity/ phenology. We further divided the forest classes into climatically driven forest ecosystems following China's vegetation atlas for KSL–China (The Geological Publishing House, 2007), Champion and Seth's classification (1968) scheme for KSL–India, and Stainton (1972) and TISC (2000) for KSL–Nepal.

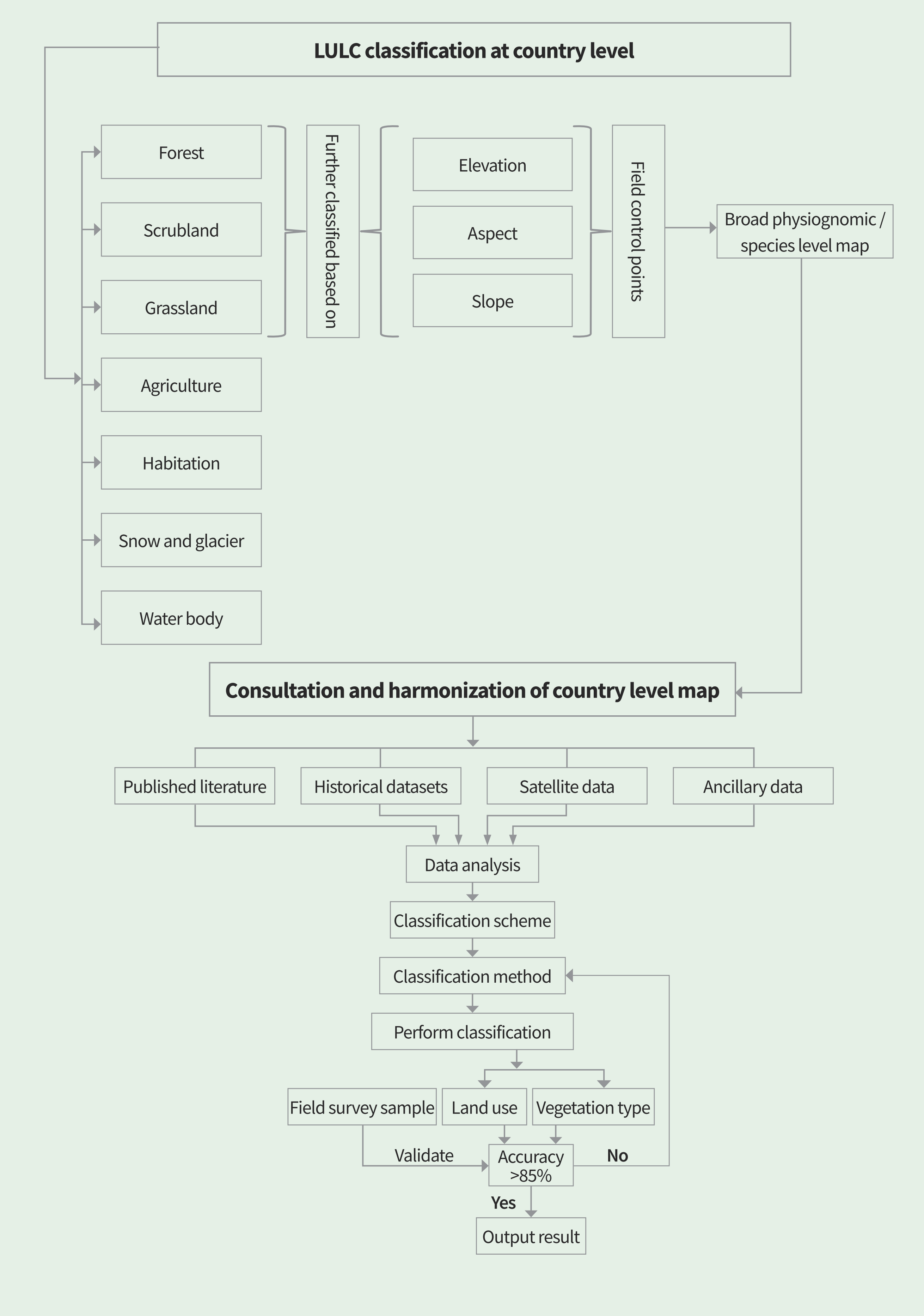
Vegetation was further classified based on biogeography, phenology, and field data. We came up with 14 vegetation types: Tropical broadleaved forest, Sub-tropical broadleaved forest, Sub-tropical needle-leaved forest, Montane broadleaved evergreen forest, Montane broadleaved deciduous forest, Montane needle-leaved forest, Secondary scrub, Montane grassland, Subalpine forest, Subalpine scrub, Alpine moist scrub, Alpine dry scrub, Alpine moist meadows, and Alpine steppe.

Vegetation types from each country were later harmonized and classified into 14 vegetation types and validated for KSL (Table 4, Figure 2). The rationale for using the land use and land cover classification system is to maintain classes that are compatible with other national classification systems but also incorporate local specificities. Existing national level vegetation classification systems are presented in Table 1 (China), Table 2 (India) and Table 3 (Nepal).

2.4 Field survey

We followed a stratified random sampling approach for collecting field data points for each vegetation type to determine the type-specific relative species composition. A total of 1025 geotagged sampling points were collected during 2015–2016 using the stratified random sampling approach. These points varied according to remote sensing-based classification of vegetation types in addition to the elevation, ecoregion, and climate. During the field surveys, we recorded all the vegetation types and verified them during field sampling and reconnaissance walks. We noted the dominant vegetation types on the satellite imagery using prominent image characteristics viz., tone, texture and association. The prominent image characteristics, elevation range, distribution, etc. helped us develop an effective interpretation key for

FIGURE 1 CONCEPTUAL FRAMEWORK OF VEGETATION AND LAND USE MAPPING



conducting on-screen visual image interpretation of satellite imagery. A thorough review of literature and interactions with relevant stakeholders such as the forest department, and the department of national parks and wildlife conservation, enabled us to gather information on the distribution of vegetation types, which we used to validate the results. We also used available information from forest-related working plans and published reports in the final classification schema. The reconnaissance surveys helped us understand the predominant phenological site-specific vegetation types (Roy et al., 2015).

2.5 Accuracy assessment of vegetation classification

Accuracy assessment is a crucial part of any vegetation and land cover classification study. It provides the degree of accuracy with which the vegetation has been classified into different types. Classification accuracy depends on sampling methods, in addition to practical factors such as accessibility and resources (Cihlar, 2000). In recent times, the confusion matrix and kappa coefficient have been widely used for assessment of classification accuracy. Error matrices compare, on a class-to-class basis, the relation between reference data which is collected during field sampling, and the classification of corresponding vegetation types in the map. We further computed the overall classification accuracy by dividing the total number of correctly classified points with the total number of reference points (Reddy et al., 2015). In the present study, ICIMOD and its partner organizations and collaborators collected a total of 1025 samples of different vegetation types from India, China and Nepal. These samples were used to obtain overall classification accuracy. Kappa analysis is a discrete multivariate technique that is widely used in accuracy assessment of vegetation classification. Kappa statistics measures the difference between the actual agreement and the chance agreement between reference data and classified data (Lillesand and Kiefer, 1999).

2.6 Validation of the vegetation type map

We conducted field validation of all vegetation types by collecting the GPS locations of a certain number of points from each vegetation type, which were calculated based on the geographical area of each vegetation type. At each selected field site, the vegetation on the ground was identified using the vegetation keys and descriptions. The dominant plant species of each forest type was recorded and photographed and given a label based on its species composition. After the forest type was classified by the validation team, it was compared to the type

TABLE 1 CLASSIFICATION SCHEMA OF MAJOR VEGETATION TYPES IN KSL–CHINA

Physiognomic units Level 1 - Vegetation type	Broad communities/Floristic units Level 2 - Formation	Characteristic/Dominant species Level 3 - Associates
Alpine scree vegetation	Alpine cushion vegetation	*Arenaria musciformis, Androsace tapete*
	Alpine sparse vegetation	*Saussurea tridactyla, Waldheimia glabra*
Alpine moist meadow	Alpine meadow	*Kobresia pygmea, Kobresia tibetica*
	Alpine marsh meadow (peatland)	*Kobresia-Blysmus*
Alpine dry scrub	Alpine broadleaved deciduous scrub	*Caragana versicolor*
		Caragana versicolor, Potentilla fruticosa var. pumila
		Caragana versicolor, Potentilla fruticosa var. pumila, Artemisia wellbyi
		Caragana versicolor, Ephedra gerardiana, Artemisia wellbyi
Dry alpine steppe	Alpine grass, carex steppe	*Stipa purpurea, Carex montis-everestii*
		Stipa purpurea
	Alpine desert steppe	*Stipa glareosa*
		Cousinia thomsonii, Stipa glareosa
		Artemisia wellbyi, Physochlaina praealta, Polygonum tortuosum
		Cousinia thomsonii, Stipa glareosa
Others		

TABLE 2	CLASSIFICATION SCHEMA OF MAJOR VEGETATION TYPES IN KSL–INDIA	
Physiognomic units Level 1 - Vegetation type	**Broad communities/Floristic units Level 2 - Formation (Corresponding Champion & Seth (1968) category**	**Characteristic/Dominant species Level 3 - Associates**
Sub-tropical broadleaved forest	5B/C1a: Dry sal bearing forest	*Shorea robusta* *Terminalia alata* *Litsea monopetala* *Mallotus philippensis*
Mid–Montane conifer forest	9/C1b: Himalayan Chir pine forest	*Pinus roxburghii* *Glochidion velutinum* *Woodfordia fruticosa*
Sub-tropical riverine forest	Not described	*Toona ciliata* *Macaranga pustulata* *Engelhardtia spicata*
Montane broadleaved (evergreen) forest	12/C1a: Ban oak forest	*Quercus leucotrichophora* *Myrica esculenta* *Dendrobium spp.* *Lyonia ovalifolia* *Sinarundinaria falcata*
	12/C1b: Moru oak forest	*Quercus floribunda* *Symplocos chinensis* *Thamnocalamus falconerii* *Sorbus vestita*
	12/C2a: Kharsu oak forest	*Quercus semecarpifolia* *Taxus wallichiana* *Prunus cornuta* *Thamnocalamus spathiflorus*
Montane broadleaved (deciduous) forests	12/1S1: *Alnus nepalensis* forests	*Alnus nepalensis* *Pilea umbrosa* *Debregeasia hypoleuca*
Montane conifer forests	12/E1: *Cupressus torulosa*	*Cupressus torulosa* *Lespedeza gerardiana* *Pogonatherum paniceum*
Temperate grassy slopes	12/DS3: Himalayan Secondary Grasslands	*Themeda anathera* *Chrysopogon gryllus* *Cymbopogon distans* *Andropogon munroi*
Hemlock (Tansen) forest	Not described	*Tsuga dumosa*
Temperate secondary scrub	12/DS2: Temperate Parkland C1/DS1: Oak Scrub C1/DS2: Himalayan Temperate Secondary Scrub	*Quercus leucotrichophora* *Berberis asiatica* *Prinsepia utilis* *Rubus niveus*
Temperate broadleaved forest (moist deciduous)	12/C1: West Himalayan Temperate Forests	*Acer villosum* *Betula alnoides* *Juglans regia* *Aesculus indica*
Temperate conifer forest	13/C4: West Himalayan High-level Dry Blue Pine Forest	*Pinus wallichiana* *Juniperus communis*
Sub-alpine forest	14/C1: West Himalayan Sub-alpine Birch/Fir Forest (*Betula/Abies*) Birch-Rhododendron Scrub Forest	*Rhododendron campanulatum* *Betula utilis* *Lonicera spp.* *Rosa macrophylla*
Alpine scrub	15/E1: Dwarf rhododendron scrub 16/E1: Dwarf juniper scrub	*Rhododendron anthopogon* *Cassiope fastigiata* *Salix denticulata* *Salix lindleyana* *Lonicera myrtillus*
Alpine pasture	15/C3: Alpine pasture (Dry and moist types)	*Danthonia cachemyriana* *Potentilla argyrophylla* *Kobresia spp.* *Trachydium roylei*

TABLE 3 **CLASSIFICATION SCHEMA OF MAJOR VEGETATION TYPES IN KSL–NEPAL**

Physiognomic units (Level 1 - Vegetation type)	Broad communities/ Floristic units (Level 2 - Formation)	Characteristic/Dominant species (Level 3 - Associates)
Upper tropical belt	*Shorea robusta* forest *Terminalia-Anogeissus* forest	*Shorea robusta, Anogeissus latifolia, Terminalia tomentosa, Adina cordifolia, Bauhinia vahlii*
	Riverine forest with *Toona* and *Albizia*	*Bombax malabaricum, Mallotus philippensis*
Lower subtropical belt	*Pinus roxburghii* forest	*Olea cuspidata, Capparis spinosa, Woodfordia fructicosa, Indigofera heterantha*
Upper subtropical belt	*Alnusnepalensis* forest	*Alnus nitida,Juglans regia, Quercus floribunda*
Collinean temperate	*Michelia - Castanopsis*	*Michelia kisopa, Castanopsis tribuloides, Alnus nepalensis*
Montane temperate	*Quercus floribunda* forest	*Q. floribunda, A. nepalensis, Q. leuchotrichophora*
	Quercus leucotrichophora	*Banj Oak* (*Q. leucotrichophora, Q. lanata*)*-chir pine* (*P. roxburghii*)
	Q. semecarpifolia Khasru/Brown Oak forest	*Q. semecarpifolia - blue pine* (*P. wallichiana*)
	Q. semecarpifolia forest	*Quercus semecarpifolia, Abies spectabilis, Betula utilis, Rosa sericea*
	Tsuga dumosa forest	*A. spectabilis, S. cuspidata*
Lower subalpine	*Silver Fir-A. spectabilis* forest	*A. spectabilis,T. wallichiana, C. acuminata*
	A. spectabilis, B. utilis forest	*A. spectabilis, B. utilis*
	A. spectabilis, J. indica forest	*A. spectabilis, J. indica*
Upper subalpine	*Betula utilis* forest	*Prunus rufa, Acer caesium, Sorbus microphylla*
	Betula utilis-Rhododendron campanulatum	*Abies spectabilis, Prunus cornuta*
Inner valleys – temperate belt	*Pine* (*Pinus wallichiana)* forest	(*P. smithiana, A. pindrow, Q. leuchotrichophora*)
	Pinus-Picea-Abies forest	(*P. wallichiana, P. smithiana, A. spectabilis*
	Cupressus torulosa Forest	*Cupressus torulosa, Abies pindrow, Rosa macrophylla*
	Cupressus torulosa (*Juniperus indica, Viburnum cotinifolium, Berberis* species, *Cotoneaster* species)	*Cupressus torulosa , Juniperus indica, Viburnum cotinifolium*
	Picea smithiana	*Pinus wallichiana, Populus ciliata, Betula utilis*
	Abies pindrow	*Abies pindrow*
	Aesculus-Juglans-Acer	*Aesculus indica, Juglans regia, Acer caesium*
	Cedrus deodara forest	*C. deodara, P. Wallichiana, Rosa sericea*
	Populus ciliata forest	*Populus ciliata, Picea smithiana*
Lower alpine	*Juniperus wallichiana*	*J. wallichiana, R. lepidotum*
	Hippophae tibetana	
Upper alpine	*Festuca ovina-Kobresia Communities*	*Festuca ovina, Kobresia seliculmus, Agrostis munroana*
Trans-Himalayan steppe	*Caragana* thickets	*C. gerardiana, C. brevifolia, Myricaria rosea*

labelled on the map. If certain vegetation types were mislabelled, the surveyors would then identify the source of the error while they were still in the field. Additionally, a regional consultation meeting on 'Vegetation type harmonization and validation for Kailash Sacred Landscape' was organized in Dehradun in December 2015 with the participation of 41 regional experts in remote sensing and vegetation ecology, representing more than 10 government and non-government organizations. The major objectives of the meeting were: (i) to share experiences related to the classification and mapping of various physiognomic and floristic units of vegetation along transboundary areas of KSL, (ii) to get expert opinion on the nomenclature of major classes and build consensus on their altitudinal and environmental correlates, and (iii) to develop a standard protocol for the mapping and integration of common classes distributed across transboundary landscapes in the HKH.

SECTION III

Results

3.1 Vegetation types and area

The vegetation type map in the present study was developed through a collaborative effort involving scientists and researchers from more than 10 institutions across the three countries. The map provides spatial information on 25 vegetation types consisting of natural, semi-natural and managed formations compiled under 14 broad categories (Figure. 2). Approximately 52.77% of Kailash Sacred Landscape is covered by vegetation, which includes diverse vegetation types.

The vegetation types range from tropical forest located at around 400 masl altitude to alpine steppe found at altitudes higher than 5500 masl, with subtropical, montane, grassland, subalpine and alpine vegetation in between. Land use and land cover classes such as agriculture, snow and glaciers, barren land, settlement and waterbody occupy the remaining 47.23% of KSL.

The vegetation types of KSL are divided into 14 classes namely: (1) Tropical broadleaved forest, (2) Sub-tropical broadleaved forest, (3) Sub-tropical needle-leaved forest, (4) Montane broadleaved evergreen forest, (5) Montane broadleaved deciduous forest, (6) Montane needle-leaved forest, (7) Secondary scrub, (8) Montane grassland, (9) Subalpine forest, (10) Subalpine scrub, (11) Alpine moist scrub, (12) Alpine dry scrub, (13) Alpine moist meadows and (14) Alpine steppe. After completing the process of accuracy assessment, the vegetation type map depicting various vegetation types of KSL is presented in Figure 3.

The floristic composition, dominant species, description and distribution of vegetation type of each physiognomic unit, area statistics of vegetation types, and land use/land cover are given in Table 4.

3.2 Accuracy assessment of classification

The overall mapping accuracy of the vegetation classification was assessed on the basis of geotagged ground control points and Google Earth images, which was found to be 82%. The mapping accuracy of more than 80% is ideal for using the map for other studies. The satellite-based vegetation mapping has been successfully used to overcome many drawbacks of manual and field-based classification systems like Champion and Seth (1968) and Stainton (1972). The map and statistics of vegetation distribution in the present study provide the exact extent and distribution of various forest vegetation types with reasonable accuracy.

3.3 Harmonized vegetation map of Kailash Sacred Landscape

By early 2016, we completed the harmonization exercise of the vegetation type classification scheme with support from country partners in China, India and Nepal. The final version of the map, which was compiled over the course of two years with all partners, stakeholders, and experts in vegetation ecology and remote sensing, was launched at ICIMOD in March 2016. The map represents 14 vegetation types that stretch across KSL and five land use/cover types prevalent in the region. The map is available through an online platform for researchers and other stakeholders working on the landscape. By combining several other relevant data layers such as wildlife population, habitat distribution, institutions of forest management, and livelihood types, the KSLCDI plans to upscale the information for effective landscape-level management at a transboundary scale, linking institutions, interventions and investments.

FIGURE 2 VEGETATION TYPE AND LAND COVER MAP OF KAILASH SACRED LANDSCAPE

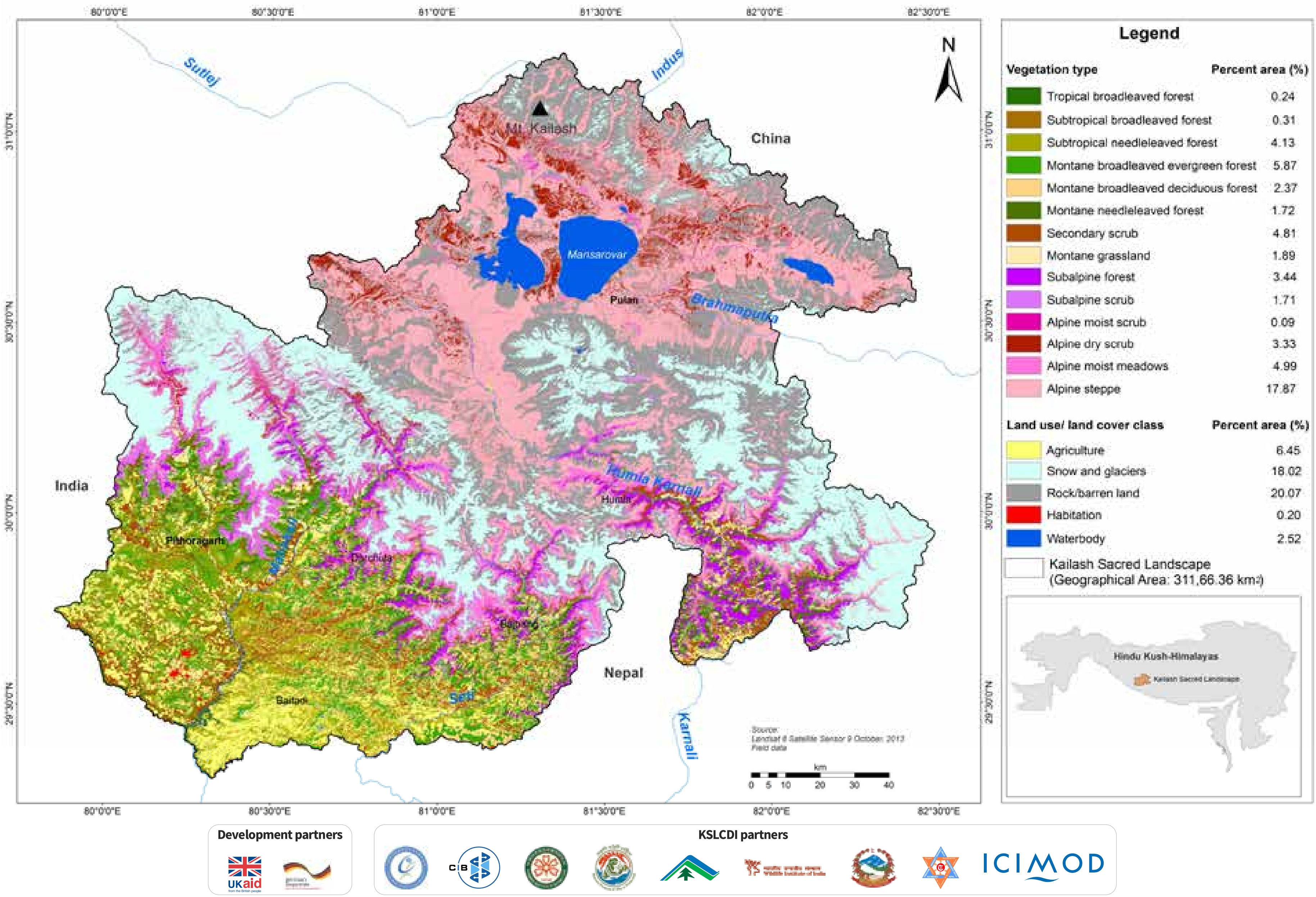


FIGURE 3 INDICATIVE LOCATIONS OF MAJOR VEGETATION TYPES OF KSL BASED ON PREDOMINANCE AND ECOLOGICAL UNIQUENESS

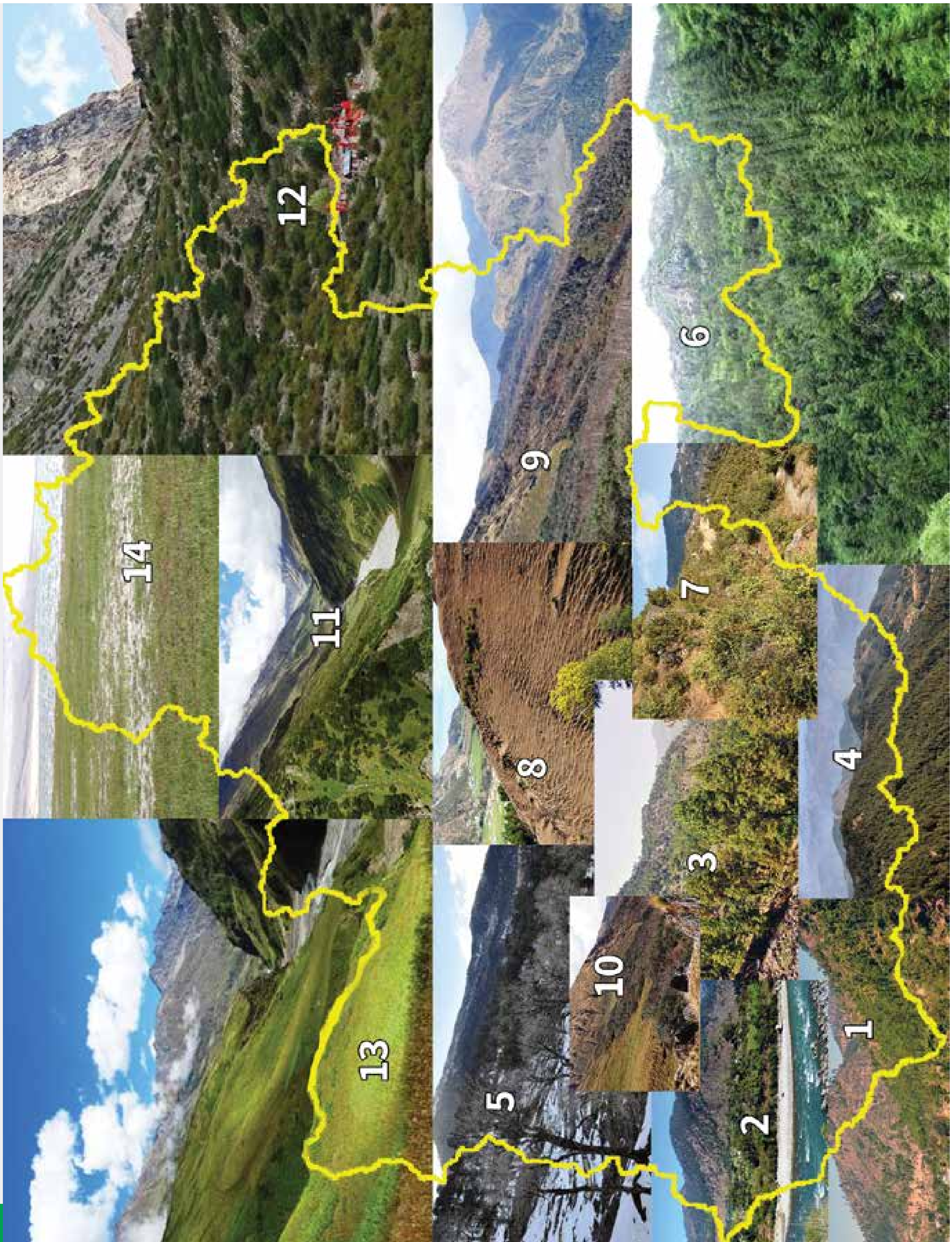


TABLE 4 **COMMON CLASSIFICATION SCHEMA OF VEGETATION TYPE CHARACTERISTICS: VEGETATION TYPE, FORMATIONS, ASSOCIATION, THE RANGE OF ELEVATION, AND DOMINANT PLANT SPECIES IN KSL**

Physiognomic units	% of Area	Broad communities / Floristic units	Characteristic/Dominant species	Altitude range (masl)
Tropical broadleaved forest	0.24	Sal forest Khair-Sissoo forest	*Shorea robusta, Acacia catechu, Dalbergia sissoo, Anogeissus* spp., *Lagerstroemia* spp., *Indopiptadenia oudhensis, Hymenodictyon excelsum*	<1000
Subtropical broadleaved forest	0.31	Sal forest (Sal bearing forests)	*Shorea robusta, Terminalia alata*	1000–1400 (1500), Drier slopes along river valley
		Toona – Engelhardtia	*Toona ciliata, Engelhardtia spicata, Albizia* spp.	800–1200
		Macaranga pustulata	*Macaranga pustulata, Debregeasia* spp.	800–1200
Subtropical needle-leaved forest	4.13	Chir pine forest	*Pinus roxburghii, Glochidion velutinum*	900–1800
Montane broadleaved evergreen forest	5.87	Banj (white) oak (Banj-Nepali)	*Quercus leucotrichophora, Myrica esculenta* *Sinarundinaria falcata, Ficus cuspidata* *Pistacia integerrima*	1600–2200
		Oak-Rhododendron	*Rhododendron arboreum*	
		Timsu (Moru) oak	*Q. floribunda, Symplocos chinensis*	2000–2600
		Ryanj oak (Thulo banj-Nepali)	*Q. lanuginosa, Q.lanata*	1400– 2200
		Kharsu (brown) oak	*Q. semecarpifolia, Thamnocalamus falconerii*	2600– 3300
		Oak – Lauraceous Mixed Forest (including pure patches of Lauraceae)	*Q. leucotrichophora, Neolitsea pallens, Machilus* spp.	1500– 2200
Montane broadleaved deciduous forest	2.37	Aesculus – Acer	*Acer villosum, Betula alnoides, Juglans regia, Aesculus indica, Carpinus* (Indian part in small pockets)	1800– 2400
		Alder forest	*Alnus nepalensis, Alnus nitida (Humla) >2500*	1500–2500
		Populus ciliata	*Populus ciliata*	2000– 3000
Montane needle-leaved forest	1.72	Deodar forest	*Cedrus deodara*	1600–2200
		Cypress forest	*Cupressus torulosa*	1800– 2400
		Hemlock (Tangsin/Thingre salla-Nepali) forest	*Tsuga dumosa*	2600–3200
		Blue pine (Kail/ Rani salla-Nepali) forest	*Pinus wallichiana*	3000– 3600
		Silver fir (west Himalayan silver fir-Nepal) forest	*Abies pindrow*	2400–3300
Secondary scrub	4.81	Mixed scrub *Lantana* scrub *Rhus* scrub *Dodonea viscosa*	*Berberis asiatica, Prinsepia utilis, Rubus niveus, Cocculus laurifolius, Pyracantha crenulata, Rhus parviflora, Woodfordia fruticosa*	800–3000
		Euphorbia scrub *Olea* spp.	*Euphorbia* royleana, *Olea cuspidata* (Karnali-Nepal), *Pyracantha crenulata*	Up to 1200
Montane grassland	1.89	Grasslands on steeper slopes	*Themeda anathera, Chrysopogon gryllus*	Up to 3300
		Hay meadows (managed pastures)	*Cymbopogon distans, Andropogon munroi, Cymbopogon jwarancusa*	

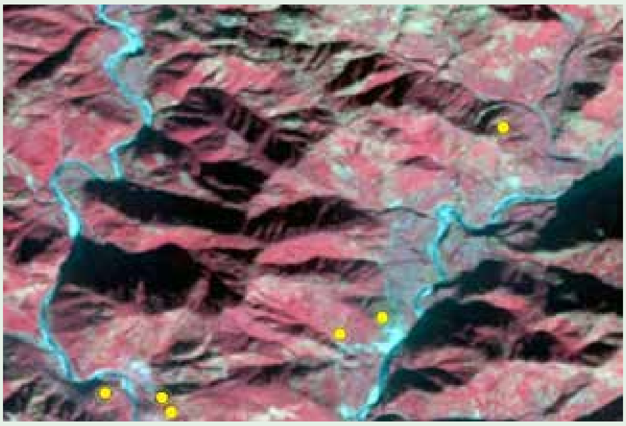
Physiognomic units	% of Area	Broad communities / Floristic units	Characteristic/Dominant species	Altitude range (masl)
Subalpine forest	3.44	Oak – Fir mixed forest	*Pinus wallichiana, Juniperus communis, Taxus wallichiana*	3000–3500
		Birch – Rhododendron	*Betula utilis, R. campanulatum*	3300–3600
		Fir- Pine-Birch (Nepal)	*Pinus wallichiana*	
		Fir dominated forest	*Abies spectabilis*	3300–3600
		Maple mixed forest	*Acer caesium*	2700–3300
Subalpine scrub	1.71	Krummholz	*R. campanulatum*	2700–4000
Alpine moist scrub	0.09	*Salix – Lonicera*	*Salix denticulata, S. lindleyana, Lonicera myrtillus*	3300– 3800
		Rhododendron scrub	*Rhododendron anthopogon, Cassiope fastigiata* *Cotoneaster microphylla*	3800– 4200
		Juniperus indica, (*Juniperus wallichiana*)		
		Salix – Myricaria	*Salix denticulata, Myricaria elegans*	3000–3800
Alpine dry scrub	3.33	*Caragana – Lonicera* scrub	*Artemisia* spp., *Caragana versicolor, Lonicera spinosa, Astragalus* spp., *Potentilla fruticosa, Rubus nivale, Rosa sericea*	3400–5000
		Ephedra scrub	*Ephedra gerardiana*	2100–4000
		Juniper scrub	*Juniperus communis*	Up to 4500
		Eurotia scrub	*E. serratoides*	
Alpine moist meadow	4.99	Mixed herbaceous formations	*Potentilla atrisanguinea, Geranium wallichianum*	3400– 4500
		Danthonia meadow	*Danthonia cachemyriana*	3400– 4000
		Kobresia meadow	*Kobresia nepalensis*	4000–4500
		Marsh meadows (peatland)	*Blysmus compressus* *Carex* spp.	4000–4500
Alpine steppe (including arid zones)	17.87	Stipa – Carex	*Stipa orientalis, S. purpurea, Carex* spp., *Leymus secalinus*	4000– 4500
		Dry alpine mixed formations (including scree vegetation and hammocks)	*Potentilla argyrophylla, Lancea tibetica, Artemisia* spp., *Festuca* spp.	4000– 4500
		Desert steppe	*Orinus thoroldii, Stipa glariosa, Artemisia wellbyi*	4500–4800
		Alpine cushionoid	*Areneria* spp. *Thylacospermum caespitosum*	4200–4800
		Marsh meadows (peatland)	*Blysmus compressus* *Carex* spp.	4000– 4500
Land use and land cover classes				
Agriculture	6.45			
Snow and glaciers	18.02			
Rock/barren land	20.07			
Habitation	0.20			
Waterbody	2.52			

The characteristics of each harmonized vegetation type are presented below, along with photos:

1. TROPICAL BROADLEAVED FOREST

A few forests dominated by *Shorea robusta* are found in the warm valleys – below 1000 masl elevation – in KSL. Here it is difficult to differentiate them from Sub-Himalayan Broadleaved Forest. Associate species are *Terminalia alata, Acacia catechu, Dalbergia sissoo, Anogeissus* spp., *Lagerstroemia* spp., *Indopiptadenia oudhensis* and *Hymenodictyon excelsum*.

Sal forest in KSL-Nepal is heavily degraded due to human encroachment. It occurs below 1000 masl in Baitadi. Little-disturbed Sal forests have a dense undergrowth. Grasses become dominant in disturbed areas mainly due to fire. *Terminalia alata, T. bellirica, Dillenia pentagyna, Lagerstroemia parviflora, Casearia graveolens, Buchanania latifolia, Anogeissus latifolia* and *Cassia fistula* are the main associates.

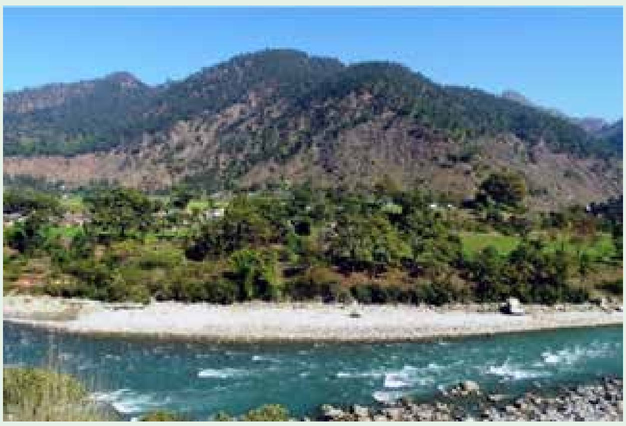


This a false colour composite (FCC) of Landsat 8 satellite image. In this composite image vegetation is shown in shades of red. Different shades of red indicate differences in vegetation composition, structure and formation.

Yellow dots show the locations of distribution of respective vegetation category.

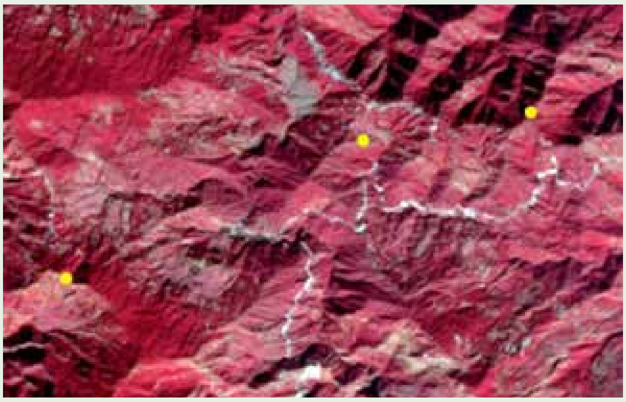
2. SUBTROPICAL BROADLEAVED FOREST

Subtropical forests are determined more by altitude than by latitude and are typically observed in hilly tracts. In KSL these forests are found in the elevation range of 1000–1500 masl. These forests are also seen in altitudes below 800 masl along drier slopes in the river valleys in KSL-India. *Shorea robusta* is the dominant species, with *Terminalia alata* as a co-dominant species. There are very few sub-tropical broadleaved forests along the river valleys bordering Nepal and in the Ram Ganga river valley. Some of the riverine forests in moist valleys are dominated by *Toona ciliata* and *Engelhardtia spicata*. *Macaranga pustulata* forms one of the dominant riverine forests along the river Kali and Gori in KSL-India. *Schima wallichii* occurs throughout, with *Castanopsis indica* more common below 1200 masl and *Castanopsis tribuloides* above this altitude in KSL-Nepal.



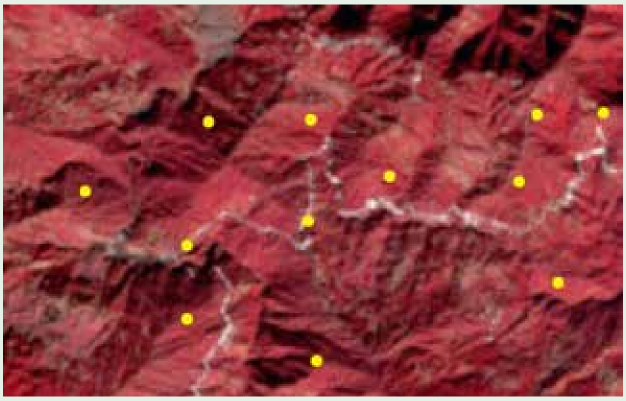
3. SUBTROPICAL NEEDLE-LEAVED FOREST

The *Pinus roxburghii* predominates and creates an environment unfavourable to most broadleaved trees. *Quercus* is the most typical broadleaved genus associated with *Rhododendron* and *Lyonia* (from higher altitude) and *Syzygium cumini, Mallotus* and *Carissa* (from lower altitude). *Rhus, Berberis* and *Rubus* are representative shrubs and one or two species of *Ficus* are present. Chir pine is the most common species, forming a relatively dominant stand on southern slopes at mid altitude in KSL-Nepal, reaching north along the dry river gorges of the transverse Himalayan valleys. This forest occurs in all the four districts of KSL-Nepal below 1900 masl. The upper canopy is composed exclusively of pine. There is limited second storey. However, in the upper limit of its distribution, it is mixed with broadleaved taxa, mostly *Quercus* sp., *Rhododendron arboreum* and *Lyonia ovalifolia*. *Engelhardtia spicata* and *Terminalia alata* sometimes intrude into the lower reaches of the Chir pine forest. The understorey species are mostly fire-tolerant and grazing-adapted (*Caryopteris foetida, Indigofera* sp., *Inula cappa, Woodfordia fruticosa, Pyracantha crenulata*, etc.).



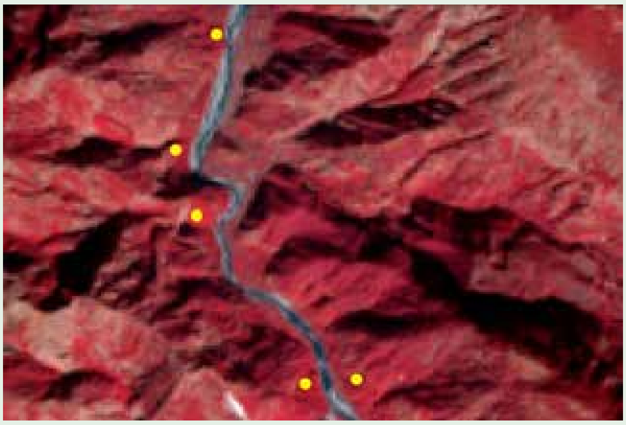
4. MONTANE BROADLEAVED EVERGREEN FOREST

These forests extend along the whole length of the Himalaya between the sub-tropical forests and the sub-alpine formations. Oaks make up the greater portion of the top canopy, the *Lauraceae* being relegated to the second storey though numerically predominant. These forests are usually composed mainly of single species of *Quercus* and replaced by other species with increasing altitude. *Q. leucotrichophora* forests are common in the 1500–2200 masl elevation zone in KSL-India. Some of the extensive patches can be found around Guptadi-Gangolihat, Thalkedar, Saurlekh, Sandev and Ghandhura areas. *Quercus dilatata* (Mohru) does not form pure patches and is mixed with other oak species and Lauraceous forests at 2000–2600 masl elevation. *Q. semecarpifolia* forms extensive patches around the subalpine region at 2500–3300 masl and extensive patches can be seen around Kalamuni top, on the way to Kanar and Karangdang areas in KSL-India. *Quercus leucotrichophora* and *Quercus lanata* forests occur on the southern exposure in KSL-Nepal. Of these, *Q. leucotrichophora* is much more common. The main understorey species are R*hododendron arboreum, Ilex dipyrena, Symplocos* sp., *Lindera pulcherrima, Rhus wallichii, Lyonia ovalifolia, Carpinus* sp. and shrubs and climbers (chiefly *Viburnum mullaha, Myrsine semiserrata, Zanthoxylum* spp., *Rubus ellipticus, Rubia cordifolia, Rubus paniculatus, Smilax* spp.). *Quercus floribunda* forest can be found in elevations between 2100 and 2750 masl in KSL-Nepal. In humid north or west slopes, there is a transition to *Quercus floribunda* forests. This type of forest occurs near Sithi and Khayakot areas in Darchula and also in Baitadi, Bajhang, and to a smaller extent in Humla.



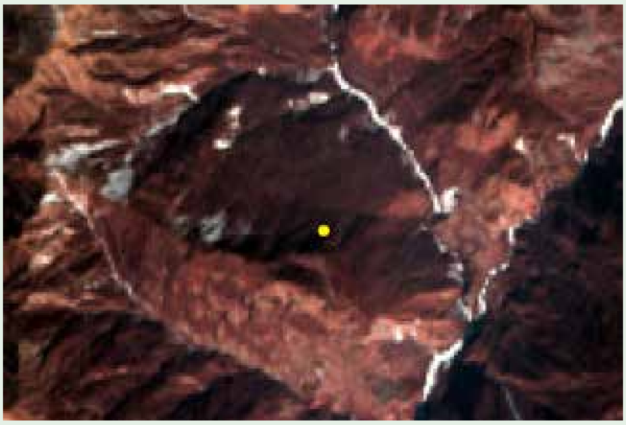
5. MONTANE DECIDUOUS BROADLEAVED FOREST

This type of forest is commonly found in elevations between 1500 and 3000 masl in moist hollow and depression areas, often as riverine strips along hill streams and old landslides, and also on gentler slopes. In KSL-India, such forests can be seen around Munsyari, Himkhola, Kalmuni top, on the way to Ralam, around Malpa and Budhi. *Alnus nitida* can be found above 2500 masl in Humla, Nepal. *Aesculus-Acer* forests occur in narrow strips alongside streams and on shady slopes in Dozam, Humla-Karnali (Humla), and Chameliya valley (Darchula) within KSL-Nepal in elevations between 1800 and 2900 masl. In Chameliya valley, the forests form a multi-storeyed, closed canopy stand of deciduous broadleaved trees with *Aesculus, Juglans* and *Acer* (*A. caesium, A. acuminatum, A. caudatum, A. pectinatum*), with *Ulmus wallichiana* and *Carpinus viminea* as minor associates. In addition, *Betula alnoides* and *Alnus nepalensis* are also common in waterside areas along with a few oak trees (chiefly *Q. semecarpifolia* in the upper reaches and *Q. floribunda* in the lower reaches of *Aesculus-Acer* forest).



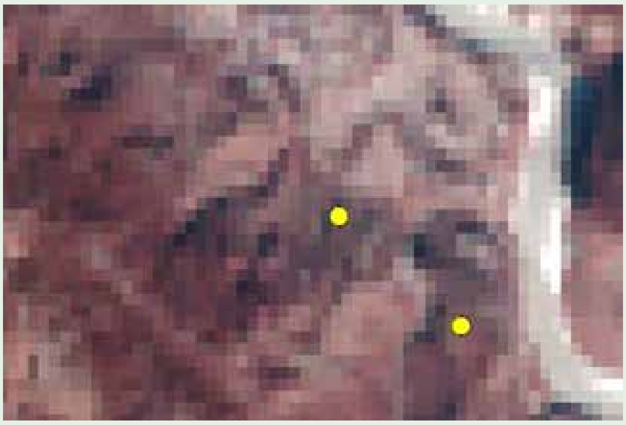
6. MONTANE NEEDLE-LEAVED FOREST

These forests are typically more or less even aged, with *Pinus wallichiana* (Blue pine) pure or predominant. Often they are intermixed with some *Cedrus deodara* if a seed source has been present, and with spruce in cool, moist sites. They tend to be dense unless thinned by fire, and have very little undergrowth. These forests are common above Kalamuni, Nagling, Karngdang, Chiyalekh, etc. *Cupressus torulosa, Abies pindrow, Tsuga dumosa*, etc. are major associates of the forests. Deodar occurs to a very limited extent, mixed with pines, in the lower Humla-Karnali valley, mainly in Chhipra, below Simikot. However, there is no pure stand left in Humla. Cypress forms scattered stands in drier southern aspects in Humla-Karnali and upper Chameliya valley within KSL-Nepal in elevations between 2100 and 2400 masl. The understorey and surrounding rocky slopes on the southern aspect harbour scattered shrubs and herbs like C*oleus barbatus, Incarvillea arguta, Colquhounia coccinea, Origanum vulgare, Rabdosia rugosa, Buddleja crispa*. *Arundinaria falcata* and *Desmodium elegans*. Cypress is also common as a village tree in Darchula (mainly in Ghusa and Sithi).



7. SECONDARY SCRUB

Secondary scrub occurs in areas where grazing has taken place in temperate forests, favourable sites on ridges and steeper slopes, especially in moist areas or near water, often with browsed clumps of *Berberis, Lonicera, Pyracantha, Arundinaria, Cotoneaster*, or patches of non-palatable and thorny shrubs such as *Viburnum foetens, Dodonea*. It is common around Pithoragarh, Gangolihat, Berinag, Dharchula and Munsyari towns and Sheraghat, above Ghat, in the low-altitude (<1500 masl) villages. This vegetation type can be observed mainly in elevations up to 3000 m in KSL. It is also found in many low-elevation areas in the Sauryu and Kali river valleys, dominated by *Lantana camara*. Lower and mid elevation areas subjected to high human disturbance support bushy vegetation on dry rocky slopes, comprising species such as *Colquhounia coccinea, Ficus palmata, Boehmeria platiphylla, Berberis* spp., *Woodfordia fruticosa, Rabdosia rugosa, Buddleja crispa, Rubus* spp. and *Pyracantha crenulata*. In KSL-Nepal, *Olea ferruginea* woodland is confined to dry river gorges of Humla-Karnali below Simikot. The woodland is highly disturbed with very scattered dwarf *Olea ferruginea* in association with *Pistacia chinensis, Celtis australis, Ficus palmata, Berberis* spp., *Zanthoxylum armatum, Pyracantha crenulata* and *Isodon rugosus*.



8. MONTANE GRASSLAND

Grazing sites on gentler slopes in lower temperate forests have gradually been cleared; they have passed through the parkland stage to open grassland. Common grasses on these slopes are *Festuca* spp., *Agrostis* spp., *Calamagrostis* spp., *Bromus* spp., *Danthonia* spp., *Themeda, Heteropogon* and *Chrysopogon*. Grassland vegetation can be detected on steeper slopes in elevations up to 3300 masl in KSL. There are extensive temperate grassy slopes around Pithoragarh city and in the Eastern Ramganga valley. The montane grasslands and meadows are the results of exploitation of timber, leaf fodder and firewood and over grazing. The proportion of taller shrubs or trees depends on accessibility. Grasslands on agricultural borderland areas on southern slopes are often managed by local people. Major species in such slopes are *Agrostis pilosula, Andropogon munroi, Apluda mutica, Arundinella setosa, Carex cruciata, Chrysopogon gryllus, Cymbopogon jwarancusa, Danthonia* sp., *Cyperus cyperinus, Eriophorum comosum, Eulalia* sp., *Pennisetum purpureum, Pennisetum* sp., *Setaria* sp. and *Themeda anathera*. Other associated herbaceous species include *Crotalaria, Gynura, Lilium, Rumex, Senecio* and *Swertia*.

9. SUBALPINE FOREST

Subalpine forests occur as the topmost trees in the Himalaya, adjoining alpine scrub or grassland, often as strips along spurs between snow-slides, on sheltered slopes and other favourable spots. Such forests are common around the treeline in Kuti, Napalchu nala, Liddar, Tedang, before Ralam, Relkot and around Khaliya top in KSL-India. Major subalpine forest species are *Pinus wallichiana*, *Juniperus communis*, *Taxus wallichiana*, *Betula utilis*, *Rhododendron campanulatum*, *Abies spectabilis*, *Acer caesium*, etc., and they occur in the altitude range of 2700 m to 3600 masl in KSL. The forests at the sub-alpine level on shady slopes consist of evergreen conifers and broad-leaved trees in pure stands or in various combinations. Major conifers of this zone (*Abies spectabilis* and *Pinus wallichiana*) and broadleaved species (*Quercus semecarpifolia* and *Betula utilis*) that form top canopy layer extend across elevations ranging from about 3000 m to the timber limit. At treeline, *Betula utilis* forms mixed communities with *Rhododendron campanulatum*, *Abies spectabilis*, or *Juniperus indica*.

10. SUBALPINE SCRUB

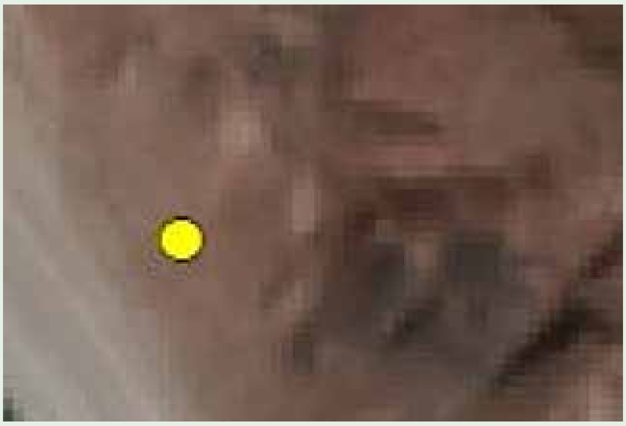
This vegetation type includes low evergreen forest dominated by *Rhododendron campanulatum* with some birch and other deciduous trees. It is very dense and difficult to penetrate; especially in the uphill direction due to the snow pressure the stems curve up from a more or less horizontal or downward bent base. Extensive patches can be seen at Khaliya top, on the way from Railkot, Ralam to Barjikang, in moist valleys at 2700–4000 masl in KSL. *R. campanulatum* forms monospecific thickets that are increasingly snow bound. Thickets gradually decrease in height as we move up the slope, from 3–4 m in the treeline ecotone to dwarf shrub size at their upper distribution limit. Other phanerophytes are rare. At treeline, *Sorbus microphylla* and *Betula utilis* overtop the thickets. The herbaceous layer is less developed. The parasitic *Boschniakia himalaica* is frequent. Extensive patches of such vegetation are found in moist valleys in the upper reaches of Chameliya, Changla Khola and Seti valley.

11. ALPINE MOIST SCRUB

Alpine moist scrub includes low deciduous/evergreen scrub formation, usually only about 1 m high, forming a dense cover continuous over extensive areas but broken up by grass, probably often secondary as a result of grazing and shrub cutting for fuelwood. Outlying patches of subalpine forest, chiefly in the form of colonies of *Betula utilis* and the larger Rhododendrons, may occur but the growth is often uniform. Extensive patches of dwarf *Rhododendron lepidotum*, *R. anthopogon* and of dwarf *Juniperus indica* may be distributed according to site conditions, particularly seasonal moisture variations. Dwarf vegetation cover of alpine scrub ranges in height from a few centimetres to 1.5 m depending on elevation. On southern slopes, the vegetation comprises scattered bushes of *Juniperus indica*, J. *squamata*, and *Berberis* spp. Other associates include *Ephedra gerardiana*, *Lonicera* spp., *Potentilla fructicosa*, and *Lonicera obovata*.

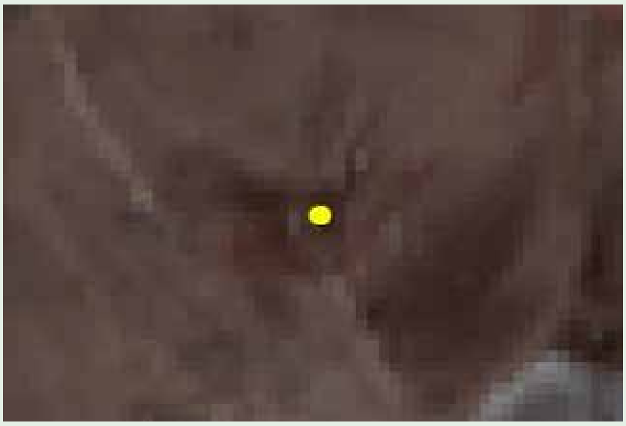
12. ALPINE DRY SCRUB

This type is widespread in the inner ranges (valleys) of KSL-India. It adjoins dry temperate forests and may occur in areas with high grazing pressure. It is often xerophytic, in which dwarf shrubs predominate. Characteristic plants are *Juniperus communis*, *Lonicera* spp., *Ephedra gerardiana*, and *Eurotia ceratoides*. Characteristic vegetation occurs along streams; *Salix*, *Myricaria* and *Hippophae* are the typical genera and form a fairly complete cover. It is dominant around Ralam, Milam, Kalapani, Nabhidhang in KSL-India. The typical ecological zone for this vegetation type is up to 5000 masl in KSL. Dry alpine scrub prevails in trans-Himalayan valleys in upper Humla and in inner Humla-Karnali, such as Limi and upper Talung. The dominant species are *Caragana versicolor*, *Juniperus indica*, *Potentilla fruticosa*, *P. bifurca*, *Ephedra gerardiana*, *Krascheninnikovia compacta*, and *Lonicera spinosa*. Along streams and river-beds the vegetation characteristically consists of *Myricaria rosea*, *M. squamosa*, *Salix* sp., and *Hippophae tibetana*.



13. ALPINE MOIST MEADOW

The meadows are composed mostly of perennial mesophytic herbs, with very little grass. The dominant formations include *Danthonia* and *Kobresia* meadows, especially on gentler slopes (<40°). Conspicuous among the herbs are *Primula, Anemone, Fritillaria, Iris, Gentiana* with several *Ranunuculace, Brassicaceae, Caryophyllaceae* and *Asteraceae*. Other associate species are *Festuca ovina, Kobresia seliculmus, Agrostis munroana, Allium carolinianum, Saxifraga stenophylla,* etc. in KSL-China. Mixed herbaceous formations of *Potentilla atrisanguinea* and *Geranium wallichianum* can be seen in elevations up to 4500 masl in KSL-Nepal. Alpine moist meadows are represented by sedges, chiefly *Kobresia nepalensis,* grasses and mesophytic forbs on southern windward slopes and on northern leeward sites not occupied by alpine dwarf *Rhododendron*. The structure, however, depends primarily on the impact of livestock grazing. The chief herbaceous and graminoid taxa belong to *Polygonaceae, Apiaceae, Asteraceae, Primulaceae, Rosaceae, Scrophulariaceae, Orobanchaceae, Caryophyllaceae, Ranunculaceae, Poaceae* and *Juncaceae* in TAR.



14. ALPINE STEPPE (INCLUDING ARID ZONES)

The alpine steppe typically includes a stony desert ecosystem with only a few herbs and grasses, as seen in TAR, China. Herbaceous vegetation is more cushioned in nature and the cover is very low. Some of the species for dry alpine mixed formations including scree vegetation and hammocks are *Potentilla argyrophylla, Lancea tibetica, Artemissia* spp. and *Festuca* spp., which occur in elevations up to 4500 masl in KSL. True Tibetan alpine steppe vegetation is rarely found in KSL-Nepal; the closest is the high-altitude arid vegetation dominated by cushion plants, hummocks and scree communities found in the trans-Himalayan valleys of Limi and Talung in upper Humla.

3.4 Standardizing and harmonizing vegetation type map

There have been efforts on a global scale to standardize nomenclature for vegetation classification. However, many countries prefer indigenous schemes of vegetation classification. This results in adjoining countries classifying vegetation communities with similar species composition differently. In an effort to develop a harmonized vegetation classification scheme for Kailash Sacred Landscape, we brought together researchers, decision makers and policy makers from China, India and Nepal. Such efforts can help strengthen transboundary cooperation for enhancing conservation and management of natural ecosystems. The other initiatives under the Transboundary Landscapes Programme at ICIMDO may refer to our methods and approaches while conducting a similar study in other regional member countries of the HKH.

SECTION IV

Discussion and conclusion

Information on spatial distribution, extent and species composition of vegetation types is crucial for planning and developing management strategies for ecosystem conservation and management. A precisely classified physiognomic level vegetation type map would enable land managers to identify what to prioritize, and where, for effective ecosystem conservation. This kind of data and information is often missing for high-altitude regions of the Hindu Kush Himalaya due to inadequate ground data collection and lack of application of advanced technologies such as geospatial technology. This study is a maiden attempt to create a harmonized vegetation classification scheme and a physiognomic vegetation map of KSL. As KSL is a transboundary conservation landscape that spans across countries, it is important that scientists and decision makers from these countries agree on vegetation classes and their nomenclature. In this regard, our study proposes a harmonized vegetation database that includes a classification scheme and map with area distribution of each vegetation type in Kailash Sacred Landscape. The geo-spatial database created in our study is location-specific and provides a detailed inventory of vegetation types in KSL. The outcomes of the study can also contribute towards effective conservation of threatened flora by providing information on the extent of occurrence, area of occupancy and habitat fragmentation (Roy et al., 2013; Rupprecht et al., 2011; Ferraz et al., 2007).

Currently available databases in the regional member countries in the HKH region only provide data and information on forest cover with density classes (FSI, 2013). The information on vegetation and land cover distribution could serve as baseline data for studies in diverse domains, e.g., habitat suitability assessment, corridor connectivity, landscape planning, and micro-scale habitat studies (Roy, 2011). The vegetation and land cover database with precise information on vegetation composition can also be used to improve the process of various climate prediction models and their outputs, since most of these models still use a coarse-resolution vegetation database for calibrating various climate forcings in climate change studies (Renssena and Lautenschlagerc, 2000).

The most important factor governing the distribution of natural vegetation is climatic, in a broad sense. The effects of altitude are the most striking; they result in broadly parallel zones of vegetation ranging from tropical forest in plains, through temperature and alpine vegetation, to permanent snow (Jackson, 1994). Detailed information on vegetation cover types is important for biodiversity conservation planning and for developing future management strategies.

The spatial database we have generated is location specific. It was developed through a detailed field survey and validated by regional experts in ecology and remote sensing. The outcomes of the study can also aid the conservation of threatened species by providing information on the extent of occurrence, area of occupancy and habitat fragmentation (Roy et al., 2013; Rupprecht et al., 2011; Ferraz et al., 2007). The spatial information on vegetation types serves as baseline data for habitat suitability assessment, prioritization for micro-scale habitat studies, corridor connectivity and landscape planning (Roy, 2011). This database can be used to improve various climate models and their outputs, which are affected by land surface response to atmospheric forcings (Renssena and Lautenschlagerc, 2000).

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The International Centre for Integrated Mountain Development (ICIMOD), is a regional knowledge development and learning centre serving the eight regional member countries of the Hindu Kush Himalaya – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan – and based in Kathmandu, Nepal. Globalisation and climate change have an increasing influence on the stability of fragile mountain ecosystems and the livelihoods of mountain people. ICIMOD aims to assist mountain people to understand these changes, adapt to them, and make the most of new opportunities, while addressing upstream-downstream issues. We support regional transboundary programmes through partnership with regional partner institutions, facilitate the exchange of experience, and serve as a regional knowledge hub. We strengthen networking among regional and global centres of excellence. Overall, we are working to develop an economically and environmentally sound mountain ecosystem to improve the living standards of mountain populations and to sustain vital ecosystem services for the billions of people living downstream – now, and for the future.

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